THIRD EDITION

NYSORA
CONTINUING MEDICAL EDUCATION

HADZIC'S PERIPHERAL NERVE BLOCKS

AND ANATOMY FOR ULTRASOUND-GUIDED REGIONAL ANESTHESIA

ADMIR HADZIC

EDITION EDITORS: ANA M. LOPEZ
ANGELA LUCIA BALOCCO • CATHERINE VANDEPITTE

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NEW YORK SCHOOL OF REGIONAL ANESTHESIA

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DEDICATION

We dedicate this book to Jerry Vloka, MD, PhD
in recognition of his pioneering contributions to regional anesthesia
and immense inspiration for generations of students
and scholars of anesthesiology.

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FOREWORD

The third edition of this standard textbook on ultrasound nerve blocks is released during a unique period in human history. The COVID-19 pandemic and the threats that the disease poses to both patients and healthcare workers have substantially changed perioperative practice. During the pandemic, regional anesthesia was established as the preferred method over general anesthesia whenever possible. Nerve blocks preserve respiratory function and avoid aerosolization during intubation and extubation and, hence, viral transmission to other patients and healthcare workers. As an example, the use of nerve blocks as the preferred surgical anesthesia method during the pandemic allowed many limb surgeries to be carried out with decreased exposure to healthcare workers and less burden on post-anesthesia care units (PACUs) and utilization of hospital beds. With regional anesthesia, patients can leave acute postoperative care facilities faster and avoid admission to the limited hospitalization beds. In our center, using regional anesthesia and nerve blocks as the main anesthetic choice allowed elective orthopedic surgery in many patients.

The use of ultrasound-guided local regional anesthesia (LRA) has increased exponentially in the last few years. The traditional techniques have been refined and a number of new approaches have been devised to better suit the evolving clinical practice. Nerve blocks are an essential component of multimodal analgesia in enhanced recovery after surgery (ERAS) protocols. Their use enhances analgesia and reduces or eliminates the use of opioids in the postoperative period. Some traditional nerve block techniques have been substituted by more selective techniques to minimize motor block and facilitate early rehabilitation and recovery. New ultrasound-guided fascial plane techniques, distal nerve blocks, and selective periarticular injections also are increasingly being used to yield a better balance between efficacy, simplicity, safety, and sensory-motor block ratio.

This third edition of NYSORA's textbook is substantially updated and revised to include the many new developments in regional anesthesia and trends in clinical practice. The new edition features entirely new artwork, new clinical images, and new fascial plane and infiltration techniques. All in all, some 500 new algorithms, illustrations, ultrasound images, clinical photographs, and cognitive aids were included to facilitate learning. In addition to anesthesiologists, the highly didactic and organized technique descriptions and functional anatomy principles will be valuable to all anesthesia providers, acute and chronic pain specialists, as well as interventional pain, musculoskeletal medicine, and emergency department physicians.

NYSORA's Reverse Ultrasound Anatomy™ (RUA) images feature functional anatomy or block techniques with clear instructions on the principles and goals of each given technique. These cognitive aids entailed countless hours of work and collaboration between NYSORA's creative and editorial teams to develop highly didactic creatives that facilitate understanding of the anatomy, fascial planes, and principles of nerve blockade. RUA helps students memorize sonoanatomy patterns, which is essential for ultrasound imaging. The knowledge of the sonoanatomy patterns substantially increases ultrasound proficiency and skills retention. Wherever applicable, clinical images of the patient's position, ultrasound transducer placement, and anatomical detail are featured. Recent relevant literature was added to the "Suggested Reading" for readers who like to explore the original sources of the information presented. We chose this approach in an effort to provide the most practical, pragmatic information and relieve the content from massive literature citations.

Readers should be advised that this book is not meant to be an encyclopedic listing of all techniques and their variations. Rather, our textbook should be viewed as a compendium of well-established knowledge, didactically organized for learning, and transferring knowledge to students of anesthesiology. With this approach, the textbook aims to help standardize, and implement well-established techniques, indications, pharmacology, monitoring, and the documentation of nerve blocks. Instead of burdening the reader with experimental block techniques with unproven clinical benefit, we aimed to include the most clinically useful nerve block, fascial, and infiltration techniques with proven efficacy and clinical applicability. Information about perioperative management and local anesthetic toxicity treatment was also added, and/or fully revised. Because patients commonly present with a vague history of allergy to local anesthetics, the new edition also features highly practical algorithms to facilitate decision-making and management of allergy to local anesthetics.

We are confident that this textbook will continue to be one of the primary resources on peripheral nerve blocks in medical practices worldwide.

Sincerely,

Drs Hadzic, Lopez, Balocco, and Vandepitte

Free access to online videos at www.accessanesthesiology.com. Search for this title in the library and select "View All Videos" in the Multimedia widget on the landing page of the book.

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This book would not be possible without the extraordinary people who contributed their time and talent and undying commitment to create an educational masterpiece. Many thanks to Drs Ana Lopez (senior editor), Angela Lucia Balocco, and Catherine Vandepitte, the third edition editors. Their combination of commitment, knowledge, research, and clinical expertise is apparent on every page of this book.

Many thanks to the leadership at Ziekenhuis Oost-Limburg (ZOL; Genk, Belgium) for their support and for facilitating a creative platform in the hospital's clinical setting. In particular, many thanks to the medical director, Dr. Griet Vander Velpen, and the "can-solve-all" manager, Chantal Desticker. Without your support, this book, and the creation of our center of excellence for regional anesthesia at ZOL, would not be possible. Thank you to the leadership of the department, especially Rene Heylen, Jan Van Zundert, and Pieter De Vooght; their vision led to the creation of one of the best regional anesthesia centers in the heart of Europe. Thank you to our regional anesthesia team and block nurses Birgit Lohmar, Joelle Caretta, Ine Vanweert, Kristell Broux, Ilse Cardinaels, Sydney Herfs, Elke Janssen, Hüda Erdem, Mohamed Rafiq, Danny Baens, and all the operating nurses in the N-Block at the orthopedic surgery unit.

Many thanks to all top fellows in regional anesthesia. These young, bright doctors contribute immense value to our teaching mission, and carry on the mission of national ambassadors of regional anesthesia after graduation. Big gratitude to our anesthesia residents who rotate through our service from their mothership Universities: Leuven (KUL), Gent, Antwerp, and others.

Our orthopedic surgery department is by all means one of the best in Europe and beyond. Made up of ultra high-achievers; physicians of national, Olympic, and professional football teams; innovators; and above all incredibly skilled and passionate surgeons. It has been an absolute pleasure building the orthopedic anesthesia service with you. A short glimpse at the website of the department of orthopedic surgery at ZOL is sufficient to get a sense that NYSORA-EUROPE at ZOL is flanked by true giants of orthopedic surgery (https://www.zol.be/raadplegingen/orthopedie).

Thank you to the NYSORA International Team: Pat Pokorny (UK), Kusum Dubey (New Delhi), Katherine Hughey-Kubena (USA), Elvira Karovic, Medina Brajkovic, Ismar Ruznjic (B&H), Nenad Markovic (SER), Jill Vanhaeren, and Greet van Meir (BE). This is an incredible team of NYSORA's go-getters.

Thank you to NYSORA's illustrator Ismar Ruznjic for the new-style illustrations and artwork he imparted to this edition. Ismar has grown with NYSORA to become one of the world's very best anatomy illustrators.

A big thank you to our designer and 3-D maestro, Nenad Markovic, an ultimate perfectionist, whose eye has been constructively critical to many artistic and stylistic aspects of this book, and NYSORA's content at large.

Finally, a huge thanks to all the contributors to this book, as there have been quite a few. Such a volume, packed with so much anatomical information, can always have hidden errors. We have relied on our stellar contributors to detect and correct them wherever possible. However, should the readers find any that we have missed that require correction, please forward them to info@nysora.com. We vouch to improve upon them and thank you immensely in advance for your feedback.

Many thanks to all,

Editors

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SECTION 1

Foundations

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1 Functional Regional Anesthesia Anatomy

Knowledge of anatomy is essential for the practice of regional anesthesia and ultrasound-guided regional anesthesia procedures. This chapter provides a concise overview of the essential functional anatomy necessary for the implementation of traditional and ultrasound-guided regional anesthesia techniques. Figure 1-1 demonstrates the anatomical planes and directions used as a conventional approach throughout the book.

Anatomy of Peripheral Nerves

The neuron is the basic functional unit responsible for nerve conduction. Neurons are the longest cells in the body, often as long as 1 meter. Most neurons have a limited ability to repair after injury. Advances in the understanding of the neurobiology of nerve regeneration and experimental advances in biotechnology may eventually result in development of the strategies to promote axonal growth and reduce neuronal death.

A typical neuron consists of a cell body (soma) with a large nucleus. The cell body is attached to several branching processes, called dendrites, and a single axon (Figure 1-2). Dendrites receive incoming messages, whereas single axons per neuron conduct outgoing messages. In peripheral nerves, axons are long and slender; they are often referred to as nerve fibers.

Connective Tissue

The peripheral nerve is composed of three types of fibers: (1) somatosensory or afferent nerves, (2) motor or efferent nerves, and (3) autonomic nerves. In a peripheral

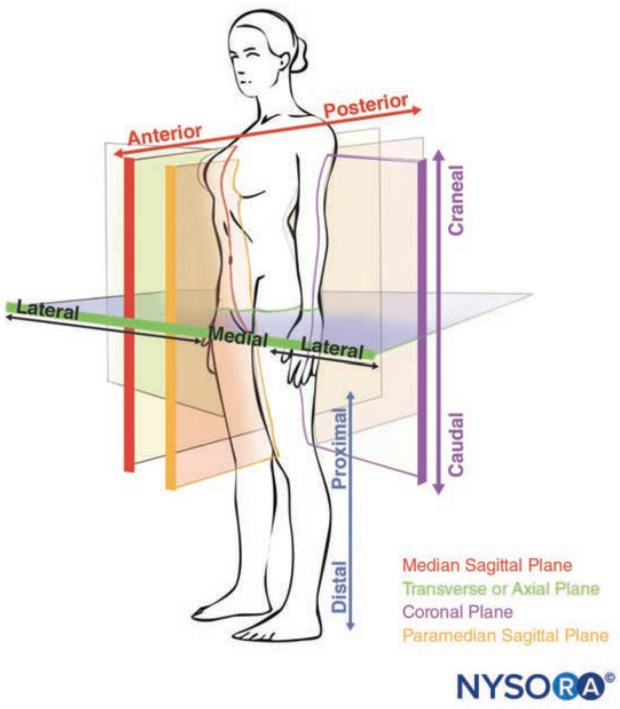


FIGURE 1-1. Conventional body planes and directions. Red, sagittal; orange, sagittal paramedian; green, transverse; and purple, coronal or axial.

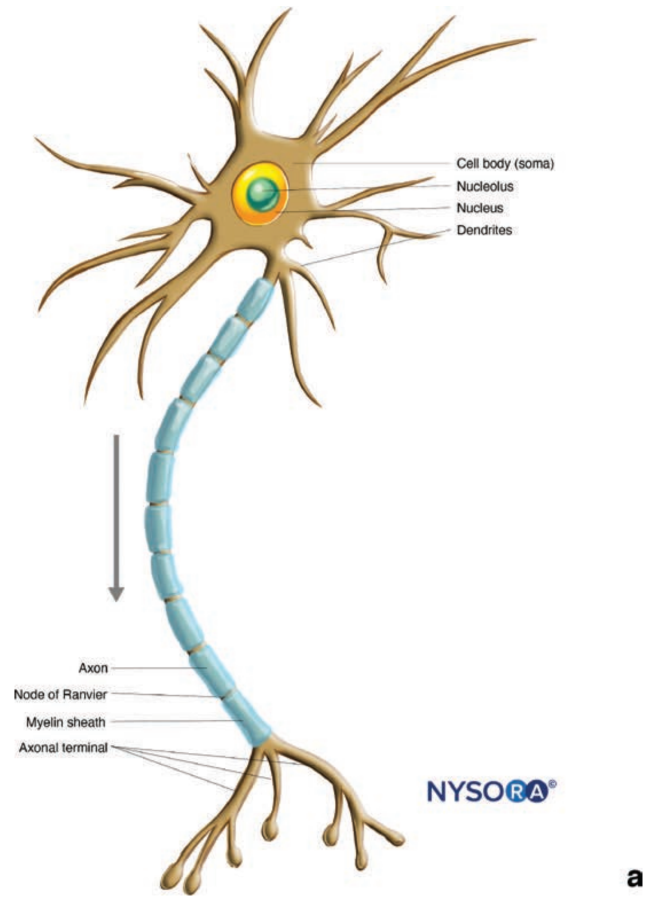


FIGURE 1-2. Composition of the neuron.

nerve (Figure 1-3), individual axons are enveloped in a loose and delicate connective tissue, the **endoneurium.** Groups of axons are arranged within a bundle (nerve fascicle) surrounded by the **perineurium.** The perineurium imparts mechanical strength to the peripheral nerve and functions as a diffusion barrier to the fascicle, isolating the endoneurial space and preserving the ionic milieu of the axon. At each branching point, the perineurium splits with the fascicle. The fascicles, in turn, are embedded in loose connective tissue called the **interfascicular epineurium**, which contains adipose tissue, fibroblasts, mastocytes, blood vessels, and lymphatics. The outer layer surrounding the nerve is the **epineurium,** a denser collagenous tissue that protects the nerve. The **paraneurium** consists of loose connective tissue that holds a stable relationship between adjacent structures filling the space in between them, such as the neurovascular bundles of intermuscular septae. This tissue contributes to the functional mobility of nerves during joint and muscular movement.

Of note, the fascicular bundles are not continuous throughout the peripheral nerve but divide and anastomose with one another as frequently as every few millimeters (Figure 1-4). This arrangement of peripheral nerves helps to explain why intraneural injections, which disrupt this organization, may result in disastrous consequences as opposed to clean needle nerve cuts, which heal more readily. In the vicinity of joints, the fascicles are thinner, more numerous, and are likely surrounded by a greater amount of connective tissue, which reduces the vulnerability of the fascicles to pressure and stretching caused by movement.

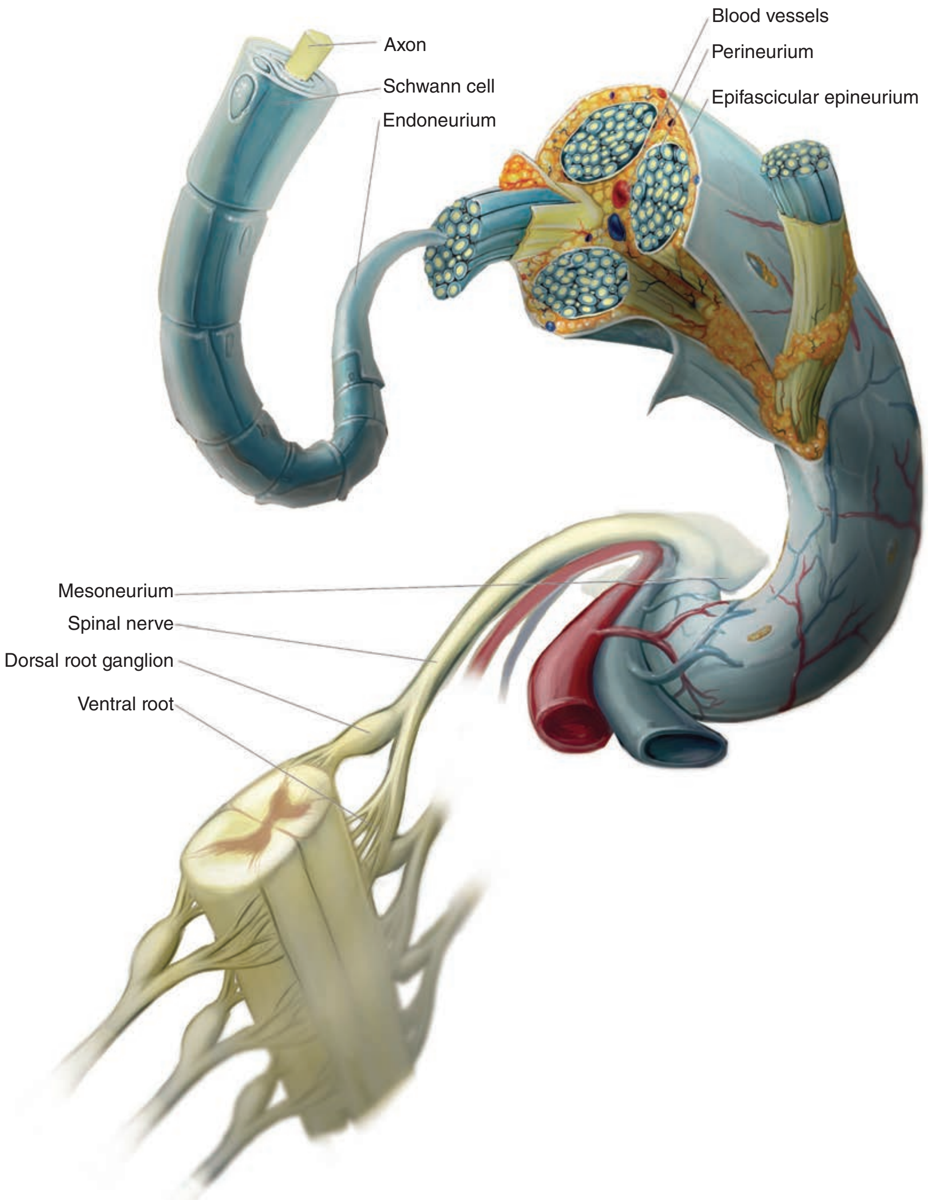


FIGURE 1-3. Organization of the peripheral nerve.

Peripheral nerves receive blood supply from the adjacent blood vessels running along their course. There are two independent interconnected vascular systems. The extrinsic system consists of arteries, arterioles, and veins that lie within the epineurium. The intrinsic vascular system comprises a group of longitudinal capillaries that run within the fascicles and endoneurium. Neuronal injury after nerve blockade may be due, at least partly, to the pressure or stretch within connective sheaths and the consequent interference with the vascular supply to the nerve.

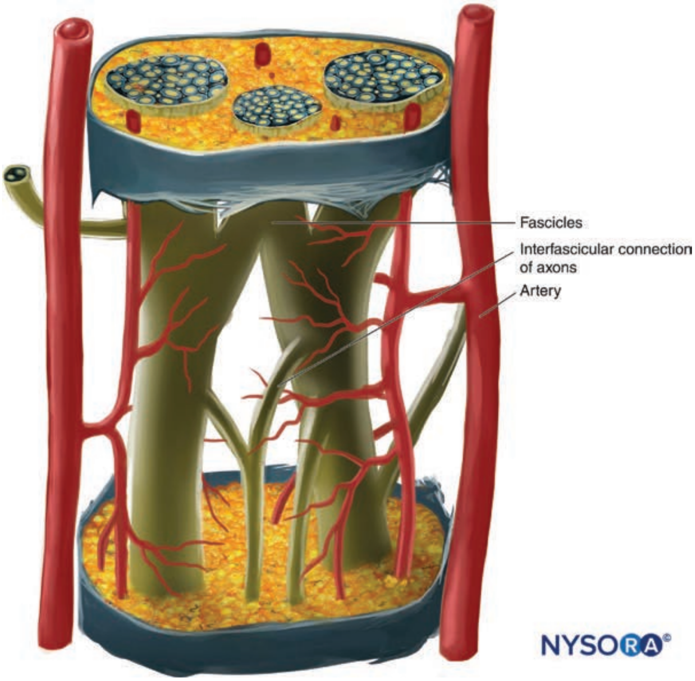


FIGURE 1-4. Diagram of fascicular arrangement in a peripheral nerve.

Communication Between the Central Nervous System and Peripheral Nervous Systems

The central nervous system (CNS) communicates with the body through spinal nerves, which have sensory and motor components (Figure 1-5). The sensory fibers arise from neurons in the dorsal root ganglia and enter the dorsolateral aspect of the spinal cord to form the dorsal root. The motor fibers arise from neurons in the ventral horn of the spinal cord and pass through the ventrolateral aspect of the spinal cord to form the ventral root. The dorsal and ventral *roots* converge in the intervertebral foramen to form the spinal nerves, which then divide into dorsal and ventral *rami*. The dorsal rami innervate muscles,

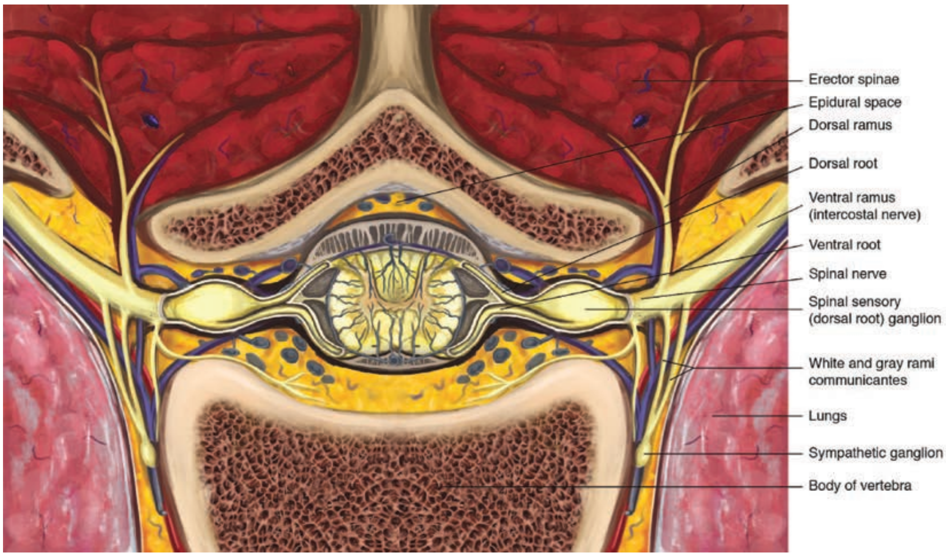


FIGURE 1-5. Schematic transverse section of thoracic vertebra showing the spine and the origin of spinal nerves.

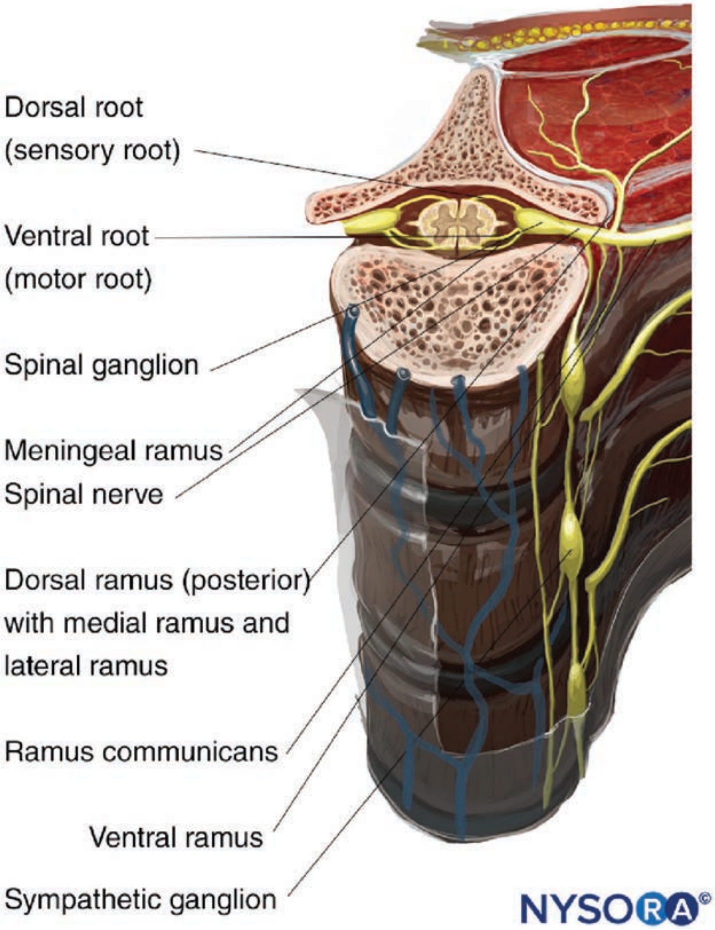


FIGURE 1-6. Anatomy of a typical spinal intercostal nerve.

bones, joints, and the skin of the back along the posterior midline. The ventral rami innervate muscles, bones, joints, and the skin of the antero-lateral aspect of the neck, thorax, abdomen, pelvis, and the extremities (Figure 1-6).

Spinal Nerves

There are 31 pairs of spinal nerves: 8 cervical, 12 thoracic, 5 lumbar, 5 sacral, and 1 coccygeal. Spinal nerves pass through the vertebral column at the intervertebral foramina (Figure 1-7). The first cervical nerve (C1) passes superior to the C1 vertebra (atlas). The second cervical nerve (C2) passes between the C1 (atlas) and C2 (axis) vertebrae. This pattern continues down the cervical spine; however, because there is no C8 vertebra, the C8 nerve passes between the C7 and T1 vertebrae.

In the thoracic region, the T1 nerve passes between the T1 and T2 vertebrae. This pattern continues down through the remainder of the spine. The vertebral arch of the fifth sacral and first coccygeal vertebrae is rudimentary. Because of this, the vertebral canal opens inferiorly at the sacral hiatus, where the fifth sacral and first coccygeal nerves pass. Roots of spinal nerves must descend through the vertebral canal before exiting the vertebral column through the appropriate intervertebral foramen since the inferior end of the spinal cord (conus medullaris) is located at the L1-L2 vertebral level in adults. Collectively, these roots are called the cauda equina.

Outside the vertebral column, ventral rami from cervical and lumbosacral spinal levels coalesce to form intricate

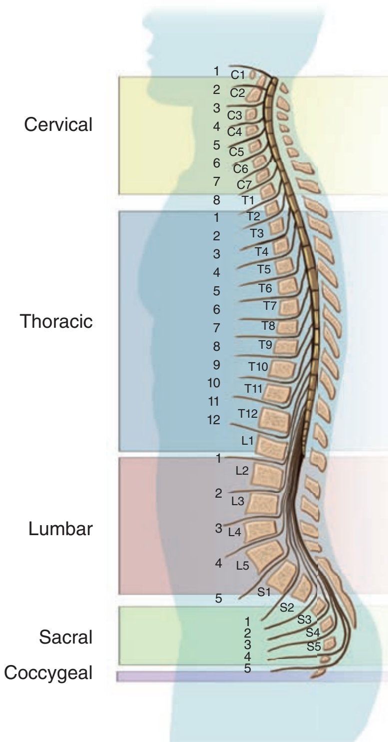


FIGURE 1-7. Spinal nerves.

networks called plexuses from which nerves extend into the neck, the arms, and the legs.

Dermatomes, Myotomes, and Osteotomes

A **dermatome** is the area of the skin supplied by the dorsal (sensory) root of a specific spinal nerve (Figure 1-8). In the trunk, each segment is horizontally disposed, except C1, which does not have a sensory component. The dermatomes of the limbs from the fifth cervical to the first thoracic nerve (C5-T1) and from the third lumbar to the second sacral vertebrae (L3-S2) extend like a series of bands from the midline of the trunk posteriorly into the limbs. Of note, there is considerable overlapping between adjacent dermatomes.

A **myotome** is the segmental innervation of skeletal muscle by a ventral root of a specific spinal nerve (Figure 1-8). An **osteotome** is the area of the bone supplied by the sensory root of the specific spinal nerve.

Distribution of dermatomes, myotomes, and osteotomes does not follow the same pattern in some areas, where different nerves supply the innervation of deep and superficial structures (Figure 1-8). Regardless, the knowledge of their distribution is relevant for the application of regional anesthesia as a guide to decide which block techniques are appropriate to provide adequate analgesia and anesthesia for specific surgical procedures.

Thoracic and Abdominal Wall

Thoracic Wall

The intercostal nerves originate from the ventral rami of the first 11 thoracic spinal nerves (T1-T11). Each intercostal nerve becomes part of the neurovascular bundle of the rib and provides sensory and motor innervations (Figure 1-9).

Except for the first, each intercostal nerve gives off a lateral cutaneous branch that pierces the overlying muscle near the midaxillary line. This cutaneous nerve divides into anterior and posterior branches, which supply the adjacent skin. The intercostal nerves from the second to the sixth space reach the anterior thoracic wall and pierce the superficial fascia near the lateral border of the sternum and divide into medial and lateral cutaneous branches.

Most fibers of the anterior ramus of the first thoracic spinal nerve join the brachial plexus for distribution to the upper limb. The small first intercostal nerve is the lateral branch and supplies only the muscles of the intercostal space, not the overlying skin. In contrast, the lower five intercostal nerves abandon the intercostal space at the costal margin to supply the muscles and skin of the abdominal wall.

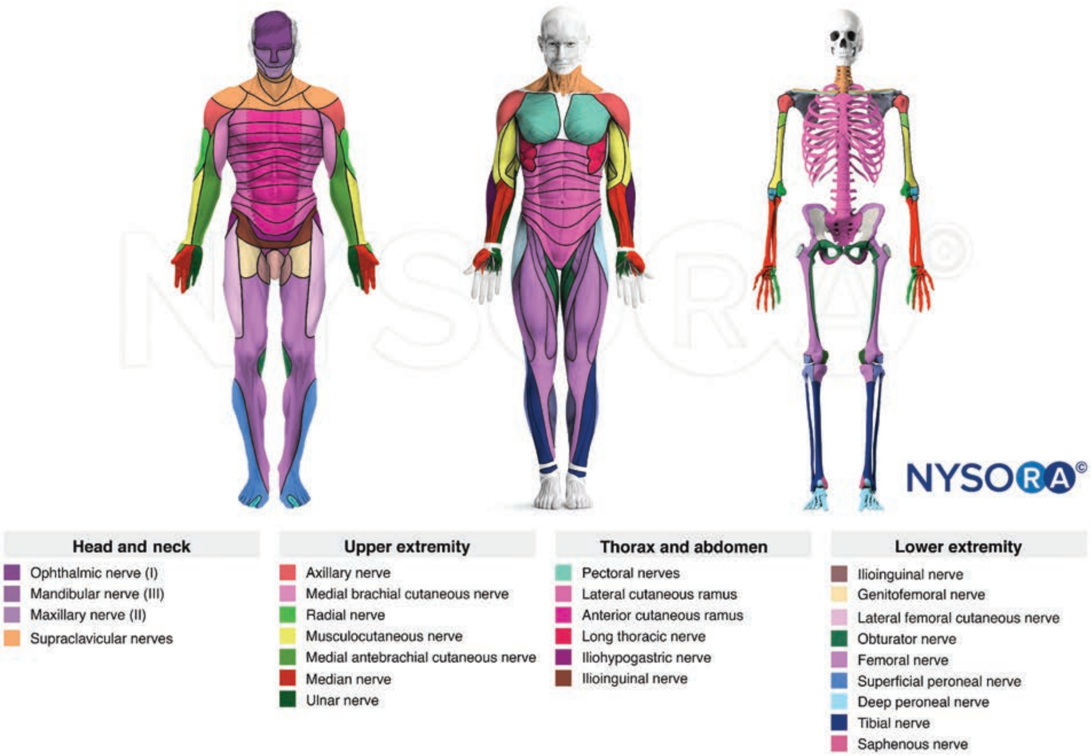
Anterior Abdominal Wall

The lower six thoracic nerves and the first lumbar nerve innervate the skin, muscles, and parietal peritoneum of the anterior abdominal wall. At the costal margin, the seventh to eleventh thoracic nerves (T7-T11) leave their intercostal spaces and enter the abdominal wall in a fascial plane between the transversus abdominis and internal oblique muscles. The seventh and eighth intercostal nerves slope upward following the contour of the costal margin, ninth runs horizontally, and the tenth and eleventh have a downward trajectory. Anteriorly, the nerves pierce the rectus abdominis muscle and the anterior layer of the rectus sheath to emerge as anterior cutaneous branches that supply the overlying skin (Figure 1-9).

The subcostal nerve (T12) takes the line of the twelfth rib across the posterior abdominal wall. It continues around the flank and terminates similarly to the lower intercostal nerves. The seventh to twelfth thoracic nerves (T7-T12) give off lateral cutaneous nerves, which further divide into anterior and posterior branches. The anterior branches supply the skin as far forward as the lateral edge of the rectus abdominis. The posterior branches supply the skin overlying the latissimus dorsi. The lateral cutaneous branch of the subcostal nerve is distributed to the skin on the side of the buttock.

The iliohypogastric and ilioinguinal nerves, both branches of L1, supply the inferior part of the abdominal wall. The iliohypogastric nerve runs above the iliac crest and splits into two terminal branches. The lateral cutaneous branch supplies the side of the buttock; the anterior cutaneous branch supplies the suprapubic region.

The ilioinguinal nerve leaves the intermuscular plane by piercing the internal oblique muscle above the iliac crest. It continues between the two oblique muscles to enter the



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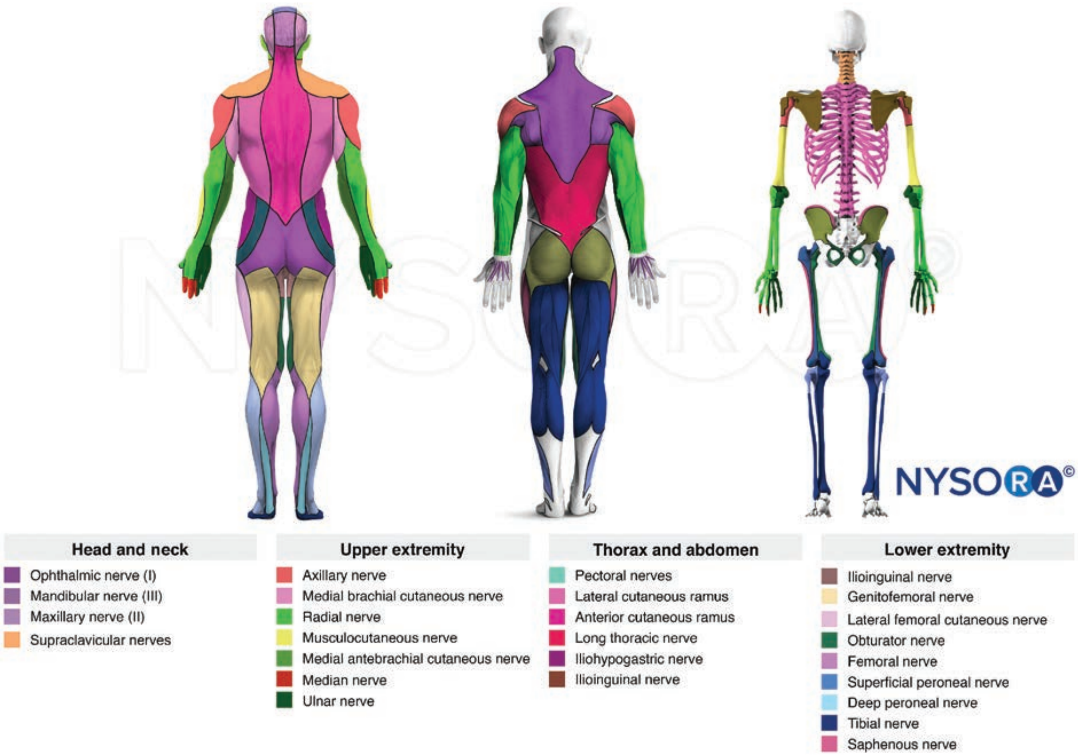

B

FIGURE 1-8. Distribution of dermatomes, myotomes, and osteotomes: (A) anterior view and (B) posterior view.

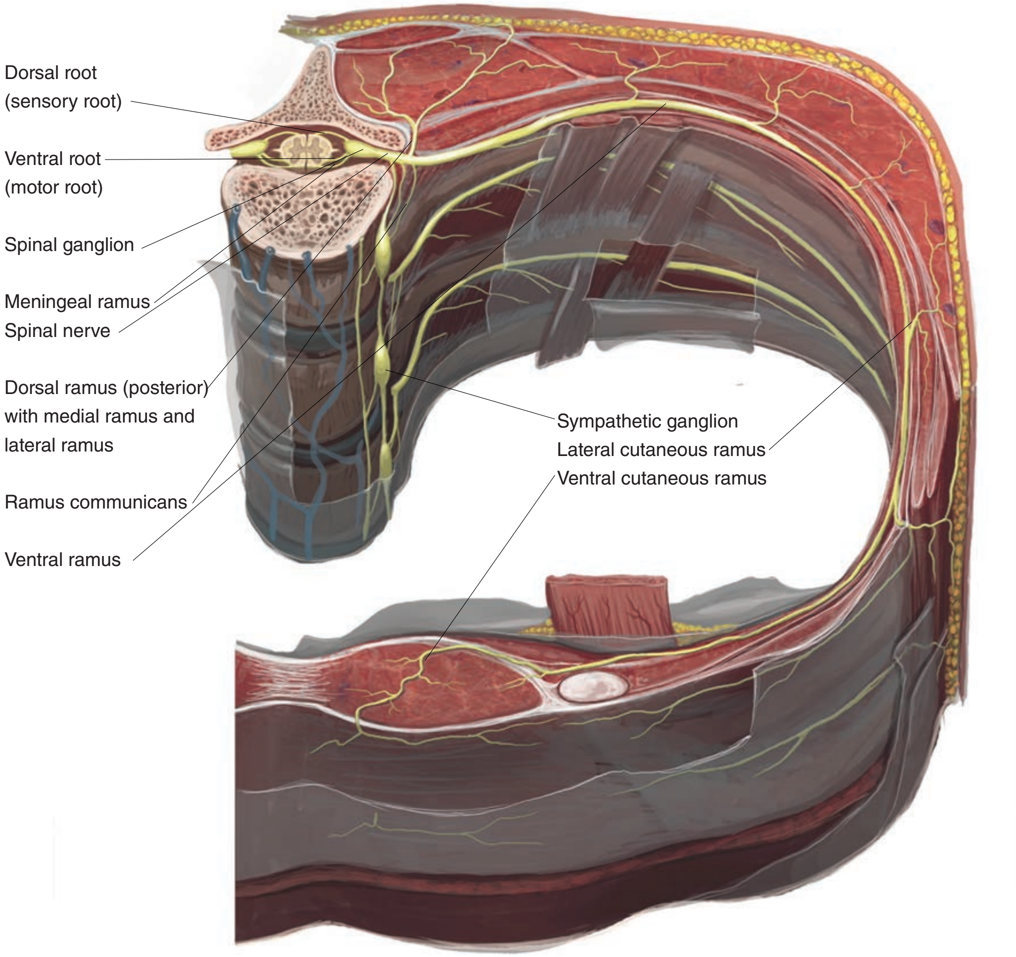

FIGURE 1-9. Course and distribution of an intercostal nerve.

inguinal canal through the spermatic cord. Emerging from the superficial inguinal ring, it gives cutaneous branches to the skin on the medial side of the root of the thigh, the proximal part of the penis, and the front of the scrotum in males and the mons pubis and the anterior part of the labium majus in females.

Nerve Supply to the Peritoneum

The lower thoracic and first lumbar nerves innervate the parietal peritoneum of the abdominal wall. The lower thoracic nerves also innervate the peritoneum that covers the periphery of the diaphragm. Inflammation of the peritoneum gives rise to pain in the lower thoracic and abdominal wall. In contrast, the peritoneum on the central part of the diaphragm receives sensory branches from the phrenic nerves (C3, C4, and C5), and irritation in this area may produce pain in the region of the shoulder (the fourth cervical dermatome).

Nerve Plexuses

The ventral rami of the cervical, lumbar, and sacral spinal nerves form a neural network known as plexuses. The nerve fibers from these spinal segments distribute in different

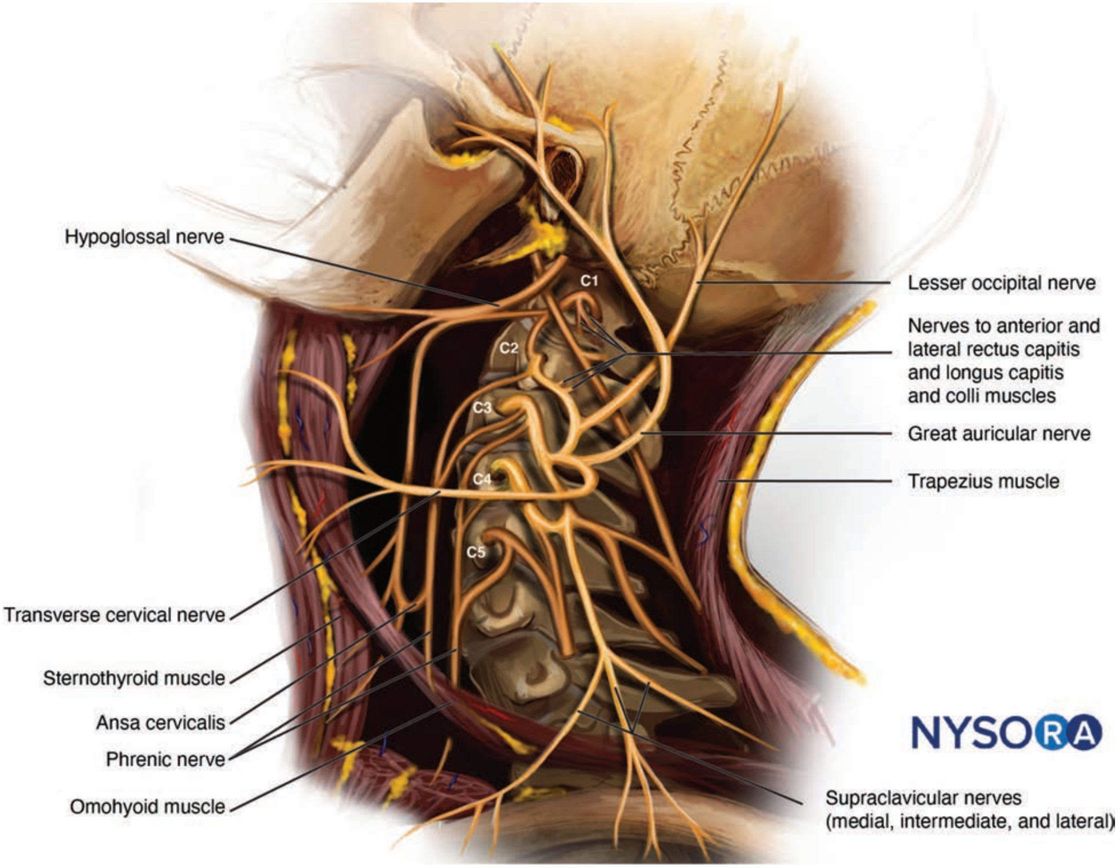

FIGURE 1-10. Organization of the cervical plexus from roots to terminal nerves.

terminal nerves. The four major nerve plexuses are the cervical, brachial, lumbar, and sacral plexus.

The Cervical Plexus

The cervical plexus originates from the ventral rami of C1 to C5, which form three loops (Figure 1-10). Deep motor branches originating from these loops innervate the infrahyoid and scalene muscles. Fibers from C3 to C5 form the phrenic nerve, which descends on the anterior surface of the anterior scalene muscle, passes through the superior thoracic aperture, and descends on the walls of the mediastinum to innervate the diaphragm (phrenic nerve). Thus, the cervical plexus has a relevant role in maintaining the respiratory function. Superficial branches from the cervical plexus pass around the posterior margin of the sternocleidomastoid muscle and provide sensory innervation to the skin of the lateral scalp, neck, clavicle, shoulder, and upper thorax (Figure 1-11). Table 1-1 describes the origin and innervation of each nerve of the cervical plexus.

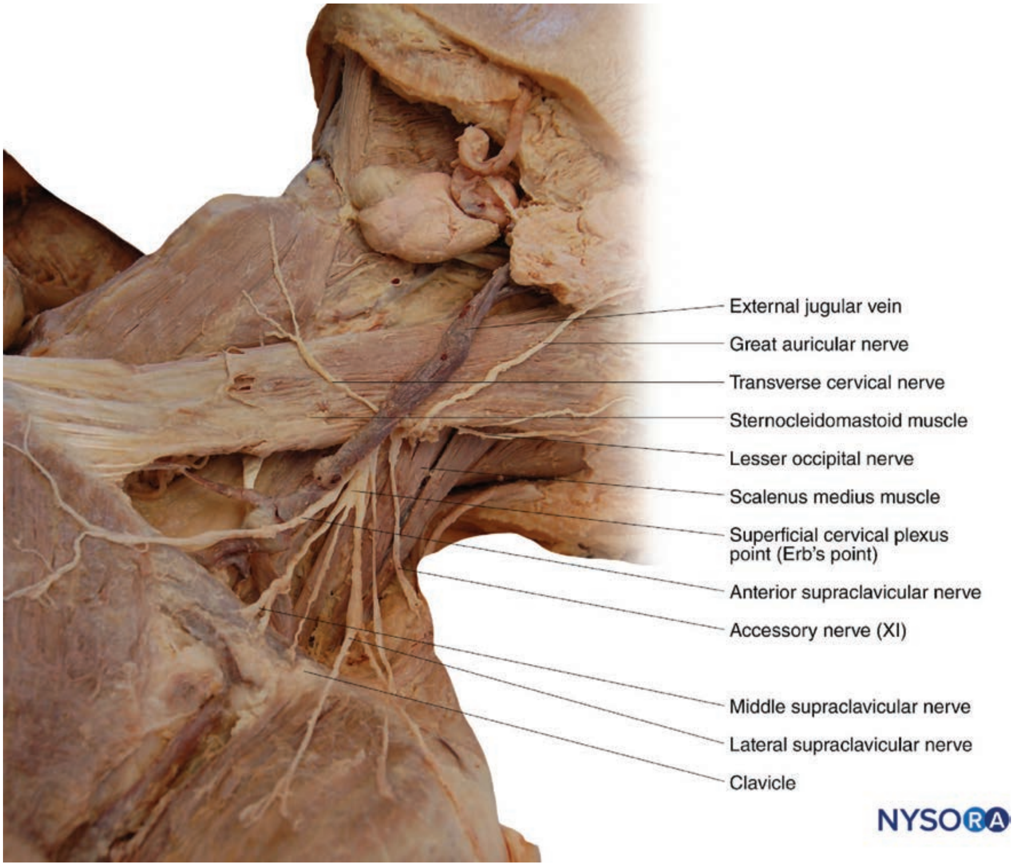

FIGURE 1-11. Dissection of the superficial branches of the cervical plexus.

TABLE 1-1 Organization and Distribution of the Cervical Plexus

NERVES	SPINAL SEGMENTS	DISTRIBUTION
Ansa cervicalis (superior and inferior branches)	C1-C3	Five of the extrinsic laryngeal muscles (sternothyroid, sternohyoid, omohyoid, geniohyoid, and thyrohyoid) by way of cranial nerve XII
Lesser occipital, transverse cervical, supraclavicular, and greater auricular nerves	C2-C4	Skin of upper chest, shoulder, neck, and ear
Phrenic nerve	C3-C5	Diaphragm
Cervical nerves	C1-C5	Levator scapulae, scalene muscles, sternocleidomastoid muscles, and trapezius muscles (with cranial nerve XI)

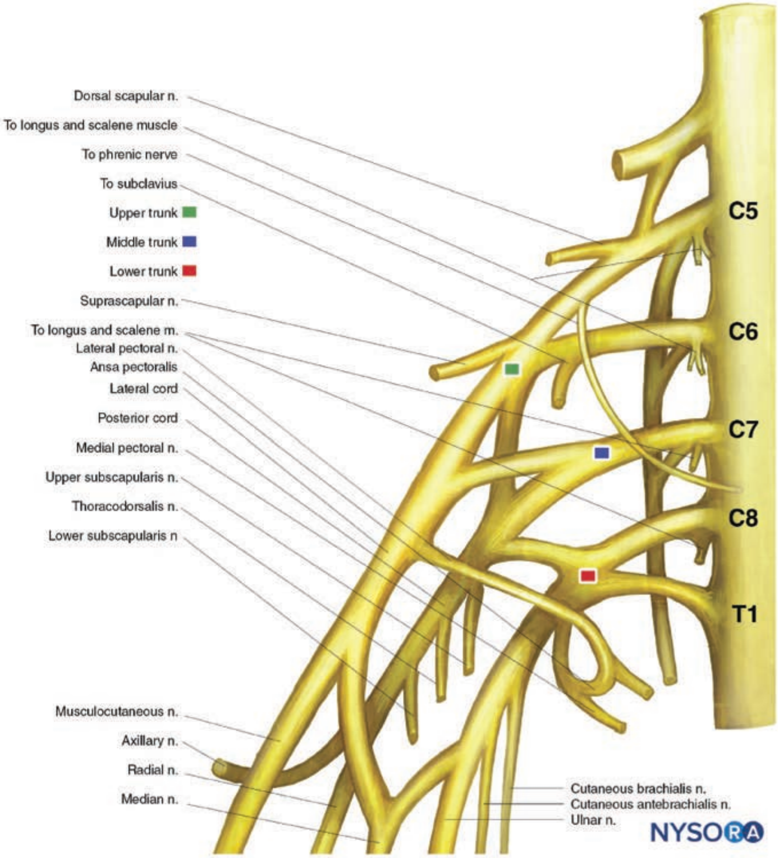

FIGURE 1-12. Organization of the brachial plexus from roots to terminal nerves.

The Brachial Plexus

The ventral rami of spinal nerves C5-T1 form the brachial plexus, which innervates bones, joints, muscles, and the skin of the upper extremity and shoulder girdle. Between the anterior and middle scalene muscles, the roots converge to form the superior (C5-C6), middle (C7), and inferior (C8-T1) trunks (Figure 1-12). At the level of the clavicle, every trunk gives off an anterior and a posterior division. These divisions rearrange their fibers to form the lateral, medial, and posterior cords, which in turn give off the peripheral nerves for the upper extremity (Figure 1-13). Table 1-2 describes the origin and innervation of each nerve of the brachial plexus.

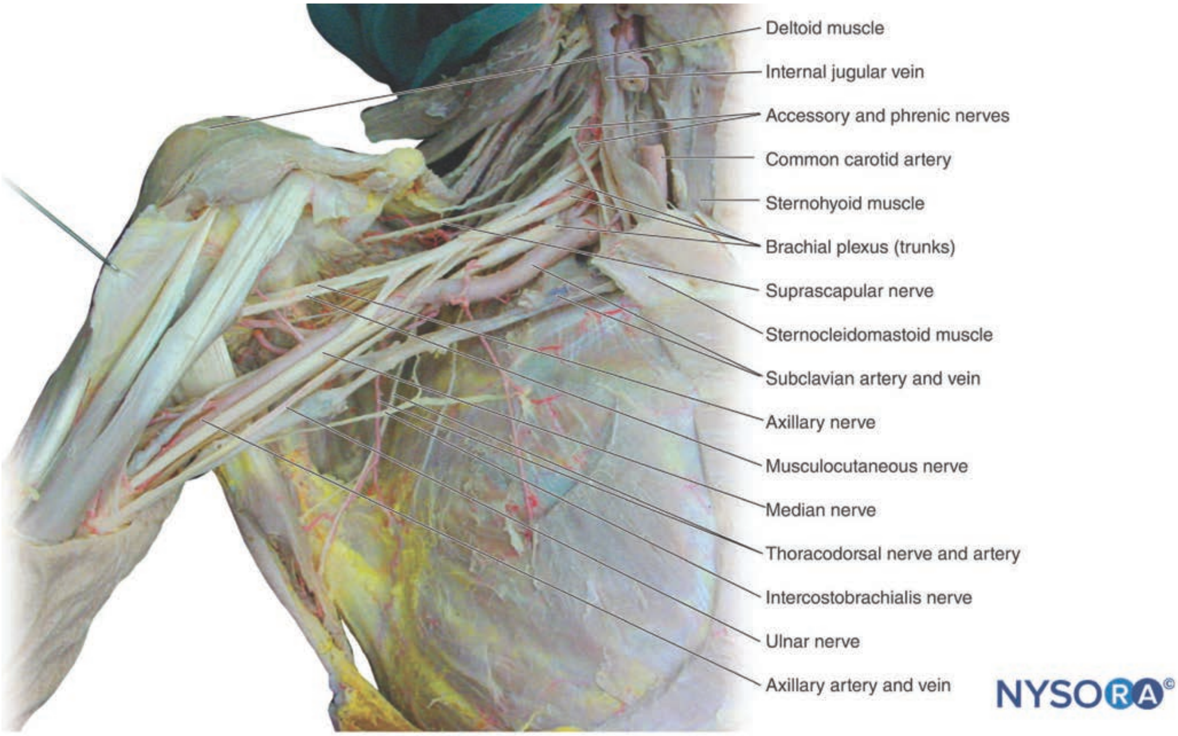

FIGURE 1-13. Dissection of the brachial plexus from the roots in the neck to the axillary fossa.

TABLE 1-2 Anatomy of the Brachial Plexus C5-T1

NERVE (TERMINAL BRANCH)	SPINAL NERVES	TRUNK	CORD	MYOTOMES		SCLEROTOMES	DERMATOMES
				MUSCLES	MOTOR RESPONSE		
Long thoracic	C5-C7			Serratus anterior	Forward flexion of the arm and contraction of the serratus anterior		
Dorsal scapular	C5			Levator scapulae, rhomboid muscles	Elevation of the scapula		
Nerves to subclavius	C4-C6	Upper		Subclavius		Sternoclavicular joint	

TABLE 1-2 Anatomy of the Brachial Plexus C5-T1 (*Continued*)

NERVE (TERMINAL BRANCH)	SPINAL NERVES	TRUNK	CORD	MYOTOMES		SCLEROTOMES	DERMATOMES
				MUSCLES	MOTOR RESPONSE		
Suprascapular	C5-C6	Upper		Supra-spinatus, infraspinatus	Abduction and lateral rotation of the shoulder	Glenohumeral and acromiocla-vicular joints, sub-acromial bursa	
Subscapular (upper and lower)	C5-C6	Upper	Posterior	Subscapularis, teres major	Adduction and medial rotation of the shoulder	Deep surface of the scapula	
Thoracodorsal	C6-C8	Upper, middle, lower	Posterior	Latissimus dorsi	Extension, adduction, and medial rotation of the shoulder		
Axillary	C5-C6	Upper	Posterior	Deltoid, teres minor	Abduction and lateral rotation of the shoulder	Glenohumeral anterior and acromioclavicular joints	Anterior and posterior shoulder
Radial	C5-T1	Upper, middle, lower	Posterior	Triceps, anconeus, brachioradia-lis, extensor carpi radialis longus and brevis, supina-tor, extensor digitorum communis, extensor digiti minimi, extensor carpi ulnaris, exten-sor indicis, extensor pol-licis longus and brevis, abductor pollicis	Extension of the elbow, wrist, and fingers, supi-nation of the forearm, abduction of the wrist and thumb	1st/3rd superior humerus, elbow joint, radius, ulna, carpus, 1st-3rd metacarpus and phalanges	Posterior arm and forearm, dorsal aspect of the hand (1st-4th fingers)
Lateral pectoral	C5-C7	Upper, middle	Lateral	Pectoralis minor, pecto-ralis major		Glenohumeral and acromiocla-vicular joints	
Musculocuta-neous	C5-C6	Upper	Lateral	Coracobra-chialis, biceps brachii, brachialis	Flexion of the elbow and supination of the forearm	Humerus elbow and proximal radioulnar joints	Lateral forearm rim

TABLE 1-2 Anatomy of the Brachial Plexus C5-T1 (*Continued*)

NERVE (TERMINAL BRANCH)	SPINAL NERVES	TRUNK	CORD	MYOTOMES		SCLEROTOMES	DERMATOMES
				MUSCLES	MOTOR RESPONSE		
Median	C6-T1	Upper, middle, lower	Lateral, medial	*Elbow*: Pronator teres, flexor carpi radialis, palmaris longus *Forearm*: Flexor digitorum superficialis/ profundus, flexor pollicis longus, pronator quadratus *Hand*: Thenar muscles, 1st-2nd lumbrical muscles	Flexion of the wrist and 2nd-3rd fingers, pronation of the forearm	Elbow joint (anterior), radius, ulna, 1st-4th metacarpus and phalanges	Palmar aspect of the hand (1st-4th fingers) and dorsal aspect of the distal half of the 2nd-4th fingers
Medial pectoral	C8-T1	Lower	Medial	Pectoralis minor, pectoralis major		Clavicle	
Medial brachial cutaneous	T1	Lower	Medial				Medial aspect of the arm
Medial antebrachial cutaneous	C8-T1	Lower	Medial				Medial aspect of the forearm
Ulnar	C8-T1	Middle	Medial	Flexor carpi ulnaris, flexor digitorum profundus and interosseous (4th-5th fingers), muscles of the hypothenar eminence, adductor pollicis, flexor pollicis brevis	Flexion of the wrist and 4th-5th fingers, adduction of the thumb	Elbow joint, ulna and medial aspect of the wrist, hand and 4th-5th fingers	Medial aspect of the hand, 4th-5th finger

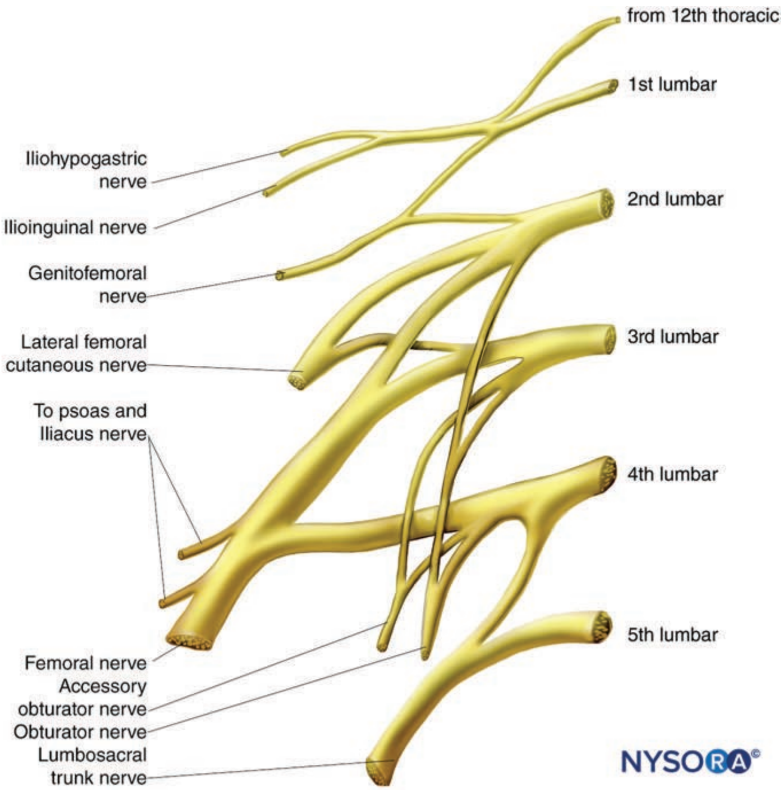

FIGURE 1-14. Organization of the lumbar plexus from roots to terminal nerves.

The Lumbar Plexus

The ventral rami of spinal nerves L1-L4 form the lumbar plexus. They divide into anterior and posterior divisions that coalesce to form the terminal nerves (Figure 1-14). The lumbar plexus innervates the skin, muscles, peritoneal lining of the lower abdominal wall, and the anteromedial aspect of the lower extremities. The plexus runs caudally in the posterior abdominal wall between the psoas major and quadratus lumborum muscles. The main branches of the lumbar plexus are the iliohypogastric, ilioinguinal, genitofemoral, lateral femoral cutaneous, obturator, and femoral nerves (Figure 1-15 and Figure 1-16). Table 1-3 describes the origin and innervation of each nerve of the lumbar plexus.

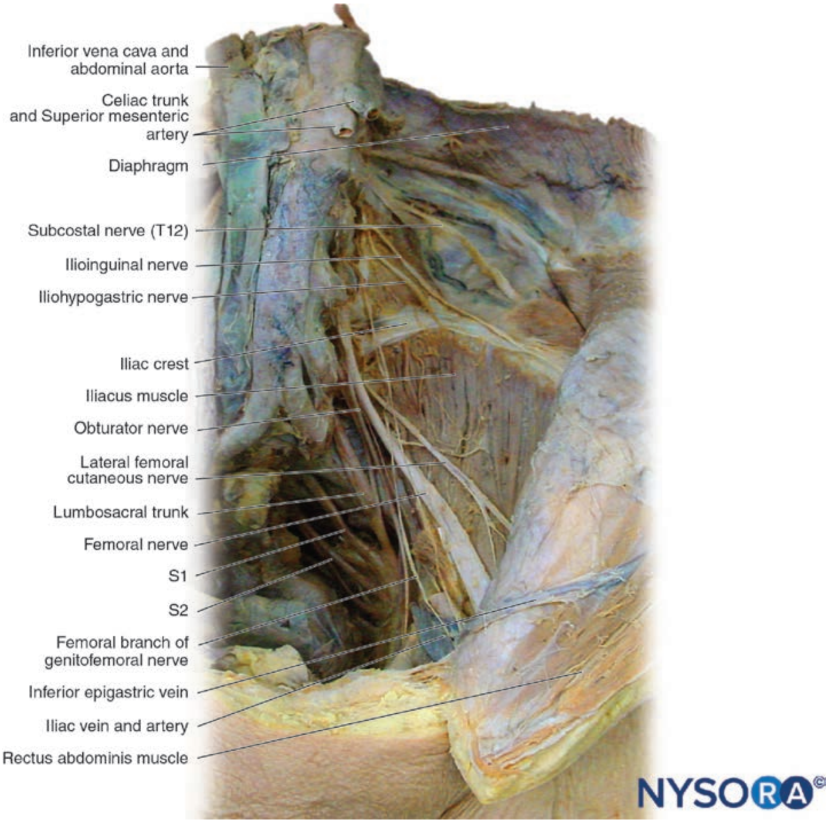

FIGURE 1-15. Dissection of the lumbar plexus in the pelvic cavity.

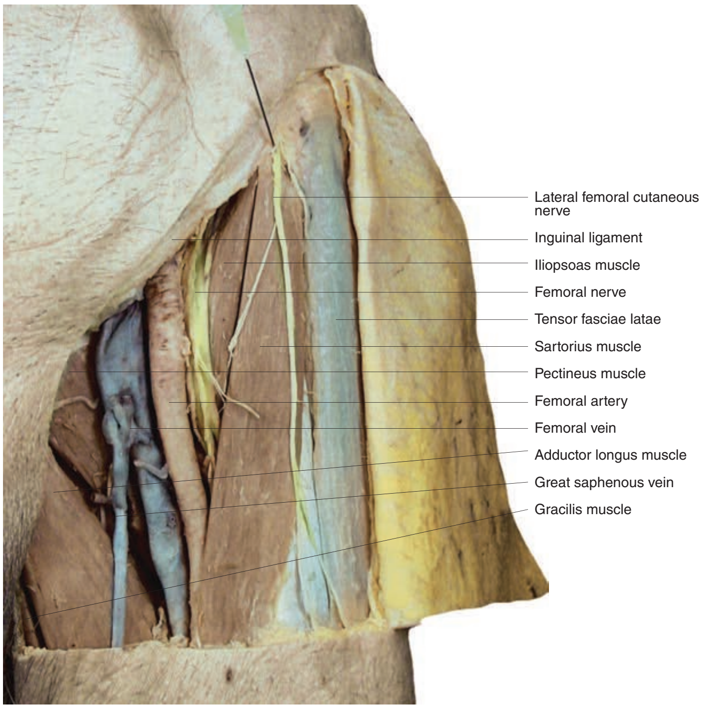

FIGURE 1-16. Dissection of the femoral nerve below the inguinal ligament.

TABLE 1-3 Anatomy of the Lumbar Plexus L1-L4

NERVE (TERMINAL BRANCH)	SPINAL NERVES	MYOTOMES		SCLEROTOMES	DERMATOMES
		MUSCLES	MOTOR RESPONSE		
Iliohypogastric	T12-L1	Abdominal muscles (external and internal oblique, transverse abdominis)	Contraction of the abdominal wall (inguinal area)		Skin over inferior abdomen and buttocks
Ilioinguinal	L1	Internal oblique	Contraction of the abdominal wall (inguinal area)		Skin over superior, medial thigh, and portions of external genitalia
Genitofemoral	L1-L2	Cremaster	Elevates the scrotum		Anteromedial surface of thigh and portions over genitalia
Lateral femoral cutaneous	L2-L3				Anterolateral aspect of thigh
Femoral (anterior/superficial branches): anterolateral cutaneous, anteromedial cutaneous	L2-L4	Sartorius, pectineus	Flexion, aduction, and external rotation of the hip		Anteromedial aspect of thigh
Femoral (posterior branch): saphenous, nerves to the quadriceps	L2-L4	Quadriceps	Extension of the knee, patellar	Ilium, anterior and lateral aspect of femur, superior articular aspect of tibia; hip and knee joints	Anterior surface of thigh, medial surface of leg, and foot
Obturator	L2-L4	Adductors of thigh (adductors magnus, brevis, and longus); gracilis, obturator externus	Adduction of the thigh, external rotation of the hip	Ischium, pubis, medial aspect of femur; hip and knee joints	Medial surface of thigh

The Sacral Plexus

The ventral rami of spinal nerves L4-L5 and S1-S4 form the sacral plexus, which innervates the buttocks, perineum, posterior aspect of the thigh, and the whole leg below the knee, except the sensory territory of the saphenous nerve (Figure 1-17). The main nerve is the sciatic nerve that leaves the pelvis through the greater sciatic foramen and travels between the greater trochanter and ischial tuberosity in the gluteal area (Figure 1-18). In the proximal thigh, the nerve lies behind the lesser trochanter of the femur and is covered superficially by the long head of the biceps femoris muscle. The two components of the sciatic nerve diverge into two recognizable nerves as it approaches the popliteal fossa: the common peroneal and the tibial nerves. Table 1-4 describes the origin and innervation of each nerve of the sacral plexus.

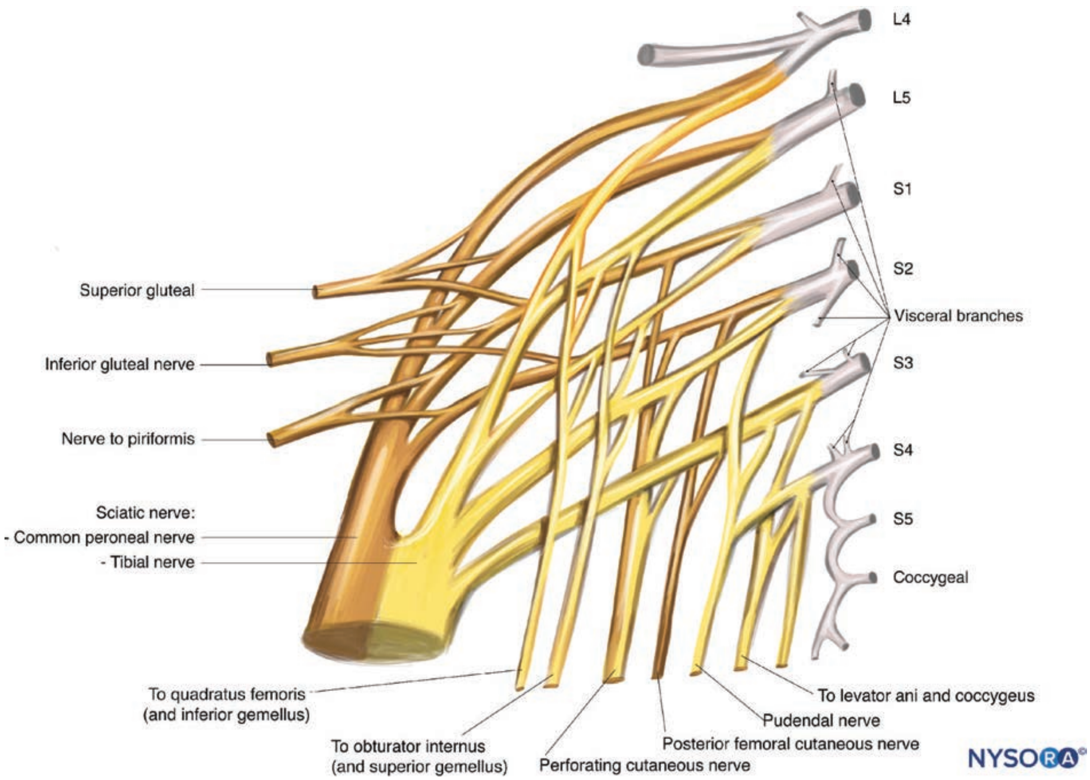

FIGURE 1-17. Organization of the sacral plexus from roots to terminal nerves.

Innervation of the Major Joints

Much of the practice of peripheral nerve blocks involves orthopedic and joint surgery. Consequently, knowledge of the sensory innervation of major joints is important for a better understanding of the neuronal components that need to be anesthetized to achieve anesthesia for or analgesia after joint surgery. Table 1-5 summarizes the innervation and kinetic function of the major muscle groups of the upper and lower extremities.

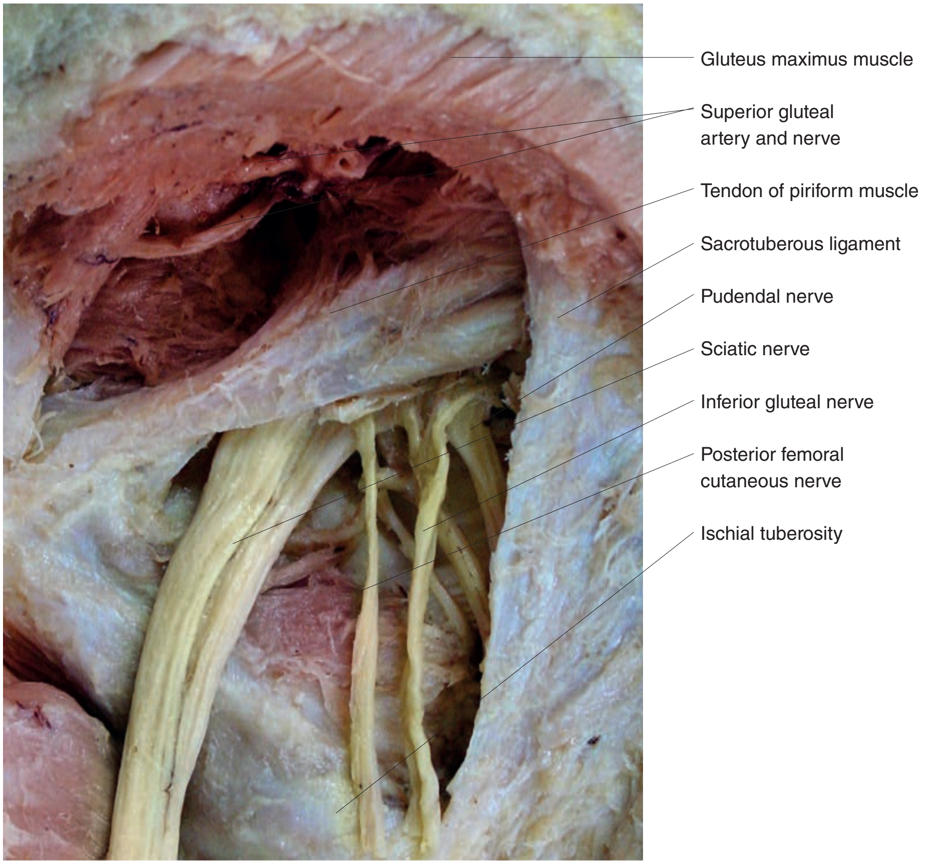

FIGURE 1-18. Dissection of the sciatic nerve at the pelvic outlet.

TABLE 1-4 Anatomy of the Sacral Plexus L4-S4

NERVE (TERMINAL BRANCH)	SPINAL NERVES	MOTOR INNERVATION	MOTOR RESPONSE TO NEUROSTIMULATION	DERMATOMES	SCLEROTOMES
Gluteal (superior/inferior)	L4-S2	Abductors of thigh (gluteus minimus, gluteus medius, and tensor fasciae latae) and extensor of thigh (gluteus maximus)	Contraction of the buttocks and external rotation of the hip	Medial and superior aspect of the buttocks	
Posterior femoral cutaneous	S1-S3			Skin of perineum and posterior surface of thigh and leg	

TABLE 1-4 Anatomy of the Sacral Plexus L4-S4 (*Continued*)

NERVE (TERMINAL BRANCH)		SPINAL NERVES	MOTOR INNERVATION	MOTOR RESPONSE TO NEUROSTIMULATION	DERMATOMES	SCLEROTOMES
Sciatic	Gluteal level		Three of the hamstrings (semitendinosus and semimembranosus long head of biceps femoris); adductor magnus (with obturator nerve)	Extension of hip, flexion of knee		Hip joint; ischium, posterior aspect of the femur
	Tibial	L4-S3	Flexor of knee and plantar flexors of ankle (popliteus, gastrocnemius, soleus plantaris, and tibialis posterior muscles and long head of biceps femoris muscle); flexors of toes	Flexion of the knee, plantar flexion of the foot and toes, inversion of the foot	Posterior aspect of leg, plantar aspect of foot	Knee, ankle, and all foot joints; tibia, fibula, and plantar aspect of the foot
	Common peroneal	L4-S2	Biceps femoris muscle (short head); fibularis (brevis and longus) and tibialis anterior muscles; extensors of toes	Flexion of the knee, dorsi flexion of the foot and toes, eversion of the foot	Anterior surface aspect of leg and dorsal aspect of foot; skin over lateral portion of foot (through the sural nerve)	Knee, ankle, and all foot joints; proximal tibia and fibula and dorsal aspect of the foot
Pudendal		S2-S4	Muscles of perineum, including urogenital diaphragm and external anal and urethral sphincter muscles; skeletal muscles (bulbospongiosus, ischiocavernosus muscles)	Motor contraction of the muscles involved	External genitalia, lower third of the urethra and vagina, skin of the anal circumference, caudal third of the rectum	
Nerve to the quadratus femoris and inferior gemellus		L4-L5	Quadratus femoris, inferior gemellus	Adduction and external rotation of the hip		Hip joint
Nerve to obturatori and superior gemellus		L5-S1	Superior gemellus, obturator internus	Abduction of the hip		
Nerve to piriformis		S1-S2	Piriformis	Abduction and lateral rotation of the hip		
Nerves to coccygeus and levator ani		S3-S4	Coccygeus, levator ani	Motor contraction of the muscles involved		

TABLE 1-5 Summary of Movement by Joint

UPPER EXTREMITY		
Shoulder (Glenohumeral) Joint		
Flexion	Biceps brachii—long head Coracobrachialis Deltoid Pectoralis major	Musculocutaneous nerve Axillary nerve Medial and lateral pectoral nerve
Extension	Triceps brachii—long head Latissimus dorsi Deltoid	Radial nerve Thoracodorsal nerve Axillary nerve
Adduction	Latissimus dorsi Pectoralis major Teres major Subscapularis	Thoracodorsal nerve Medial and lateral pectoral nerves Lower subscapular nerve Upper and lower subscapular nerve
Abduction	Supraspinatus Deltoid	Suprascapular nerve Axillary nerve
Medial rotation	Pectoralis major Latissimus dorsi Teres major Subscapularis	Medial and lateral pectoral nerve Thoracodorsal nerve Lower subscapular nerve Upper and lower subscapular nerves
Lateral rotation	Teres minor Infraspinatus	Axillary nerve Suprascapular nerve
Elbow (Humeroulnar, Humeroradial) Joint		
Flexion	Brachialis Biceps brachii—long and short heads Flexor carpi radialis	Musculocutaneous Median nerve
Extension	Triceps brachii—long lateral, medial head Anconeus	Radial nerve
Radioulnar Joints		
Supination	Biceps brachii—long and short head Supinator	Musculocutaneous Radial nerve
Pronation	Pronator teres Pronator quadratus	Median nerve
Wrist (Radiocarpal, Ulnocarpal) Joint		
Flexion	Flexor carpi radialis Palmaris longus Flexors of fingers listed below Flexor carpi ulnaris	Median nerve Ulnar nerve
Extension	Extensor carpi radialis longus and brevis Extensors of fingers listed below Extensor carpi ulnaris	Radial nerve
Carpometacarpal Joints		
Opposition	Opponen pollicis Opponens digiti minimi	Median nerve Ulnar nerve

TABLE 1-5 Summary of Movement by Joint (*Continued*)

UPPER EXTREMITY		
Metacarpophalangeal Joints		
Flexion	Flexor digitorum superficialis	Median nerve
	Flexor digitorum profundus	Median and ulnar nerves
	Flexor pollicis longus and brevis	Median nerve
	Interosseus	Ulnar nerve
	Lumbricals	Median and ulnar nerves
Extension	Extensor digitorum communis	Radial nerve
	Extensor indicis	
	Extensor digiti minimi	
Adduction	Palmar interosseous	Ulnar nerve
	Abductor pollicis	
Abduction	Dorsal interosseous	Ulnar nerve
	Abductor digiti minimi	
	Abductor pollicis longus	Radial nerve
	Abductor pollicis brevis	Median nerve
Interphalangeal Joints		
Flexion	Flexor digitorum superficialis	Median nerve
	Flexor digitorum profundus	Median and ulnar nerves
	Flexor pollicis longus and brevis	Median nerve
Extension	Extensor digitorum communis	Radial nerve
	Extensor indicis	
	Extensor digiti minimi	
	Lumbricals (index, middle fingers)	Median nerve
	Lumbricals (ring, little fingers)	Ulnar nerve
	Interosseous muscles	
LOWER EXTREMITY		
Hip (Acetabulofemoral) Joint		
Flexion	Iliacus/psoas major	Femoral nerve
	Pectineus	
	Rectus femoris	
	Sartorius	
	Adductor magnus	Obturator nerve
	Adductor longus and brevis	
	Tensor fascia lata	Superior gluteal nerve
Extension	Biceps femoris—long head	Sciatic nerve
	Semimembranosus	
	Semitendinosus	
	Gluteus maximus	Inferior gluteal nerve
	Adductor magnus	Obturator nerve

TABLE 1-5 Summary of Movement by Joint (*Continued*)

LOWER EXTREMITY		
Hip (Acetabulofemoral) Joint		
Adduction	Adduct magnus, longus, brevis	Obturator nerve
	Gracilis	
	Pectineus	Femoral nerve
Abduction	Gluteus minimus	Superior gluteal nerve
	Gluteus medius	
	Tensor fascia lata	
Medial rotation	Gluteus minimus	Superior gluteal nerve
	Gluteus medius	
	Tensor fascia lata	
Lateral rotation	Piriformis	Nerve to piriformis
	Obturator internus	Nerve to obturator internus
	Superior gemilli	Nerve to obturator internus
	Inferior gemelli	Nerve to quadratus femoris
	Quadratus femoris	Nerve to quadratus femoris
	Sartorius	Femoral nerve
Knee (Tibiofemoral) Joint		
Flexion	Bicep femoris—long and short heads	Sciatic nerve
	Semitendinosus	
	Semimembranosus	
	Popliteus	Tibial nerve
	Gastrocnemius	
	Sartorius	Femoral nerve
Extension	Rectus femoris	Femoral nerve
	Vastus lateralis	
	Vastus intermedius	
	Vastus medialis	
Medial rotation	Popliteus	Tibial nerve
	Semimembranosus	Sciatic nerve
	Semitendinosus	
Lateral rotation	Biceps femoris	Sciatic nerve
Ankle (Talocrural) Joint		
Plantar flexion	Soleus	Tibial nerve
	Gastrocnemius	
	Tibialis posterior	
	Flexor digitorum longus	
	Flexor hallucis longus	
	Peroneus longus and brevis	Superficial peroneal nerve
Dorsiflexion	Tibialis anterior	Deep peroneal nerve
	Extensor digitorum	
	Extensor hallucis longus	

Shoulder Joint

Innervation to the shoulder joints originates from the superior and middle trunks of the brachial plexus that can be blocked at the interscalene level. Most of the shoulder capsule is supplied by the axillary and suprascapular nerves, which can be selectively blocked more distally. (Figure 1-19).

Elbow Joint

Branches of all major nerves of the brachial plexus that cross the joint, including the musculocutaneous, radial, median, and ulnar nerves, supply the elbow joint (Figure 1-20).

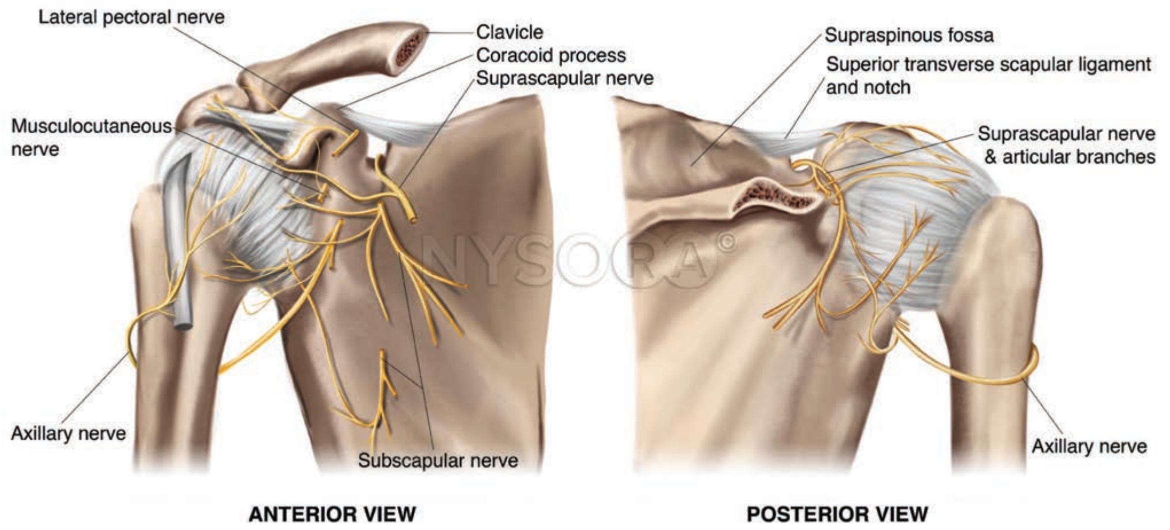

FIGURE 1-19. Innervation of the shoulder joint.

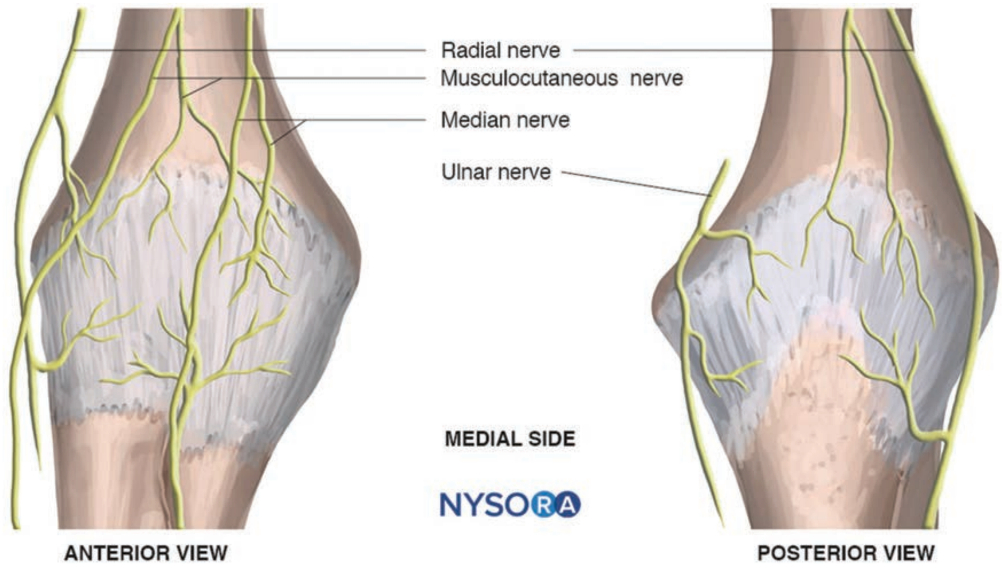

FIGURE 1-20. Innervation of the elbow joint.

Hip Joint

Branches from the femoral and obturator nerves from the lumbar plexus and from the sciatic nerve and the nerve to the quadratus femoris from the sacral plexus innervate the hip joint (Figure 1-21).

Knee Joint

Branches from the femoral nerve innervate the knee joint anteriorly. On its medial side, the nerve receives branches from the posterior division of the obturator nerve, while both divisions of the sciatic nerve supply its posterior side (Figure 1-22).

Wrist and Hand

Most of the terminal branches of the brachial plexus, including the radial, median, and ulnar nerves, innervate the wrist and hand joints (Figure 1-23).

Ankle and Foot

The innervation of the ankle and foot joints is complex and involves the terminal branches of the common peroneal (deep and superficial peroneal nerves), tibial (tibial nerve), and femoral nerves (saphenous nerve). An easier view is that the entire innervation of the ankle joint originates from the sciatic nerve,

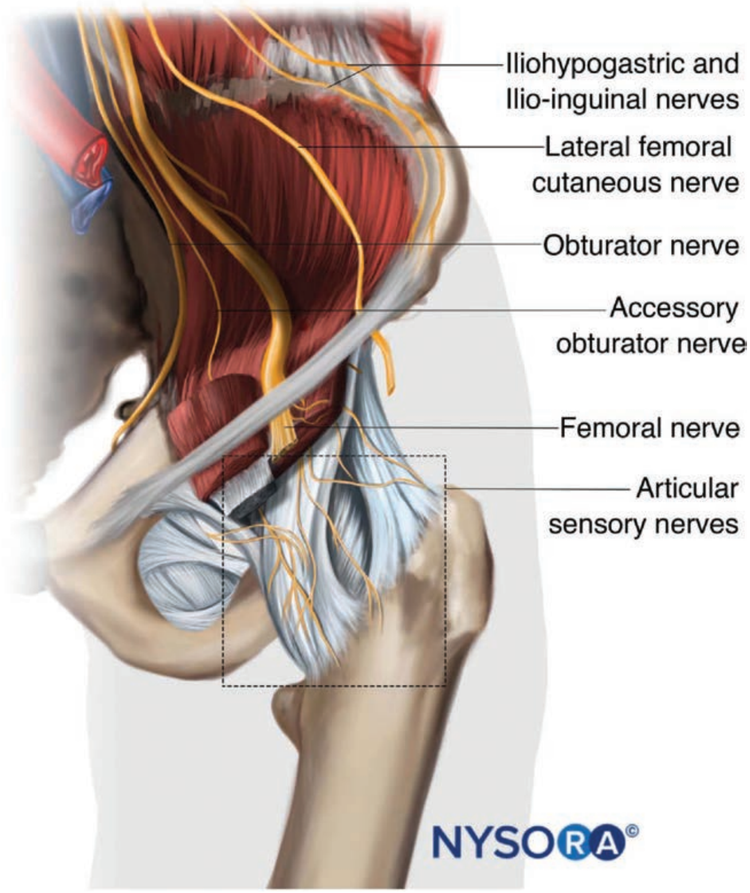

FIGURE 1-21. Innervation of the hip joint.

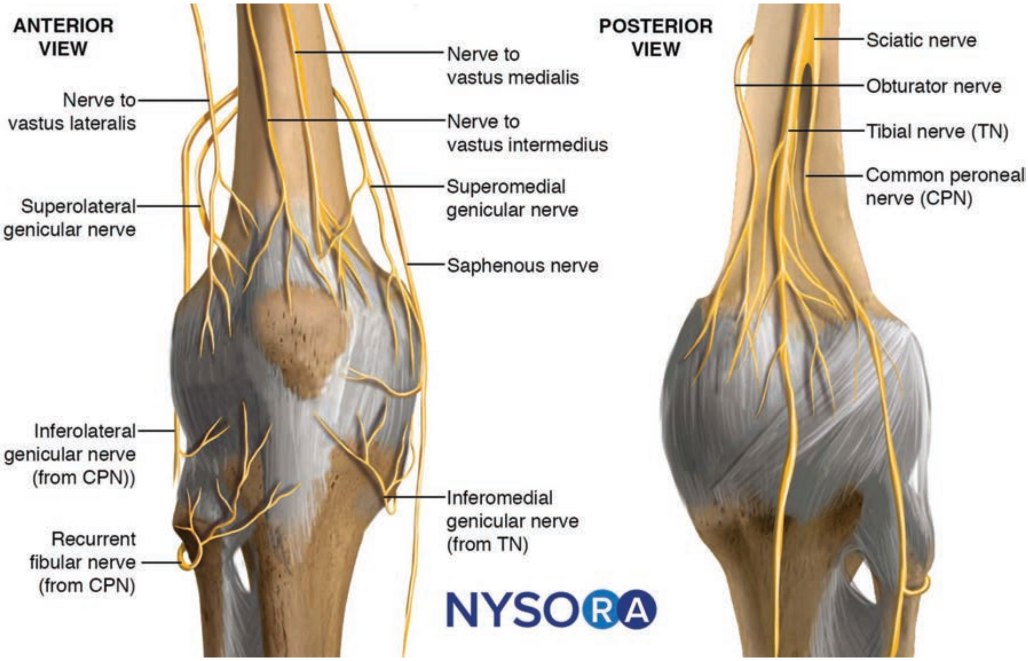

FIGURE 1-22. Innervation of the knee joint. The origin of the superomedial and superolateral genicular nerves (from the sciatic nerve or femoral nerve) is controversial.

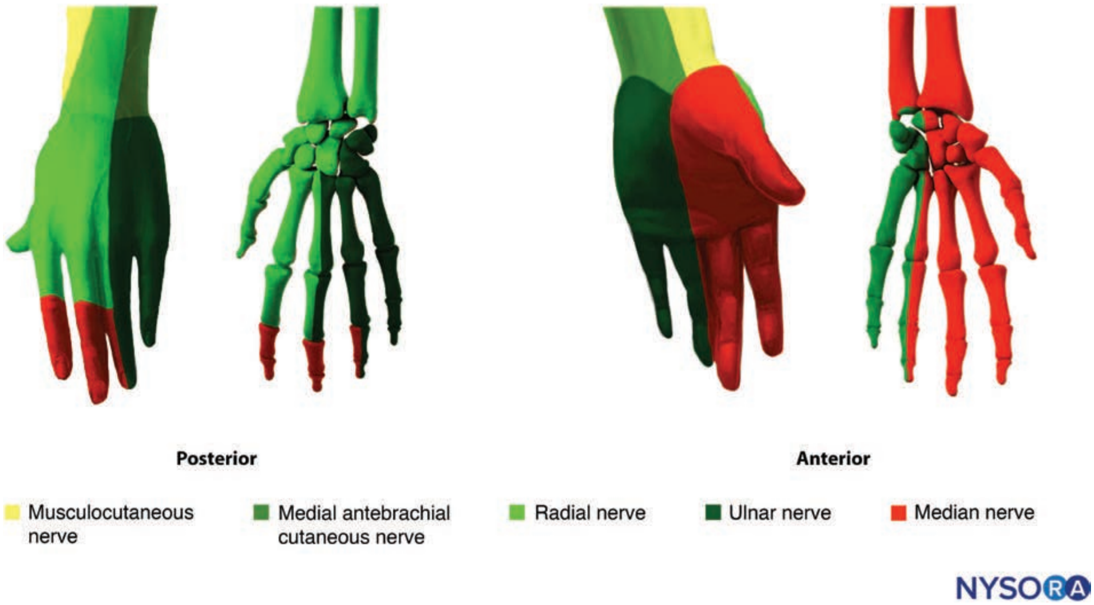

FIGURE 1-23. Innervation of the wrist.

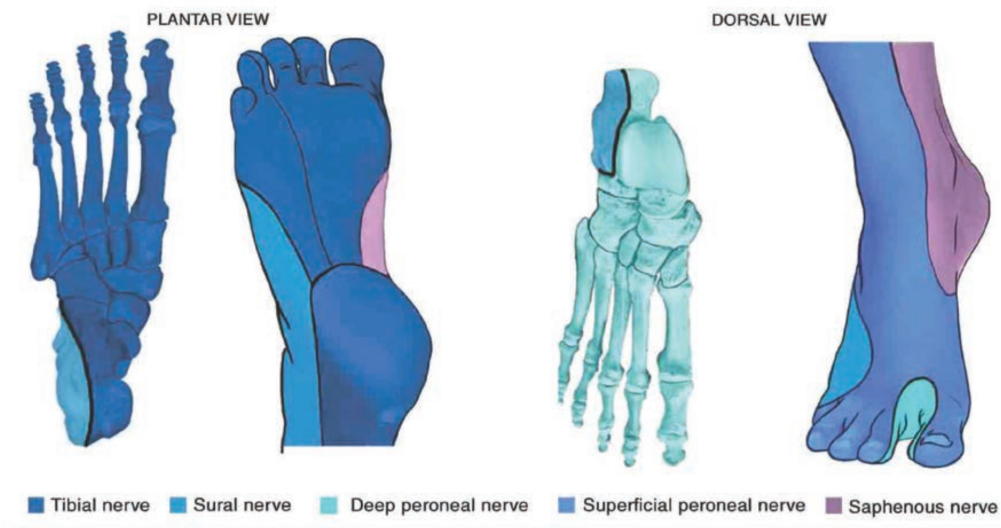

FIGURE 1-24. Innervation of the ankle.

except for the medial aspect around the medial malleolus, which is innervated by the saphenous nerve (Figure 1-24).

Autonomic Component of Spinal Nerves

All spinal nerves transmit autonomic sympathetic fibers to glands and smooth muscles in the regions they innervate. No parasympathetic fibers are present in spinal nerves. The sympathetic fibers originate in the spinal cord between T1 and L2 and pass from the spinal cord through the ventral roots of the T1-L2 spinal nerves. They depart from the spinal nerve through white rami communicantes to enter the sympathetic trunk, which is formed by a series of interconnected paravertebral ganglia that are adjacent to the vertebral bodies and extend from the axis (C2 vertebra) to the sacrum. The preganglionic fibers synapse on cell bodies of neurons forming the paravertebral ganglia. The axons of paravertebral ganglia (postganglionic fibers) can remain at the same level or can change level by ascending or descending the trunk. These fibers pass from the trunk through gray rami communicantes to spinal nerves. The sympathetic trunk sends a gray ramus to all spinal nerves. The sympathetic nerves travel along branches of the spinal nerve to the target destination (Figure 1-25).

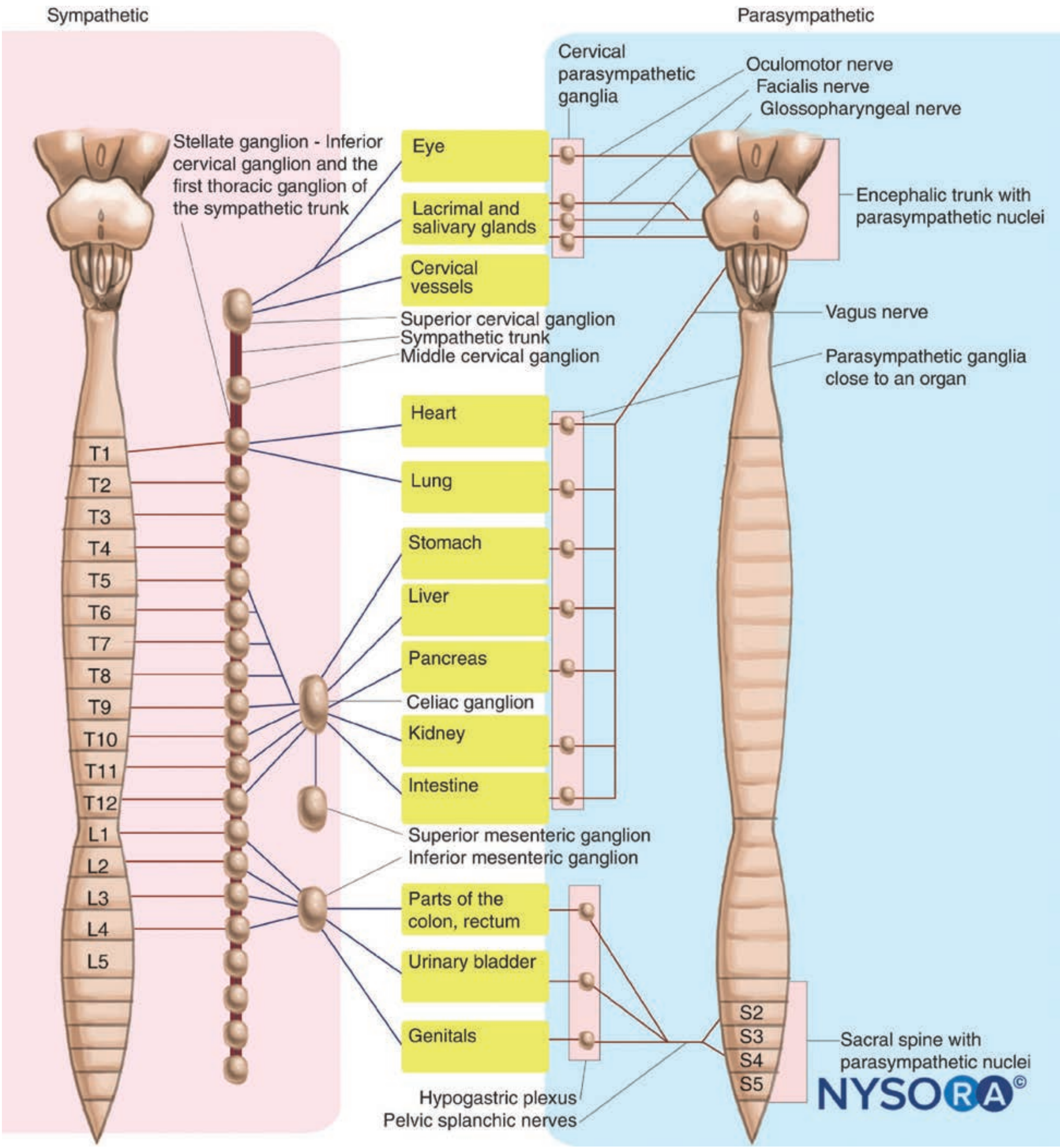

FIGURE 1-25. Organization of the autonomic nervous system.

SUGGESTED READINGS

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2 Local Anesthetics: Clinical Pharmacology and Selection

Local anesthetics (LAs) have been used for more than a century to block nociceptive signals. They bind to the specific receptor sites on the sodium (Na^+) channels in nerve cells to interrupt nerve conduction by blocking the entrance of ions across the cell membrane. LAs also activate a number of downstream pathways in neurons by G protein-coupled receptors and interact with calcium, potassium, and hyperpolarization-gated ion channels, ligand-gated channels. The clinical properties of the LAs are determined by their chemical and pharmacologic properties with a significant variation in individual patients' responses. The current developments in LAs focus on formulations of local anesthetic that prolong the duration of the action. Formulations of encapsulated slow-release LAs, on-demand release, and those with a selective nociceptive block are being developed. This chapter discusses the mechanism of action of LAs and their clinical use. The prevention and treatment of toxicity and allergy by LAs are explained in Chapter 9.

Nerve Conduction

Nerve conduction is the transmission of an electrochemical signal from one neuron to another. The axon, a prolongation of the soma of the neuron, plays an essential role in nerve conduction. Axons can be myelinated or unmyelinated depending on the type of nerve fiber. Myelin is the fatty substance that insulates the nerves and surrounds the axon. The myelin sheath, however, is not continuous. The section where no myelin is present is called a node of Ranvier. A high concentration of ion channels at the level of these nodes in myelinated nerve fibers results in high conduction speeds. The greater the internodal distance, the greater the conduction speed. Unmyelinated fibers, lacking the saltatory mechanism, conduct more slowly than myelinated fibers.

The propagation of an electrical impulse in nerve conduction is generated by the rapid movement of small amounts of cations, sodium (Na^+) and potassium (K^+), across the nerve membrane. The ionic gradient caused by Na^+ (high extracellular; low intracellular) and K^+ (high intracellular; low extracellular) is maintained by a Na^+/K^+-adenosine triphosphate (ATPase) pump mechanism within the cell membrane of the nerve. In the resting state, the nerve membrane is more permeable to K^+ ions than to Na^+ ions. This results in the continuous, slow leakage of K^+ ions out of the nerve cell. This leakage of cations, in turn, creates a negatively charged interior relative to the exterior, producing an electric potential of −60 to −70 mV across the nerve membrane, also called the resting potential (Figure 2-1).

Receptors at the distal ends of sensory nerves act as sensors and transducers of mechanical, chemical, or thermal stimuli. The stimuli are then converted into minuscule electric currents. For example, a surgical incision releases chemical mediators that react with the receptors. The mediators in interaction with the nerve membrane near the receptor alter the electrical potential across the membrane making it less negative. When the threshold potential is reached, an action potential occurs, with a sudden increase in the permeability of the nerve membrane to Na^+ ions. As a result, there is a rapid influx of positively charged Na^+ ions (Figure 2-2.). This transient reversal of charge is called depolarization. Depolarization generates an electrical current that flows to the adjacent segments of the nerve and sequentially depolarizes them. This process of sequential depolarization alongside the nerve membrane is essential for nerve conduction and is caused by the rapid influx of Na^+ ions in response to a change in the transmembrane potential. Na^+ channels in the nerve are therefore characterized as "voltage-gated." These channels are protein structures with three subunits, one main α subunit, and two auxiliary subunits, that penetrate the full depth of the membrane bilayer and are in communication with both the extracellular surface of the nerve membrane and the axoplasm (interior) of the nerve. The α subunit contains the pore-forming domain and is responsible for voltage gating and unidirectional signal transmission by inactivation of the channel. This time-dependent inactivation is called the refractory period.

Repolarization takes place after the refractory period and will restore the electrical balance to the resting potential. During repolarization, Na^+ permeability decreases, while K^+ permeability increases, resulting in an efflux of K^+ from within the cell. Subsequently, both ions are restored to their initial intracellular and extracellular concentrations by the Na^+/K^+-ATPase pump.

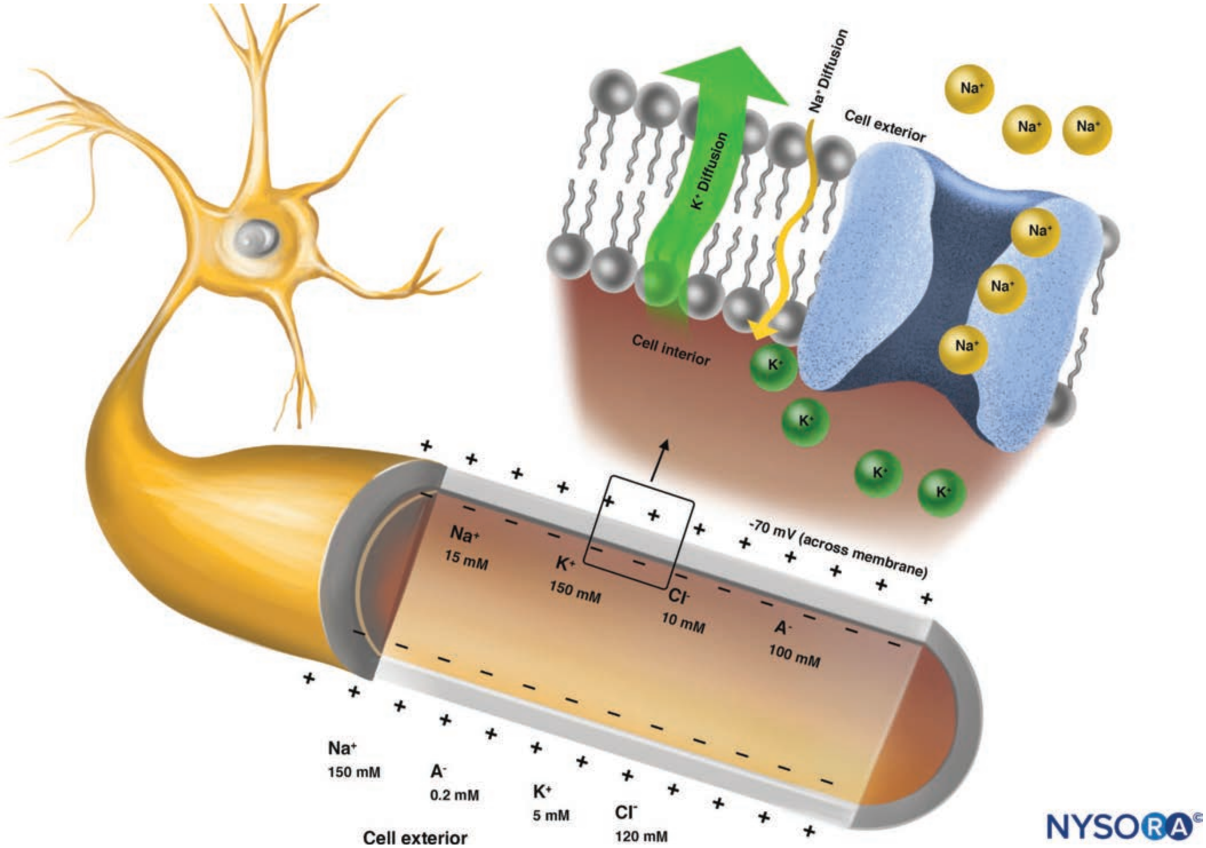


FIGURE 2-1. Resting membrane potential. The Na^+/K^+ pump is responsible for maintaining the ionic gradient between Na^+ and K^+ ions within the nerve. Typically, the resting membrane potential is between –60 and –70 mV.

Mechanism of Action of Local Anesthetics

LAs prevent the generation and conduction of nerve impulses by binding to the Na^+ channel and inhibiting the influx of Na^+ into the cell, thereby halting the transmission of the advancing wave of depolarization down the length of the nerve (Figure 2-3).

The LAs bind, in a reversible and concentration-dependent manner, to the α subunit located on the inner surface of the Na^+ channel. Since the LA molecules cannot pass through the channel itself to reach the binding site, they need to traverse the neuronal membrane first, and then enter the channel from the cytoplasmic side (Figure 2-3). LAs exist in two forms: unionized (lipophilic) and ionized (hydrophilic). The unionized form permeates more readily the phospholipid membrane, whereas the ionized form is more hydrophilic and binds with greater affinity to the open sodium channels.

The voltage-dependent Na^+ channel exists in three states: (1) open, (2) inactivated, and (3) resting. LAs have a higher affinity with the open and inactivated state of the voltage-dependent Na^+ channel than with the resting state. Repeated depolarization facilitates the encounter of the LA molecule with a Na^+ channel that is in the activated or open form, as opposed to the resting form. A resting nerve is less sensitive to an LA than a nerve that is repeatedly stimulated. Increasing the stimulation frequency causes a decrease in the flow of Na^+ in the presence of a low dose of LAs.

Structure-Related Clinical Properties of Local Anesthetics

LAs are water-soluble salts of lipid-soluble bases that behave as weak acid or base depending on the pH of the fluid they are in. The typical structure of an LA consists of hydrophilic (tertiary amine) and lipophilic (aromatic ring)

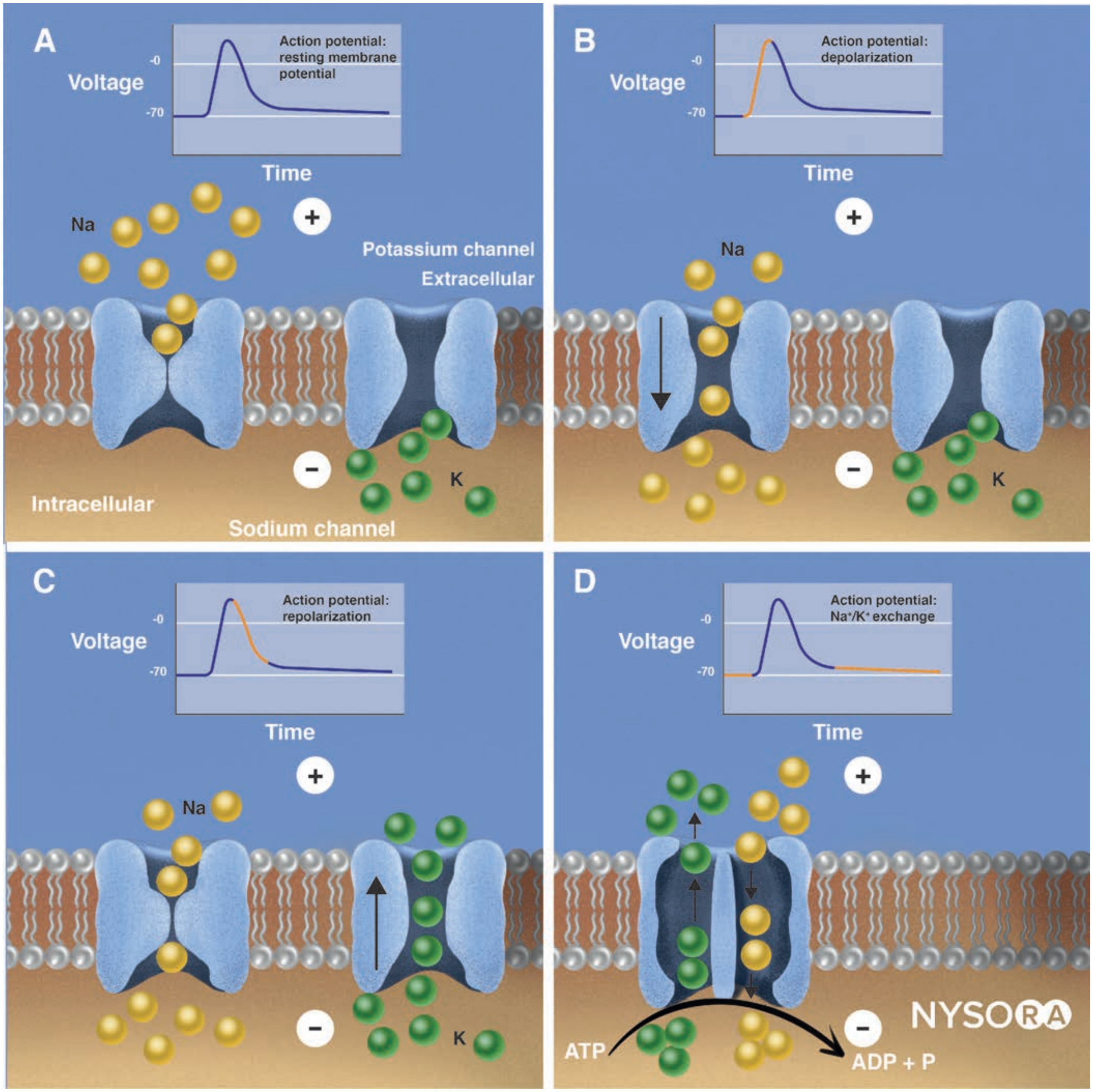


FIGURE 2-2. The working mechanism of action potentials. (A) At rest, the Na^+/K^+ pump is responsible for maintaining the ionic gradient between Na^+ and K^+ ions. The nerve membrane is more permeable to K^+ ions than to Na^+ ions, resulting in the leakage of K^+ ions out of the intracellular space. This creates a negatively charged interior relative to the exterior, producing a resting membrane potential of –60 to –70 mV across the nerve membrane. (B) A stimulus generates small electrical currents causing the membrane potential to become less negative. When the threshold potential is reached, an action potential results in a sudden increase in the permeability to Na^+ ions (voltage-gated Na^+ channels open) and a rapid influx of positively charged Na^+ ions into the interior of the neuron, resulting in depolarization (transient reversal of charge). (C) At the peak of the action potential, the voltage-gated Na^+ channels are inactivated, thereby preventing further entry of Na^+ ions. Simultaneously, the voltage-gated K^+ channels open and K^+ ions leak out of the neuron. This renders the neuron interior negative relative to the exterior (repolarization). (D) Finally, both ions are restored to their initial intracellular and extracellular concentrations by the Na^+/K^+ pump mechanism.

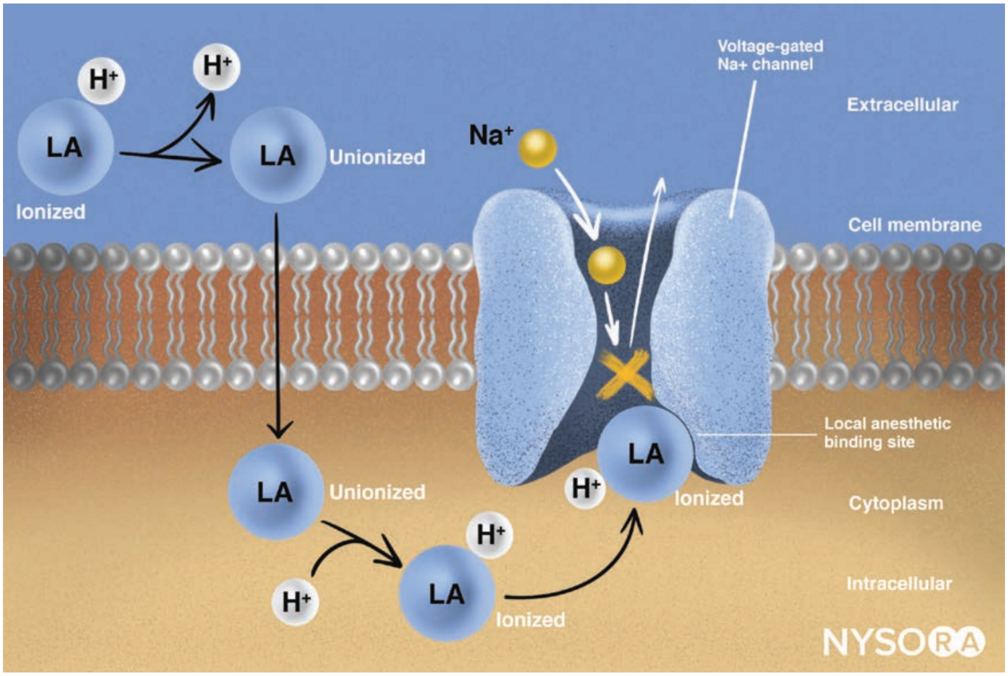


FIGURE 2-3. Mechanism of action of local anesthetics. Local anesthetics work by binding to the α subunit of the voltage-gated Na^+ channels, thus preventing the generation and conduction of nerve impulses. Subsequently, Na^+ ions cannot flow into the cell, thereby halting the transmission of the advancing wave of depolarization down the length of the nerve. Fraction of local anesthetic molecules are in the ionized form. LA molecules change from ionized to unionized in a fraction of a second.

domains separated by an intermediate ester or amide linkage (Figure 2-4). Each of these components contributes to the specific clinical properties of the LA.

- The ***amino group*** determines the pK_a of the LA and conveys hydrosolubility, which is important for the binding of the LA with the sodium channels. The pK_a is the pH at which 50% of the drug is ionized and 50% is present as a base. The pK_a is related to pH and the concentrations of the ionized (cation) and unionized (base), governed by the Henderson-Hasselbalch equation: pH = pK_a + log ([unionized]/[ionized]). If we reorganize the Henderson-Hasselbalch equation as log ([unionized]/[ionized]) = pH − pK_a, it is evident that a lower pK_a increases the amount of the unionized form of LA that facilitates crossing the nerve cell membrane. It follows that the lower the pK_a of an LA, the faster the onset. Of note, the tissue pH also affects the onset and the duration of LAs. Ischemic or infected tissue with a low pH will delay the onset of the LA action. This is because drug penetration of the nerve membrane by the LA requires the base (unionized) form to pass through the nerve lipid membrane, and the local tissue pH may affect the balance between unionized and ionized fractions of LA.

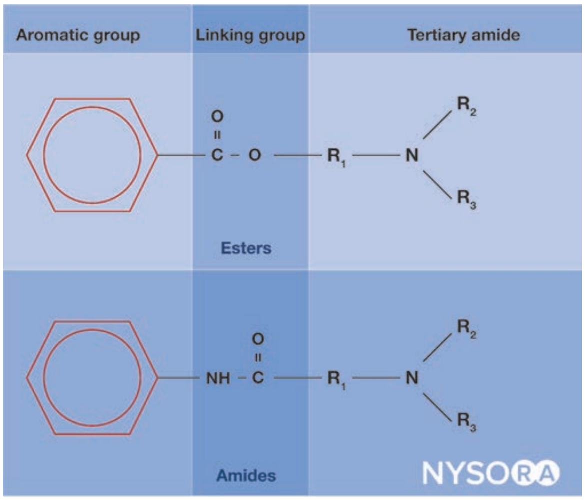


FIGURE 2-4. Structures of commonly used local anesthetics.

- The ***aromatic group*** and its substitutions determine the lipid solubility (hydrophobicity) of the LA molecule that is expressed as partition coefficient. Greater lipid solubility enables higher affinity to lipid membranes, which results in longer permanence in the proximity to the sites of action (Figure 2-5). Therefore, lipid solubility increases the potency and duration of their action. Unfortunately, higher lipid solubility also increases toxicity, decreasing the therapeutic index. In the clinical setting, higher lipid solubility does not enhance

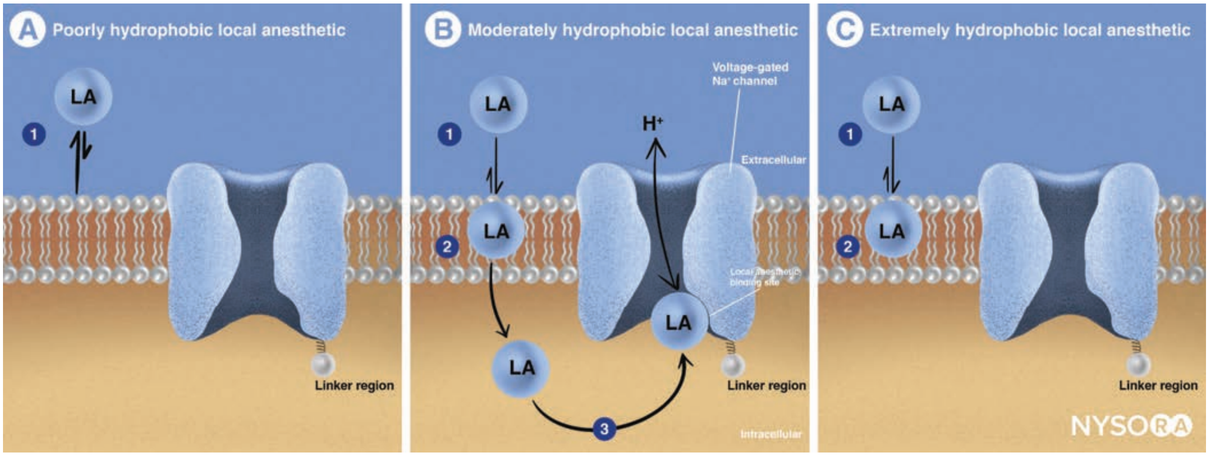


FIGURE 2-5. Local anesthetic hydrophobicity, diffusion, and binding. Local anesthetics act by binding to the intracellular side of voltage-gated Na^+ channels (α subunit). The hydrophobicity of a local anesthetic determines how efficiently it diffuses across the lipid membrane and how tightly it binds to the Na^+ channel and therefore governs its potency. (A) Less hydrophobic local anesthetics are unable to cross the hydrophobic lipid bilayer efficiently because the local anesthetic is stable in the extracellular solution. (B) Moderately hydrophobic local anesthetics are the most effective agents. These local anesthetics have a higher affinity for lipid membranes and greater proximity to the sites of action. (C) Extremely hydrophobic local anesthetics are absorbed by the neuronal cell membrane and are unlikely to dissociate or diffuse out of the membrane. Therefore, they remain trapped in the lipid bilayer.

the speed of onset of the LA, despite a faster diffusion through lipid membranes. This is due to a higher uptake by adipose tissue and myelin sheaths.

- The nature of the ***linking group*** determines the pharmacokinetic properties of the LA. There are two categories: **ester** LAs that are hydrolyzed rapidly in plasma by pseudocholinesterase to the metabolite para-aminobenzoic acid (PABA), and **amide** LAs that undergo metabolization in the liver. Exceptions are cocaine, an ester LA that is metabolized in the liver by carboxylesterase, and articaine, an amide LA that is hydrolyzed by plasma carboxylesterase.

Pharmacologic Properties of Local Anesthetics

In general, the greater the molecular weight of LA molecules and lipophilicity and the protein binding, the longer the duration of action, potency, and toxicity of the LA. However, the reverse is true with regards to the speed of onset. Additional factors that influence LA action are dose, intrinsic vasoactivity, physical characteristics of the tissue surrounding the nerve, and formulation of the LA. For instance, extended-release formulations produce a delayed onset but extended duration.

Simplified, block duration is determined largely by three factors: (1) lipid solubility, (2) vascularity of the tissue, and (3) the presence of vasoconstrictors. Of the three, the most important factor influencing the conduction block duration is the lipid solubility of the LA.

Site of Injection

In peripheral nerve blockade, the LA is deposited in the vicinity of or around the nerves, typically between the fascial sheaths that contain the nerve. The pattern of the spread of the injected solution longitudinally and circumferentially determines the exposure of the nerve surface to the LA. Intraneural or subepineural injections typically result in a faster block onset but are not recommended as a safe practice. These injections increase the risk of neurologic injury due to mechanical needle-nerve injury, the risk of intraneural hematoma, or the risk of LA neurotoxicity.

Nerve Factors

Anatomical Characteristics of Nerve Fibers

Nerve anatomy, with its surrounding connective tissues, presents barriers to the diffusion and the action of LAs. Peripheral nerves have three connective tissue sheaths. A mixed peripheral nerve consists of individual nerves surrounded by an investing epineurium. The epineurium is collagenous and envelops a multitude of nerve fascicles separated by adipose and other connective tissues, and nutrient blood vessels. The outermost epineurium surrounds the peripheral nerve and provides mechanical support during flexing and stretching. The perineurium encloses a bundle of nerve fibers called fascicle and acts as an endothelial-like structure, while imparting mechanical strength to the nerve. Inside the perineurium, individual nerve fibers are embedded in the endoneurium, a loose connective tissue made up of glial cells, fibroblasts, and capillaries.

When an LA is deposited in proximity to a peripheral nerve, it diffuses from the outer mantle toward the core of the nerve along a concentration gradient. Consequently, nerve fibers located in the outer mantle of the mixed nerve are blocked first (Figure 2-6). The outside fibers are typically distributed to more proximal anatomic structures than the fibers situated near the core of the nerve. As a result, the block evolves from proximal structures to distal structures (the core often consists of motor fibers). The LA eventually diffuses inward alongside the concentration gradient to block the centrally located fibers. Smaller doses and/or concentrations of LAs predominantly block the smaller and more susceptible nerves in the outer mantle.

Differential Sensitivity of Nerve Fibers to Local Anesthetics

Different nerve fibers differ not only by myelin thickness and size but also by different patterns of electrophysiological properties and ion channel composition. Two general rules

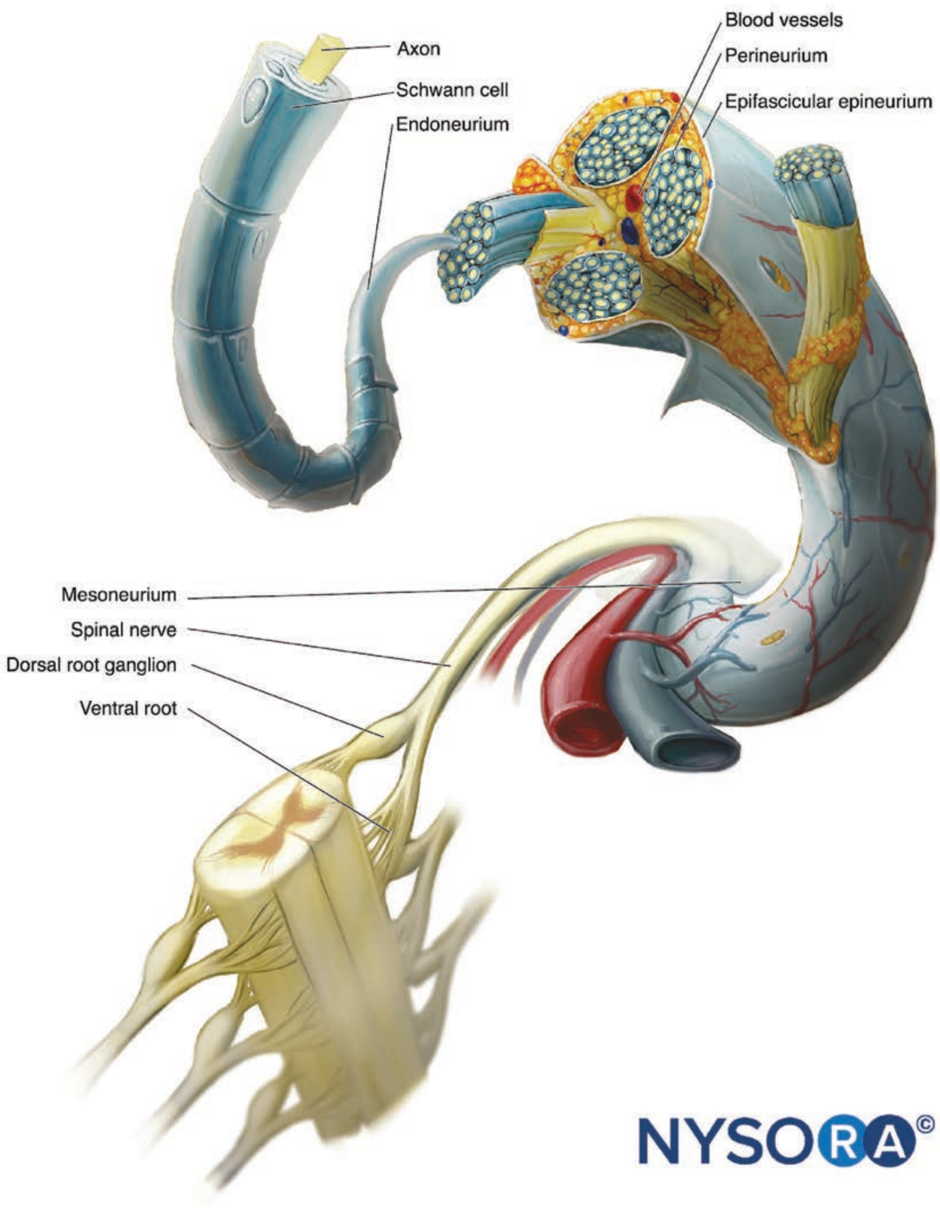
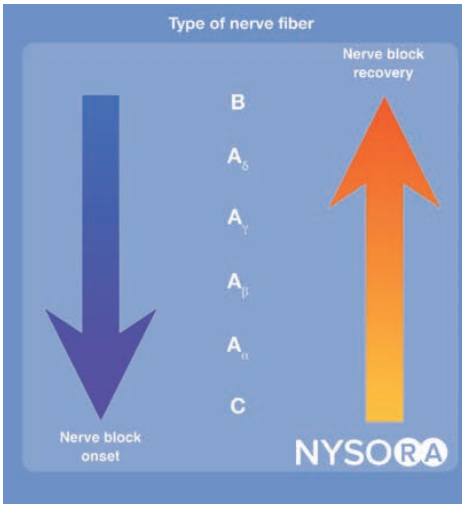


FIGURE 2-6. The structure and organization of the peripheral nerve.



Classification of nerve fibers

Type	Diameter (μm)	Myelin	Conduction velocity (m/s)	Location	Function
A_α	12-20	+++	70-120	Afferents/efferents for muscles and joints	Motor and proprioception
A_β	6-12	+++	30-70	Afferents/efferents for muscles and joints	Touch Pressure
A_γ	3-6	+++	15-35	Efferent to muscle spindle	Muscle tone
A_δ	1-4	+++	5-25	Afferent sensory nerve	Pain Touch Temperature
B	<3	+	3-15	Preganglionic sympathetic	Autonomic function
C	0.3-1.3	-	0.7-1.3	Postganglionic sympathetic Afferent sensory nerve	Autonomic function Pain Temperature

FIGURE 2-7. Classification of nerve fibers and differential rate of nerve blockade.

apply regarding the susceptibility of nerve fibers to LAs. First, smaller nerve fibers are more susceptible to the action of LAs than large fibers (Figure 2-7). Smaller fibers are preferentially blocked because a shorter length of the axon is required to halt the conduction completely. Second, myelinated fibers are more easily blocked than unmyelinated fibers. In general, nerve fibers with a cross-sectional diameter greater than 1 μm are myelinated.

Clinically, the differential speed of the nerve conduction block and recovery may differ, depending on the site of injection (spinal, epidural, or peripheral nerve) and the type and concentration of LA used. In general, the sensation of pain is usually the first modality to disappear, followed by the loss of sensations to cold, warmth, touch, deep pressure, and, finally, loss of motor function.

Types of Local Anesthetics

LAs are broadly divided into two categories: esters and amides. Other than metabolization pathways, the physicochemical properties of both amino esters and amino amides are similar and mainly determined by their dissociation constant, lipophilic makeup, and spatial arrangement of the molecule (Table 2-1).

Ester-Linked Local Anesthetics

Ester-linked LAs are hydrolyzed at the ester linkage in plasma by pseudocholinesterase. The rate of hydrolysis of ester-linked LAs depends on the type and location of the substitution in the aromatic ring. For example, 2-chloroprocaine is hydrolyzed about four times faster than procaine, which in turn is hydrolyzed about four times faster than tetracaine. The rate of hydrolysis of all ester-linked LAs may be slower in patients with atypical plasma pseudocholinesterase (uncommon; incidence for homozygosity 1:2 000-4 000). The metabolism (hydrolysis) of ester-linked LAs leads to the formation of para-aminobenzoic acid (PABA), which is known to cause allergic reactions. A history of an allergic reaction to LAs is often due to the presence of PABA derived from an ester-linked LA. Of note, although rare, allergic reactions can also develop from amide-linked LAs; however, this is more likely due to the PABA as a preservative, which is commonly added to multiple-dose vials.

2-Chloroprocaine

2-Chloroprocaine is an amino ester introduced in 1952 and is the most rapidly metabolized LA. Because of its rapid breakdown in plasma (<1 minute), it has a very low potential for systemic toxicity. The chloroprocaine preservatives, sodium bisulfite, and disodium ethylenediaminetetraacetate (EDTA) used in the past were reported to cause neurologic symptoms, which precluded its use for spinal anesthesia until recently. Newer 2-chloroprocaine formulations are preservative-free preparations and are often used for short-acting spinal anesthesia.

A 3% 2-chloroprocaine solution is a good choice in peripheral nerve blocks (PNBs) for surgical anesthesia of short duration or for patients having a relatively minor surgery, not resulting in postoperative pain (e.g., carpal tunnel syndrome, knee arthroscopy, muscle biopsy, shoulder dislocation treatment). PNBs with chloroprocaine (2%-3%) are characterized by fast onset and short duration of action (60-90 minutes).

Cocaine

Cocaine occurs naturally in the leaves of the coca shrub and is an ester of benzoic acid. Cocaine blocks the nerve conduction and causes local vasoconstriction due to inhibition of the

TABLE 2-1 Physicochemical Properties of Clinically Used Local Anesthetics

LOCAL ANESTHETIC	pK_a	PERCENT IONIZED (AT pH 7.4)	PARTITION COEFFICIENT (LIPID SOLUBILITY)	PERCENT OF PROTEIN BINDING
Amides				
Bupivacaine[a]	8.1	83	3 420	95
Etidocaine	7.7	66	7 317	94
Lidocaine	7.9	76	366	64
Mepivacaine	7.6	61	130	77
Prilocaine	7.9	76	129	55
Ropivacaine	8.1	83	775	94
Esters				
Chloroprocaine	8.7	95	810	N/A
Procaine	8.9	97	100	6
Tetracaine	8.5	93	5 822	94

[a]Levobupivacaine has the same physicochemical properties as a racemate. N/A, not available.

Data from Liu SS. Local anesthetics and analgesia. In: Ashburn MA, Rice LJ, eds. *The Management of Pain*. New York: Churchill Livingstone; 1997:141.

Adapted from Barash PG, Cullen BF, Stoelting RK, Cahalan MK, Stock MC, Ortega R, et al. *Clinical Anesthesia*, 8th ed. Philadelphia, PA: Wolters Kluwer; 2017.

norepinephrine reuptake locally. Its toxicity and potential for abuse preclude its wider clinical use. Its euphoric properties are primarily due to inhibition of catecholamine uptake, particularly dopamine, at central nervous system (CNS) synapses.

Procaine

Procaine, an amino ester, was the first synthetic LA. Procaine is characterized by low potency, slow onset, and short duration of action. Procaine is used less frequently today since more effective (and hypoallergenic) alternatives such as lidocaine exist. Like other LAs (such as mepivacaine and prilocaine), procaine is a vasodilator.

Tetracaine

Tetracaine, a long-acting amino ester, was introduced in 1932. It is much more potent and has a longer duration of action than the aforementioned esters procaine or 2-chloroprocaine. Tetracaine has a slower onset in comparison to other commonly used ester-linked LAs and is more toxic. Due to its slow onset and potential for toxicity, it is rarely used for PNBs.

Amide-Linked Local Anesthetics

Amide-linked LAs are metabolized in the liver by a dealkalization reaction in which an ethyl group is cleaved from the tertiary amine. The hepatic blood flow and liver function determine the hepatic clearance of these anesthetics. Consequently, factors that decrease hepatic blood flow or hepatic drug extraction both result in an increased elimination half-life. Renal clearance of unchanged LAs is a minor route of elimination, accounting for only 3% to 5% of the total drug administered.

Lidocaine

Introduced in 1948, lidocaine remains one of the most widely used LAs. Lidocaine is absorbed rapidly after parenteral administration, and from the gastrointestinal and respiratory tracts after topical administration. The high concentration of lidocaine (5%) has been related to transient neurologic symptoms (TNS) in intrathecal use for spinal anesthesia. A concentration of 1.5% or 2%, with or without the addition of epinephrine, is most commonly used for surgical anesthesia in PNBs. Diluted concentrations are often used for diagnostic blocks in pain management.

Mepivacaine

Mepivacaine, introduced in 1957, has pharmacologic properties similar to those of lidocaine. Although it was suggested that mepivacaine is more toxic to neonates (and as such is not used in obstetric anesthesia), its therapeutic index in adults is similar to that of lidocaine. Its onset of action is similar to that of lidocaine, but with a slightly longer duration of action than lidocaine. Nerve blocks with 2% mepivacaine result in an intermediate-duration blockade (3-6 hours).

Prilocaine

Prilocaine is an LA of intermediate duration with a pharmacologic profile similar to that of lidocaine, except that it does not cause vasodilatation. It also has a larger distribution volume, which reduces its CNS toxicity. It is unique among amide LAs for its ability to induce methemoglobinemia. The development of methemoglobinemia depends on the total dose administered (usually requires 8 mg/kg) and is caused by its effect on the metabolism of the aromatic ring to o-toluidine and does not have significant consequences in healthy patients. It can be treated by intravenous (IV) administration of methylene blue (1-2 mg/kg). Prilocaine is used infrequently for PNBs but is increasingly more often used for spinal anesthesia, particularly for fast-track surgery.

Bupivacaine

Since its introduction in 1963, bupivacaine has been one of the most widely used LAs in regional anesthesia, both in neuraxial and PNBs. Its structure is similar to that of lidocaine, except that the amine-containing group is butylpiperidine. Bupivacaine is characterized by a slower onset and long duration of conduction blockade that can result in anesthesia and analgesia of >24 hours in some nerve blocks (e.g., sciatic and ankle block). The addition of a vasoconstrictor (e.g., epinephrine 1:300,000) can prolong the block duration up to 30%. Bupivacaine is more cardiotoxic than lidocaine, and the cardiotoxicity is cumulative with all LAs. Its cardiotoxicity partly may be mediated centrally, as direct injection of small quantities of bupivacaine into the medulla can produce malignant ventricular arrhythmias. Bupivacaine-induced cardiotoxicity can be resistant to treatment. Because of its toxicity profile, large doses of bupivacaine should be avoided.

Levobupivacaine

Levobupivacaine contains a single enantiomer of bupivacaine hydrochloride (S sinister, levo). The *S*-enantiomer, like most LAs with a chiral center, has a lower toxicity profile than the *R*-enantiomer. The available studies of levobupivacaine suggest that conduction block properties are similar to bupivacaine. Therefore, levobupivacaine is perceived as an alternative to bupivacaine with a somewhat more favorable cardiovascular toxicity profile.

Ropivacaine

Ropivacaine is a long-lasting LA (*S*-enantiomer of 1-propyl-2′, 6′-pipecolocylidide). It has a somewhat slower uptake than bupivacaine, resulting in lower blood levels for a given dose. Ropivacaine is also slightly less potent than bupivacaine when used in the same concentration. However, in concentrations of 0.5% and higher, it produces a dense block with a shorter duration than that of bupivacaine (typically up to 12 hours). In concentrations of 0.75% to 1%, the onset of the blockade is rapid and close to that of 1.5% mepivacaine or 3% 2-chloroprocaine. Ropivacaine is less lipophilic than bupivacaine and may penetrate less across large myelinated motor fibers, possibly resulting in less motor block. However, this is not obvious clinically. Regardless, because of its slightly better CNS toxicity and cardiotoxic profile, ropivacaine has gained popularity and almost replaced bupivacaine in some centers. As the ultrasound guidance during regional anesthesia has decreased the minimum dose of LA for a successful block, and therefore the risk of toxicity, bupivacaine and levobupivacaine are making a comeback and are increasingly more used as the long-acting LAs of choice where long-duration analgesia is sought.

Additives to Local Anesthetics

Clinicians have been using a variety of adjuvants to LAs to prolong nerve blocks. Although the risk of neurotoxicity is relatively small, the advantages of these adjuvants in clinical trials have not been consistent, posing questions of clinical benefits. The most common additives include epinephrine, clonidine, dexmedetomidine, opioids, and dexamethasone.

Vasoconstrictors

The addition of a vasoconstrictor to an LA delays its vascular absorption by the surrounding tissues and increases the duration of the LA contact with nerves. The net effect is the prolongation of the blockade by 30% to 50% and a decrease in the systemic absorption of the LA. These effects vary significantly among different types of LAs and individual nerve blocks. The prolongation of the block is greater with LAs that have greater vasodilatory properties (e.g., bupivacaine) than with ropivacaine, which has a slight vasoconstricting effect. Epinephrine is the most commonly used vasoconstrictor in PNBs with concentrations ranging from 1:400,000 to 1:200,000 (2.5-3.3 μg/mL) (Figure 2-8).

Epinephrine can also serve as a marker of intravenous injection of LA. An increase in heart rate of 10 bpm or higher and/or an increase in systolic blood pressure of 15 mmHg or higher after a dose of 10 to 15 μg epinephrine should raise a suspicion of intravascular injection. Note: These "intravascular marker" properties of epinephrine are less relevant with smaller volumes of LA used during ultrasound-guided nerve blocks.

Opioids

The injection of opioids into the epidural or subarachnoid space to manage acute or chronic pain is based on the presence of opioid receptors in the substantia gelatinosa of the spinal cord. The intrathecal addition of an opioid enhances the neuraxial block and prolongs analgesia. However, opioids are not as effective in peripheral nerves. Perhaps the best-studied opioid is buprenorphine, a partial μ-opiate receptor agonist. Buprenorphine acts on κ- and δ-opioid receptors, and also possesses voltage-gated sodium channel-blocking

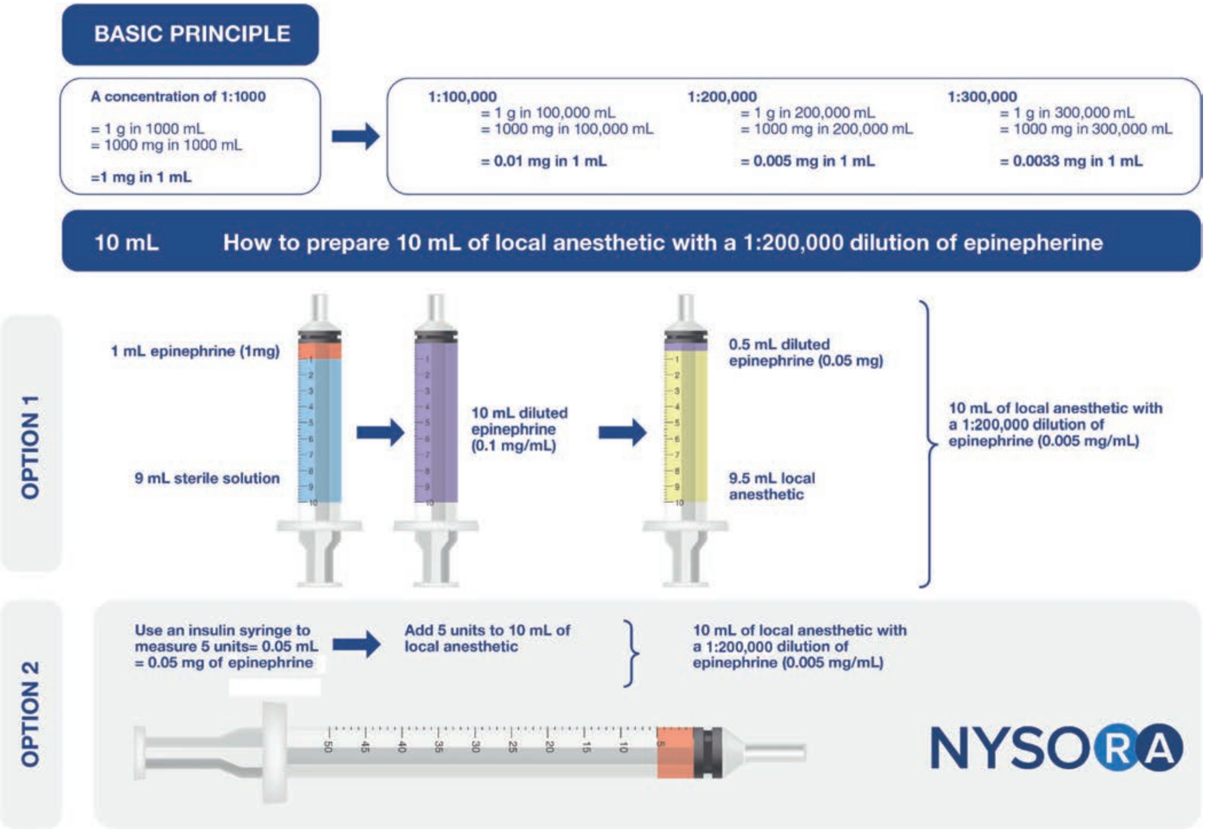


FIGURE 2-8. Addition of epinephrine to the mixtures of local anesthetics to decrease LA absorption and increase the duration of action.

properties. Older reports indicated that buprenorphine might be used instead of LAs to provide postoperative analgesia. While it can prolong the sensory-motor block by a few hours, and even provide some degree of transmission block on its own, a significant increase in nausea and vomiting limits its clinical use.

Clonidine

Clonidine is a centrally acting selective α2-adrenergic agonist. It is most commonly used as an antihypertensive drug because it reduces the sympathetic CNS output. Preservative-free clonidine, administered into the epidural or subarachnoid space (150-450 μg), produces dose-dependent analgesia via supraspinal and spinal adrenergic receptors. Unlike opioids, clonidine does not produce a depression of ventilation, pruritus, nausea, or vomiting. Clonidine also has direct inhibitory effects on peripheral nerve conduction (A and C nerve fibers), and may also prolong the duration of the sensory-motor block by 1.5 to 2 hours. There appears to be no benefit to using clonidine in continuous perineural infusions. The side effects of clonidine, however, notably sedation, orthostatic hypotension, and disbalance, may be limiting. Although life-threatening hypotension or bradycardia has not been reported when clonidine is used with PNBs, its circulatory effects may complicate resuscitation in a setting of local anesthetic systemic toxicity.

Dexmedetomidine

In contrast to clonidine, dexmedetomidine is more effective and a more specific α2 agonist. It can prolong both motor and sensory block by approximately 4 hours beyond the duration of the LA. Commonly reported side effects are bradycardia, hypotension, and sedation, but normally these episodes are transient and do not require intervention. The optimal dose of dexmedetomidine has not been determined, but it seems to be between 50 and 100 μg.

Dexamethasone

Dexamethasone is the best studied, most effective, and probably the most widely used adjuvant for prolonging block duration with the lowest risk of side effects. Its precise mechanism of action is not known. However, the addition of dexamethasone to an LA may increase the block duration by 4 hours or more. This prolongation may be accompanied by a prolonged motor block. Of note, intravenous administration

TABLE 2-2 Selecting Local Anesthetics for Peripheral Nerve Blocks

LOCAL ANESTHETIC	AVERAGE ONSET (MINUTES)	AVERAGE DURATION OF ANESTHESIA (HOURS)	AVERAGE DURATION OF ANALGESIA (HOURS)
3% Chloroprocaine	6-12	0.5-1	
2% Lidocaine + epinephrine	10-20	2-5	3-8
1.5% Mepivacaine + epinephrine	10-20	2-5	3-8
0.5% Ropivacaine	13-30	4-8	5-12
0.75% Ropivacaine	10-15	5-10	6-24
0.5% Bupivacaine or levobupivacaine + epinephrine	15-30	5-15	6-30

may be equally effective, yet simpler to administer. Typically 4 to 10 mg of dexamethasone is used perineurally or intravenously. Although frequently used, perineural injection of dexamethasone is an off-label indication.

Other Adjuvants

Other pharmacologic agents like magnesium, neostigmine, anti-inflammatory agents, etc., also have been used in the perineural space with mixed results. In the older literature, the addition of sodium bicarbonate was suggested to decrease the latency of onset and pain on the injection of mepivacaine and lidocaine. However, the newer LA formulations have a pH closer to the tissue pH; consequently, sodium bicarbonate is not often used any longer.

Selecting Local Anesthetics for Peripheral Nerve Blocks

The choice of LA is most commonly based on the desired duration of the block, e.g., duration of the surgical procedure, and the anticipated level and duration of postoperative pain. For example, the creation of an arteriovenous fistula is a relatively short operation with minor postoperative pain. Therefore, the selection of a short-acting agent (e.g., lidocaine or mepivacaine) provides excellent intraoperative anesthesia with a low systemic risk profile and without the unnecessary long duration of the insensate extremity postoperatively. In an opposite example, a rotator cuff repair is associated with significant and sustained postoperative pain. Therefore, a better choice for analgesia is a long-acting LA such as bupivacaine or ropivacaine. Bupivacaine provides the longest block duration of the currently available LAs.

The onset and duration for a given LA vary according to the nerve or plexus to be blocked. For example, 0.5% ropivacaine in the brachial plexus can provide 10 to 12 hours of analgesia. The same volume, dose, and concentration for the sciatic nerve may provide a significantly longer block (e.g., 30%-50% longer). As discussed, multiple factors influence duration, such as differences in the perineural vascularity, which influences the LA absorption and uptake.

Patients with anticipated pain lasting longer than 24 hours should be considered for perineural infusion of LAs through a catheter or combination of bupivacaine and liposome bupivacaine, where indicated.

Table 2-2 shows the commonly used LAs, with their expected onset and duration of actions. As mentioned previously, these numbers do not apply to all scenarios, nerves, or plexuses, but can be used as a rough comparative guide to aid in decision making.

Table 2-3 shows the maximum doses (with and without epinephrine) of the commonly used LAs.

Mixing Local Anesthetics

Mixing LAs (e.g., lidocaine and bupivacaine) is often done in clinical practice with the aim to shorten the onset and prolong the duration of a block. Unfortunately, when LAs are mixed, their onset, duration, and potency become less

TABLE 2-3 Maximum Doses of Local Anesthetic

LOCAL ANESTHETIC	MAXIMUM DOSE WITHOUT EPINEPHRINE (mg/kg)	MAXIMUM DOSE WITH EPINEPHRINE (mg/kg)
Chloroprocaine	11	14
Lidocaine	5	7
Mepivacaine	5	7
Prilocaine	6-7	8
Ropivacaine	3	-
Levobupivacaine	2	3
Bupivacaine	2	3-4

predictable. As an example from the literature, combining mepivacaine 1.5% with bupivacaine 0.5% does not offer a meaningful clinical advantage over each drug alone. Onset times for each drug injected individually or their mixture were similar, whereas the duration of the combination was shorter than bupivacaine alone. Therefore, if a long duration of block is desired, a long-acting drug alone will provide the best conditions. In addition, mixing LAs also carries a risk of drug error. Many nerve block goals can be met using a single agent, i.e., one short, intermediate, or long-acting LA.

Extended-Release Formulations of Local Anesthetics

The current research on LAs focuses mainly on formulations that can extend the duration of action of these medications through a slow, continuous release over a period of time. Liposomal, sucrose, and collagen-based systems are among the most studied slow-release delivery mechanisms for LAs. There are good reasons for the quest for extended-release or delayed-release LAs, such as a prolonged duration of action, or lowering the risk of local and systemic toxicity, as the quantity and concentration of the free LA being released are small. The new formulations may largely replace the perineural catheters, and their problems of tip migration, displacement, cumbersome and costly management, and risk of infection.

At the time of this book-writing, Exparel (Pacira Pharmaceuticals, Inc.; US) or liposome bupivacaine is the only currently approved delayed-release LA for clinical use. Exparel is approved for surgical site infiltration and interscalene brachial plexus block in USA. In EU, Exparel was also approved for femoral nerve block. Liposomes are multivesicular structures that contain an aqueous core surrounded by a phospholipid bilayer. The onset time and duration of liposome bupivacaine is dependent on the degradation of the vesicles and its release from this liposomal delivery formulation. In essence, multivesicular liposomes are made of a myriad of cavities that can be filled with various pharmacologic agents. Their large size creates a medication depot, which gradually discharges the LA (or other content) with natural liposome membrane breakdown. First proposed as a medication carrier in 1965, multivesicular liposomes have been used to encapsulate pharmaceuticals as diverse as ibuprofen, neostigmine, chemotherapeutics, and opioids. In 2004, liposome morphine (DepoDur; Pacira Pharmaceuticals; US) became the first liposome-encased medication to be approved for postoperative analgesia by the U.S. Food and Drug Administration. Subsequently, this formulation was approved for infiltration analgesia and some nerve block procedures both in the United States and the European Union.

Although it can be used without additives, liposome bupivacaine is often combined with standard bupivacaine (hydrochloride bupivacaine) to enhance the onset of the block as the free bupivacaine is gradually released for a sustained blockade. Liposomal bupivacaine should not be mixed with other agents (e.g., lidocaine) because other local anesthetics compete with bupivacaine for the liposomes. Consequently, mixing Exparel with non-bupivacaine local anesthetics may result in displacement of bupivacaine from the liposomes. Most clinical experience with liposome bupivacaine has been in the surgical site and wounqueryd infiltrations, where the formulation can provide analgesia beyond 72 hours after surgery. However, since its approval for use in interscalene brachial plexus block, there is a growing evidence and clinical experience that Exparel provides meaningful analgesia for several days, particularly when mixed with bupivacaine.

Compared to standard bupivacaine alone, the combination of bupivacaine and liposome bupivacaine improves postoperative analgesia with interscalene block throughout the first postoperative week, even in the setting of full multimodal analgesia. Recent reviews and meta-analyses have questioned the clinically relevant efficacy of liposome bupivacaine over bupivacaine in perineural applications. However, liposome bupivacaine must be added to bupivacaine to realize the benefits of bupivacaine. Important in consideration of choosing liposome bupivacaine for approved nerve blocks is to select indications in which the nerve block technique provides a sensory block to the entire region of interest. As an example, an interscalene block or femoral nerve block, in patients having major shoulder or patellar (knee) surgery, provides excellent analgesia with bupivacaine; adding liposome bupivacaine to bupivacaine extends the analgesia benefits of these blocks beyond the bupivacaine alone. Of note, liposome bupivacaine is unable to provide surgical anesthesia due to the insufficient amount of active substance, free-bupivacaine being released for a surgical block. However, the weaker, primarily sensory block with liposome bupivacaine is favored for analgesia over the dense, surgical block obtained with traditional LAs. Other indications for perineural or neuraxial administration of liposome bupivacaine are currently being researched and are likely to follow since liposome bupivacaine has a documented safety profile.

Other slow-release drugs in development are sucrose and collagen-based controlled release systems. SABER-bupivacaine (DURECT Corporation, Inc.; US) consists of sucrose acetate isobutyrate (SAIB), bupivacaine, and a solvent. After infiltration, the SAIB starts to dissolve and release bupivacaine without delay in onset, resulting in approximately 72 hours of analgesia. XaraColl (Innocoll Pharmaceuticals, Inc.; Ireland), a collagen-based matrix impregnated with bupivacaine, is implanted during the surgery and starts to release bupivacaine immediately. Resorption of the matrix will prolong the duration of analgesia over 72 hours.

Extended-release formulations will likely be integrated into many multimodal analgesia protocols, and further decrease the need for postoperative opioids. Future studies are needed to provide additional guidance for the indications and modes of use of liposome bupivacaine and other upcoming delayed-release formulations. In the meantime, the addition of liposome to bupivacaine in the approved perineural indications is probably the best method to prolong nerve block analgesia in most acute-pain service settings.

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3 Equipment for Peripheral Nerve Blocks

Introduction

Regional anesthesia equipment has undergone recent technological advances. The practice of regional anesthesia has been substantially modernized with the introduction of ultrasound (US), better needles, catheter systems, and ultrasound monitoring of needle advancement and injection pressure.

Induction and Block Room

Regional anesthesia is ideally performed in a designated area with access to the equipment for the time-efficient and safe practice of peripheral nerve blocks (PNBs). Adequate space, proper lighting, equipment, drugs, and material to perform blocks are essential. Full patient monitoring, source of oxygen, equipment for emergency airway management and positive-pressure ventilation, and access to emergency drugs are all necessary (Figure 3-1). When performing the block, an assistant trained in regional anesthesia is useful to prepare and handle equipment and help with the procedure.

TIPS

Routine patient monitoring during the administration of nerve blocks:

- Pulse oximetry
- Noninvasive blood pressure
- Electrocardiography
- Capnography
- Mental status (verbal contact)

Cardiovascular and Respiratory Monitoring During Application of Regional Anesthesia

Patients receiving regional anesthesia should be monitored with the same degree of vigilance as patients receiving general anesthesia. Local anesthetic (LA) toxicity due to intravascular injection or rapid absorption into the systemic circulation is uncommon but potentially a life-threatening complication. Likewise, premedication, often beneficial for patient comfort and acceptance of regional anesthesia procedures, may result in respiratory depression, hypoventilation, and hypoxia. Patients often present with comorbidities and clinical conditions that require monitoring during and after the block procedure and would go unnoticed without proper monitoring (e.g., arrhythmias, hypertension, hypoxemia). For these reasons, patients receiving PNBs should always have vascular access and be appropriately monitored. Routine cardiorespiratory monitoring should consist of pulse oximetry, noninvasive blood pressure, and electrocardiography. Respiratory rate and mental status should also be monitored. LA toxicity has a biphasic pattern and should be anticipated during the injection, immediately after the injection, and again 10 to 30 minutes after the injection. Signs and symptoms of toxicity occurring during or shortly after the completion of the injection are due to an intravascular injection or channeling of LAs to the systemic circulation (1-2 minutes). In the absence of intravascular injection, the typical absorption rate of LAs after injection peaks at approximately 10 to 30 minutes after the performance of a PNB; therefore, patients should be continuously and closely monitored for at least 60 minutes for signs of LA toxicity.

FIGURE 3-1. Typical block room setup. Shown are monitoring, oxygen source, suction apparatus, ultrasound machine, and nerve block cart with equipment.

FIGURE 3-2. Typical nerve block cart.

FIGURE 3-3. Nerve block cart content organized in a logical manner to ensure quick and easy access to supplies.

Regional Anesthesia Equipment Storage Cart

A regional anesthesia cart should be portable to enable transport to the point of care. The anesthesia cart should also be well stocked with all the necessary equipment and supplies, which should be well labeled and readily identifiable so that practitioners can perform PNBs effectively, safely, and efficiently (Figures 3-2 and 3-3).

Different drawers should be organized logically to ensure quick and easy access (Table 3-1). One drawer should be designated for emergency equipment and should include laryngoscopes with an assortment of commonly used blades, stylets, endotracheal tubes, and airways of various sizes. Immediately available emergency medications should include atropine, ephedrine, phenylephrine, propofol, succinylcholine, and intralipid 20% (Table 3-2). The latter can alternatively be stored in a nearby drug cart or drug-dispensing system that is immediately available and close to the block room. This way, it can be quickly prepared in case of LA toxicity. It is recommended to include an emergency flowchart in a visible and accessible place to treat LA toxicity.

Peripheral Nerve Block Trays

Commercially available, specialized nerve block trays are best for the time-efficient practice of PNBs. An all-purpose tray that can be adapted to a variety of blocks may be the most practical, given the wide array of needles and catheters that may be needed for specific procedures. Appropriate needles, catheters, and other specialized equipment are simply opened and added to the block tray as required (Figure 3-4).

Nerve Block Needles

Needles vary with regards to the tip design, length, gauge, and the presence or absence of electrical insulation or other specialized treatment of the needles (e.g., etching to enhance US visualization). Needle choice depends on the block being performed, the size of the patient, and the preference of the clinician.

Nerve injury can be caused by direct nerve penetration or forceful mechanical needle-nerve contact and the consequent trauma. Therefore, the bevel of the needle can have an impact on the extent of damage on needle insertion close to

TABLE 3-1 Suggested Organization of the Nerve Block Cart

DRAWER	CONTAINING ELEMENTS
Emergency equipment	Laryngoscopes, assorted blades, Magill forceps, stylets, endotracheal tubes, laryngeal mask airways of assorted sizes, nasal airways, oral airways, oxygen masks
Medications	Sterile saline, propofol, long- and short-acting local anesthetics, emergency medications, syringe labels
Needles	Stimulating needles, non-stimulating catheters, spinal needles
General equipment	Syringes of assorted sizes, electrocardiogram leads, pressure monitors, skin adhesive and catheter securing systems, alcohol swabs, clear occlusive dressing, tape, lubricating gel, sterile gloves
Sterile sets	Sets that include sterile drapes, sponges, transducer covers

TABLE 3-2 Suggested Emergency Drugs Required During Local Anesthetic Systemic Toxicity

DRUG	SUGGESTED DOSE (70 kg ADULT)
Intralipid 20%	Bolus • 100 mL over 2-3 min if patient >70 kg • 1.5 mL/kg over 2-3 min if patient <70 kg Infusion • 200–250 mL over 15-20 min if patient >70 kg • 0.25 mL/kg/min if patient <70 kg (ideal body weight) If circulatory stability is not achieved, consider a new bolus or increasing infusion to 0.5 mL/kg/min.
Seizure control: Midazolam Propofol* Muscle relaxant (succinylcholine)	 2-10 mg IV 1 mg/kg IV 1-2 mg/kg IV
If cardiac arrest occurs: Epinephrine Amiodarone (if ventricular arrhythmias develop)	 ≤1 µg/kg (small initial doses are preferred)
Atropine	0.2-0.4 mg IV increments
Ephedrine	5-10 mg IV
Phenylephrine	50-200 µg IV

*Propofol can stop seizures but large doses can further depress the cardiac function; therefore, propofol should be avoided or used cautiously.

a nerve (Figure 3-5). Short beveled (45°) needles may have the advantage of reducing nerve damage caused by cutting or penetrating the nerve. Long beveled (14°-15°) needles have been shown to be more likely to penetrate perineurium and cause fascicular injury than short beveled needles, especially when oriented transversely to the nerve fibers. The most commonly used needles have an intermediate bevel angle (30°), which appears to be a reasonable balance.

FIGURE 3-4. Example of a custom nerve block tray: syringes (1), disinfection swabs (2), fenestrated procedure drape (3), nerve block needle with extension tubing (4), injection pressure monitors (5), ultrasound gel (6), ultrasound transducer cover (7), medication basin (8), and tray for disinfectant (9).

Needle tip design can also directly affect the practitioner's ability to perceive tissue planes using a tactile sense during the procedure. Tuohy and short bevel noncutting needles encounter more resistance by the tissues and enhance the tactile feedback as the needle traverses different types of tissues. As an example, the passage of a short bevel needle through a fascial plane is often perceived as a palpable "click," or "loss of resistance." This tactile needle feedback is useful in supplementing or confirming the information obtained by US monitoring. Long bevel "cutting" needles do not provide much tactile information while traversing different tissues. Finally, pencil-point needles may be associated with less tissue trauma than short bevel needles. However, their use in the practice of PNBs, where frequent changes of the angle of needle insertion

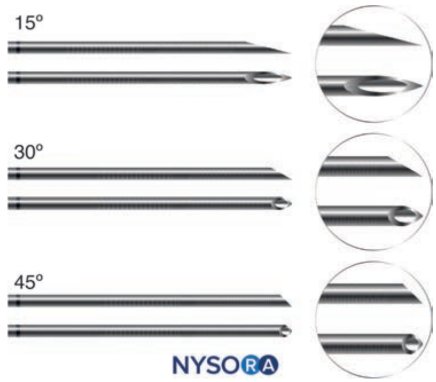

FIGURE 3-5. Common needle tip bevel designs.

are necessary, is not practical due to the excessive resistance by the tissues during needle advancement.

The length of the needle should be selected according to the type of block being performed (Table 3-3). A short needle may not reach its target. Long needles have a higher risk of causing injury due to increased difficulty in their maneuverability and the possibility of being inserted too deeply. The needle length often needs to be longer by 2 to 3 cm for ultrasound-guided blocks because needles are inserted further from the target to visualize the course of the needle on the image. The correct needle length will allow for optimal handling and manipulation. Ideally, needles should have depth markings on their shaft to allow monitoring for the depth of placement at all times.

TABLE 3-3 Block Technique and Recommended Needle Length

BLOCK TECHNIQUE	RECOMMENDED NEEDLE LENGTH
Cervical plexus block Wrist block Ankle block	30-40 mm
Interscalene, supraclavicular, and axillary brachial plexus block Fascia iliaca block Femoral nerve block Popliteal block	50 mm
Shoulder block Costoclavicular and infraclavicular brachial plexus block Erector spinae plane block Pectoralis and serratus plane blocks Transversus abdominis plane block Adductor canal block Obturator nerve block	50-100 mm
Thoracic paravertebral block Lumbar paravertebral block Lumbar plexus block Quadratus lumborum block iPACK block Proximal sciatic nerve block (posterior approach)	80-100 mm
Proximal sciatic nerve block (anterior approach)	100-150 mm

Needle Gauge

The gauge refers to the inner diameter of the needle expressed as a fraction of an inch; thus the larger the gauge, the smaller the needle diameter and vice versa. The choice of the needle gauge depends on the depth of the block and whether a continuous catheter is placed. Steinfeldt et al. demonstrated a positive correlation between the needle gauge and the degree of nerve damage after intentional nerve perforation. Large diameter needles (20-22 gauge) increase tissue trauma and patient discomfort but are best used for deeper blocks, where the larger diameter helps avoid bending of the shaft and maintains control of the needle path. In contrast, thinner needles (25 and 26 gauge) bend more easily, making them more difficult to steer as they penetrate deep tissue planes and easier to be inserted intraneural. The smaller diameter needles have more internal resistance, making it more difficult to gauge injection pressure and reliably aspirate to rule out intravascular placement. When placing a perineural catheter, the needle diameter must be large enough to allow the passage of the catheter. Consequently, 17- to 19-gauge needles are most commonly used with an 18-gauge catheter for continuous catheters.

"Echogenic" Needles and Tip Tracking Systems

Visualization of the needle tip is one of the more challenging aspects of performing an ultrasound-guided PNB. To enhance needle visualization, specialized needle designs have been developed. Some designs incorporate coating with a biocompatible polymer that traps microbubbles of air, thus creating specular reflectors of air. Another design has improved needle visibility by etching the surface of the needle tip or shaft to enhance the reflection of US back to the transducer. The technology to improve needle tip visualization continues to evolve. Examples of recent innovations are systems based on tip sensors, electromagnetic guidance, the magnetization of needles, and complex image processing algorithms to track the needle trajectory. These technologies have great potential in training and education and may improve the performance of deep blocks. Whichever needle is chosen, the ability to track the needle path and needle-nerve relationship in real-time should contribute to the safety.

Ultrasound Machines

US allows visualization of the anatomic structures, approaching needle, and spread of LA. Ease of use, image quality, ergonomic design, portability, and cost are all important considerations when choosing an US machine. A number of newer, more portable US machines can be mounted on a swivel in settings where there is limited space to perform a block. The US technology is continually and rapidly evolving,

FIGURE 3-6. Examples of different ultrasound machine models.

FIGURE 3-7. Time-out transducer cover.

with an increasing focus on its application in regional anesthesia and point of care. Newer machine designs also have higher resolution and frame refreshment rates, and increasingly more often incorporate automated needle-detection algorithms, tissue-pattern recognition, and needle-tracking technologies (Figure 3-6).

Sterility

Infections due to PNBs are uncommon and largely preventable. Strict adherence to sterile techniques is mandatory in the practice of regional anesthesia. A report of a fatality due to an infectious complication of a PNB underscores the importance of sterile techniques. Cuvillon et al. found that 57% of femoral catheters demonstrated bacterial colonization, although only 3 of 208 showed signs suggestive of infection (i.e., shivering and fever) that subsided after catheter removal. Bergman et al. documented one infectious complication of 405 axillary catheters placed, reflecting the relative rarity of such events. However, several case reports reflect the severity of infections caused by indwelling catheters, including a case of psoas abscess complicating a femoral catheter placement and acute cellulitis and mediastinitis following placement of a continuous interscalene catheter. These cases illustrate the importance of adherence to aseptic techniques in all phases of the procedure, catheter insertion, and management, as well as administration of LAs.

The hands of healthcare workers are the most common vehicles for the transfer of microorganisms from one patient to another. Studies show that although soap and water may remove bacteria, only alcohol-based antiseptics, povidone-iodine, and chlorhexidine provide adequate disinfection. Sterile gloves and techniques should be used throughout the procedure.

Transducer Covers and Gel

Contaminated US probes and transmission gel are potential vectors of nosocomial infections. Thus, sterile US transducer covers and sterile gel should be routinely used. A variety of sterile US transducer covers are available. Some come in sets with sterile US gel and rubber bands to pull the transducer covers tightly over the transducers to facilitate imaging. Transducer covers may include removable indicia to remind clinicians to perform the one last time-out (checklist) at the point of care (Figure 3-7).

Injection Pressure Monitoring

Intrafascicular injections during the performance of PNBs may be associated with high injection pressures during the injection of the LA. Such injections may lead to nerve injury and neurologic deficits in animal models. For that reason, assessment of resistance to injection is routinely done in clinical practice to reduce the risk of intraneural injections and constitutes suggested routine documentation of the PNB procedure. Traditionally, anesthesiologists have relied on a subjective "syringe feel," that is, the feeling of increased resistance on injection. However, studies demonstrate that while practitioners can readily perceive a change in resistance or pressure (e.g., loss of resistance during epidural block), gauging the absolute pressure when injecting a nerve block is challenging. This is because the operator does not have a reference point of resistance (before and after), but must assess the opening pressure before the injection occurs. An inline injection pressure manometer can be placed between the syringe and injection tubing with the needle to objectively quantify and monitor the injection pressure (Figure 3-8). Injection pressures greater than 15 psi may be associated with intraneural needle placement and intrafascicular injections. Alternatively, an air-compression test in the syringe is used to avoid injection using pressure greater than 20 psi (Figure 3-9). In actual clinical practice, injection with pressures <15 psi establishes a wider margin of safety in reducing the risk of an intrafascicular injection or too forceful spread of the LAs.

FIGURE 3-8. Injection pressure monitor (BSmart, Concert Medical USA). A color-coded piston moves during the block performance to indicate pressure during injection.

Several inline injection pressure monitors and indicators are now commercially available.

Continuous Nerve Catheters

For the practice of continuous PN infusions, a wide range of needles and catheter types are available. Two main types of catheters are the stimulating catheters, which can provide stimulation through the catheter itself, and the nonstimulating catheters, which do not allow this option. Although it would appear logical that the confirmation of the catheter placement using electrolocalization should result in greater consistency of catheter placement and higher success rate, the data on any advantages of stimulating catheters over nonstimulating catheters remain conflicting. Whatever the design, the use of nonstimulating catheters is preferred under US guidance. The use of US is an objective method to verify catheter location. The position of a nonstimulating catheter

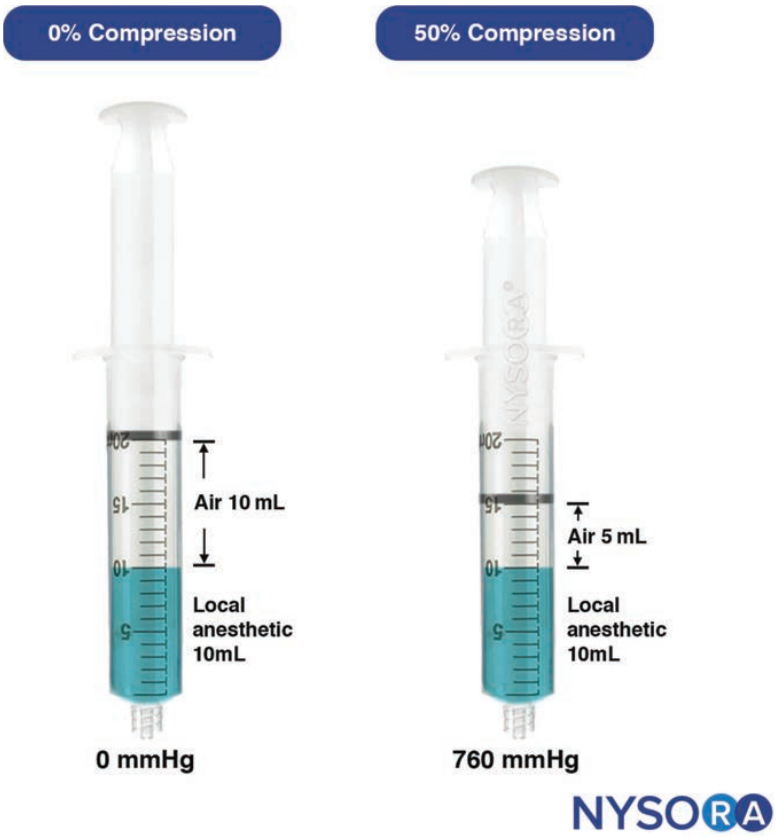

FIGURE 3-9. Injection pressure technique designed by Tsui. Left syringe: Uncompressed, containing 10 mL of air and 10 mL of local anesthetic. Right syringe: Air compressed by 50% results in exerted pressure of 760 mmHg (approximately 15 psi).

FIGURE 3-10. Nonstimulating catheter set, including nonstimulating catheter, extension tubing, clamp-style catheter connector, 2-in stimulating Tuohy needle, 4-in stimulating Tuohy needle, and label.

tip should be confirmed by its direct visualization with US, and by injecting boluses of LA or saline through the catheter while visualizing the correct perineural spread of the injectate (Figure 3-10).

Securing Perineural Catheters

Securing the perineural catheter is essential in preventing its failure. Catheter failure can be classified as primary or secondary. Primary failure is defined as a catheter misplacement during the initial ultrasound-guided insertion. Secondary failure is defined as the failure of a catheter to provide analgesia after a period of effective analgesia. Secondary failure can result from catheter displacement, leakage, disconnection, or infusion pump malfunction. Both primary and secondary failures lead to unanticipated breakthrough pain.

Dislodgement of a catheter is relatively common and leads to ineffective analgesia and requires reinsertion of the catheter. There are a variety of methods and devices for securing indwelling continuous catheters, most of which incorporate some means of fixing the device and/or catheter to the skin via adhesive tape on one side of the device.

Some practitioners tunnel the indwelling catheters to secure them better; the effectiveness of tunneling a catheter to prevent dislodgement has not been well documented. The benefits of tunneling should be weighed against the potential for dislodging the catheter in the process of needle insertion. Application of topical skin adhesive to the puncture site that the catheter passes through can help to secure the catheter and prevent LA leakage because the puncture sites produced by catheters have a larger diameter than the catheters themselves. The catheter should be covered with a transparent, sterile occlusive dressing to allow daily inspection of the catheter exit site. This allows for monitoring of catheter migration and early signs of infection.

Infusion Pumps

PN catheters can be attached to portable infusion pumps to ensure reliable delivery of LA. The pumps can be either elastomeric or electronic. Elastomeric pumps use a nonmechanical balloon mechanism to infuse LAs and consist of an elastomeric membrane within a protective shell. The pressure generated on the fluid when the balloon is stretched is determined by the material of the elastomer (e.g., latex, silicon, or isoprene rubber) and its shape. These pump sets typically contain an elastomeric pump with a fill port, a clamp, an air-eliminating filter, a variable controller, a flow rate dial, a rate-changing key, and a lockable cover. Most electronic pumps have a capacity of 400 mL of LA, and the anesthesiologist can easily program the concentration, rate, and volume. These pumps are lightweight, typically come with carrying cases, and do not impose any limitations on mobility for the patient. One study found that the elastomeric pumps were as effective as electronic pumps in providing analgesia following ambulatory orthopedic surgery; however, the elastomeric pumps led to higher patient satisfaction scores due to fewer technical problems. However, underfilling the elastomeric pump results in a faster flow rate, whereas overfilling results in a slower rate. The elastomeric pump flow rate is also affected by changes in temperature that affect the solution viscosity. The patient should be given emergency contact information and be informed of the signs and symptoms of excessive LA absorption. Typically the catheter remains in place for 2 to 3 days postoperatively, and the patient is guided by a healthcare worker through the self-removal of the catheter at home over the phone.

Nerve Stimulators

The advent of nerve stimulation allowed advances in the performance of regional anesthesia. Nerve stimulators substantially vary in their functionality, which is why practitioners should be familiar with the model used in their practice. Ideally, the current output of a nerve stimulator should not change as the needle is being advanced through various resistances (impedance) encountered from the tissue, needle, and connectors. Impedance is a measure of the resistance to the flow of alternating current through tissue, and there is an inverse relationship between impedance (resistance) and current thresholds necessary to elicit a motor response. Modern models deliver a constant current output in the presence of varied resistance. Some models include settings of stimulating frequency, pulse-width, and current delivered (mA). Nerve stimulators are described in greater detail in Chapter 4.

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4 Electrical Nerve Stimulation

Introduction

With the growing use of ultrasound (US) in the practice of regional anesthesia, peripheral nerve stimulation (PNS) continues to be useful to monitor needle-nerve relationship to decrease the risk of nerve trauma. This chapter reviews electrical nerve stimulation and its role in the practice of peripheral nerve blocks (PNBs).

Basics of Electrical Peripheral Nerve Stimulation

Voltage, Current, and Resistance

Voltage (U) is the difference in electrical potential between two points carrying different amounts of positive and negative charges, measured in volts (V) or millivolts (mV). Voltage can be compared to the fill level of a water tank, which determines the pressure at the bottom outlet (Figure 4-1A).

Current (I) is the measure of the flow of a positive or negative charge, expressed in amperes (A) or milliamperes (mA). The current can be compared to the amount of flow of water.

The **electrical resistance (R)** is the obstacle to the flow of electric current, measured in ohms (Ω) or kilo-ohms (kΩ). In other words, resistance limits the flow of current at a given voltage (see Ohm's law).

Ohm's Law

Ohm's law describes the relationship between voltage, current, and resistance according to the following equation:

$$\mathbf{U\,[V] = R\,[\Omega] \times I\,[A]}$$

or conversely,

$$\mathbf{I\,[A] = U[V]\,/\,R\,[\Omega]}$$

This means that, at a given voltage, the intensity of the electrical current is dependent on the resistance between the two electrodes (in patients, the resistance of the skin and tissues between the grounding electrode and needle). Figure 4-1 (Ohm's law) illustrates Ohm's law and the functional principle of a constant-current source.

Impedance and Constant-Current Source

During PNS, the electrical circuit consists of the nerve stimulator, nerve block needle, needle tip design, patient's tissue characteristics, skin, skin-electrode (grounding electrode), and cables. This circuit has a complex resistance (impedance) in living tissue because of the capacitance of the tissue, intravascular fluids, electrode-to-skin interface, and needle tip. The needle design and electrode-to-skin connection contribute a great deal to the overall impedance. The first largely depends on the geometry and insulation (conductive area), while the latter varies considerably among individuals (e.g., skin type, hydration status) and can be influenced by the quality of the electrocardiogram (ECG) electrode material. Modern nerve stimulators are a **constant-current source** and automatically adjust to the varying impedance by increasing or decreasing the output voltage to keep the set current (mA) constant. They compensate for the wide range of impedances that may exist among patients.

Coulomb's Law, Electric Field, and Current Density

Current density is a measure of the distribution of current flow, defined as current per cross-sectional area. According to **Coulomb's law,** the strength of the **electric field,** and therefore the corresponding **current density (J)**, in relation to the distance from the current source is given by

$$\mathbf{J(r) = k \times I_0/r^2}$$

where k is Coulomb's constant, I_0 is the initial current, and r is the distance from the current source. This means that the current (or charge) that reaches the nerve decreases by a factor of 4 if the distance to the nerve is doubled, or conversely, it increases by a factor of 4 if the distance is divided in half (ideal conditions assumed). Coulomb's law is used as a basis for estimating the needle-nerve distance. The shorter the needle-nerve distance, the less current is required to obtain a motor response after nerve stimulation. Although this relationship is quite complex, it is generally accepted that the appearance of a motor response at 0.5 mA or less indicates needle-nerve contact or intraneural needle placement.

Figure 4-2 shows the basic anatomic structure of myelinated Aα fibers (motor) and unmyelinated C fibers (pain)

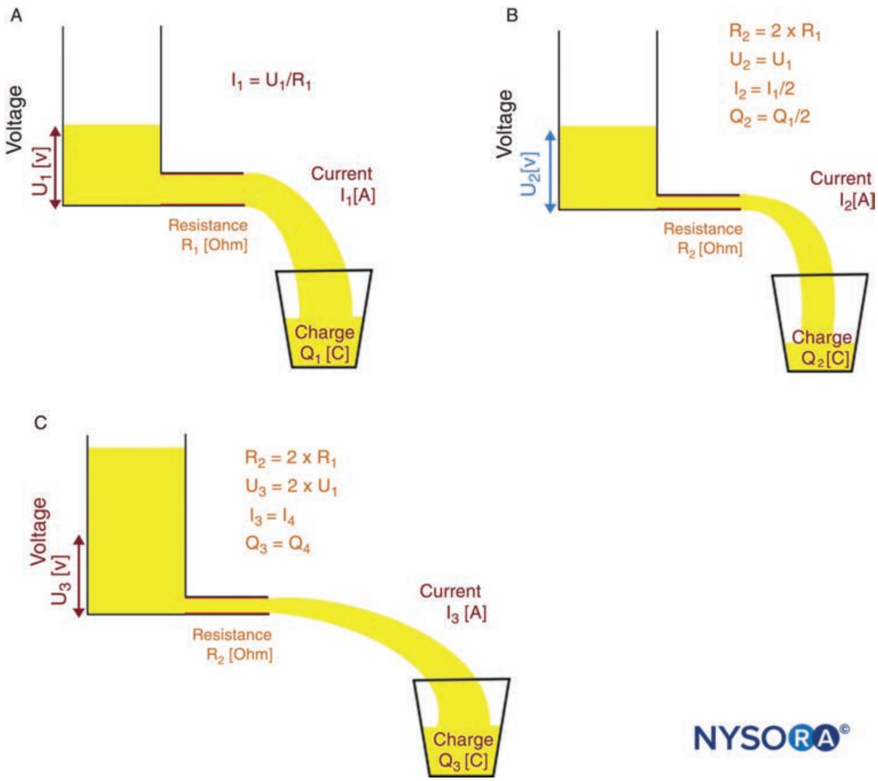

FIGURE 4-1. Ohm's law and the functional principle of a constant-current source. (A) Low-resistance R_1 requires voltage U_1 to achieve desired current I_1. (B) High-resistance $R_2 = 2 \times R_1$ causes current I to decrease to $I_2 = I_1/2$ if voltage U remains constant ($U_2 = U_1$). (C) Constant-current source automatically increases output voltage to $U_3 = 2 \times U_1$ to compensate for higher-resistance R_2; therefore, current I increases to the desired level of $I_3 = I_1$.

schematically. Figure 4-3 shows the relationship between different stimuli and the triggering of the action potential in motor and pain fibers, respectively.

How Nerve Stimulation Works

Nerve stimulators used in regional anesthesia deliver a pulsed, square-wave current to rapidly depolarize the nerve and subsequently produce an action potential (i.e., motor response). The total electrical **charge** (**Q**) applied to a nerve equals the product of the **current intensity or amplitude** (stimulus strength; I) and **pulse duration** (pulse width; t) of the current: **Q = I × t**. As such, both sufficient strength (I) and duration (t) are required to cause depolarization.

Threshold Level, Rheobase, and Chronaxie

A certain minimum current intensity is necessary at a given pulse duration to reach the **threshold level** of

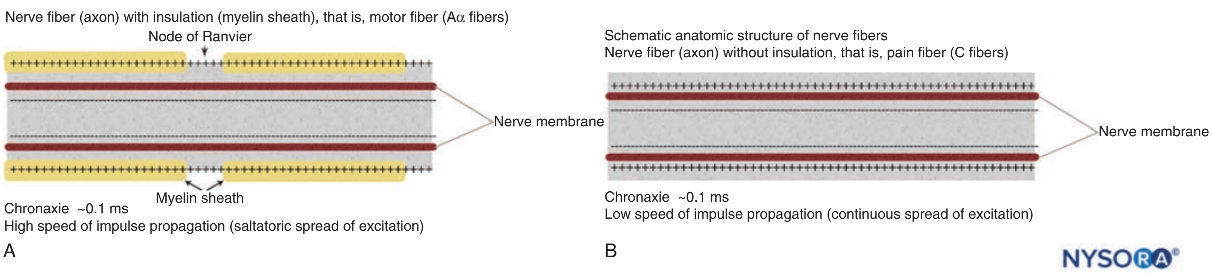

FIGURE 4-2. Schematic anatomic structures of nerve fibers. (A) Nerve fiber (axon) with insulation (myelin sheath), (Aα fibers). (B) Nerve fiber (axon) without insulation (C fiber).

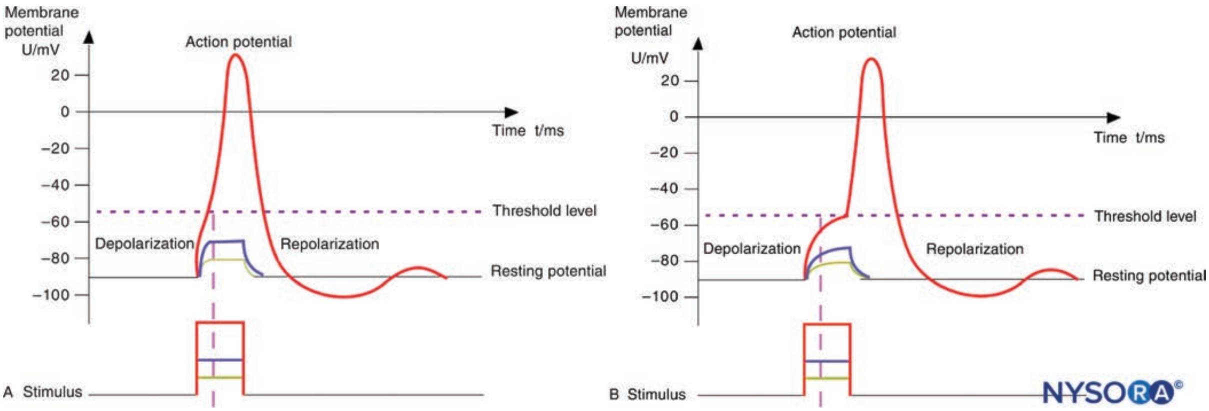

FIGURE 4-3. (A) Action potential, threshold level, and stimulus. Motor fibers have a short chronaxie because of the relatively low capacitance of their myelinated membrane (only the area of the nodes of Ranvier count); therefore, it takes only a short time to depolarize the membrane up to the threshold level. (B) Action potential, threshold level, and stimulus. Pain fibers have a long chronaxie because of the higher capacitance of their nonmyelinated membrane (the entire area of the membrane counts); therefore, it takes a longer time to depolarize the membrane up to the threshold level. Short impulses (as indicated by the vertical dotted line) cannot depolarize the membrane below the threshold level.

neuronal excitation. Current intensity ($I_{Threshold}$) depends on three variables: rheobase ($I_{Rheobase}$), chronaxie (C), and pulse duration (t) and can be expressed by the following relationship:

$$I_{Threshold} = \frac{I_{Rheobase}}{1-e^{-t/c}}$$

where *c* is the time constant of the nerve membrane related to chronaxie.

Rheobase (in amperes) is the minimum threshold current required to stimulate (i.e., depolarize) the nerve at infinitely long pulse durations. In other words, a current below rheobase will not generate a motor response. **Chronaxie** (in milliseconds) is the minimum pulse duration necessary to stimulate (i.e., depolarize) the nerve at double the rheobase current. Electrical pulses with the duration of chronaxie are most effective (at relatively low amplitudes) to elicit action potentials. Chronaxie values are dependent on the properties of nerve fibers, such as axon diameter, myelination, and distance between nodes of Ranvier. Myelinated Aα motor fibers are large in diameter, whereas unmyelinated C-type pain fibers are smaller. PNS uses these differences to preferentially activate motor fibers at short pulse durations (e.g., 0.1 ms) and relatively low current amplitudes while avoiding the stimulation of C-type pain fibers. Typical chronaxie figures are 50 to 100 μs (Aα fibers), 170 μs (Aδ fibers), and 400 μs or greater (C fibers). Figure 4-4 (rheobase and chronaxie) illustrates the relationship of the rheobase to chronaxie for motor versus pain nerve fibers.

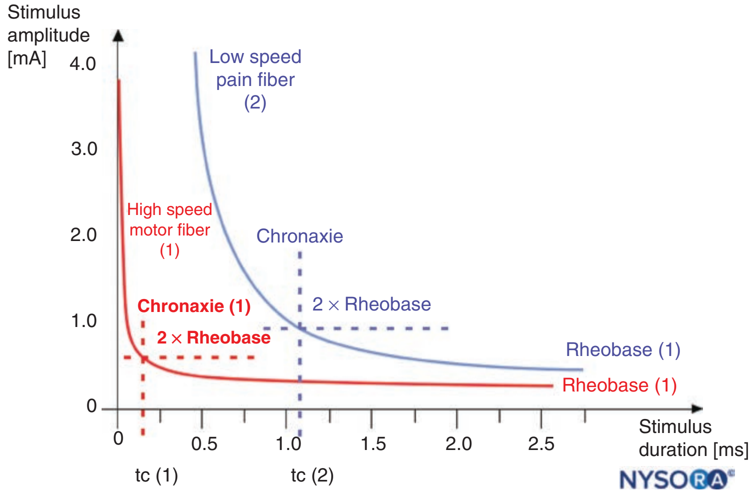

FIGURE 4-4. Comparison of threshold curves, chronaxie, and rheobase level of motor (high-speed) and pain (low-speed) fibers.

Needle-to-Nerve Distance

The following formula describes the current–distance relationship:

$$I_{Threshold}(r) = I_0 + kr^2$$

where $I_{Threshold}$ is the threshold current for excitation of the neuron, I_0 is an offset, k the current-distance constant, and r the needle-to-nerve distance. Thus, the threshold current increases with the squared distance. Hence, as the needle moves closer to the nerve, less current is required to stimulate the nerve and subsequently evoke a motor response. The needle-to-nerve distance is estimated with this principle, using a constant-current source.

The Role of Nerve Stimulation in Conjunction with Ultrasound-Guided Nerve Blocks

When used with US guidance, PNS may detect needle-nerve contact should the operator miss the needle-nerve relationship on US. Unexpected motor response during needle advancement may alert the operator that the needle is in the immediate vicinity of the nerve and, therefore, prevent further needle advancement and consequent mechanical needle-nerve injury. The motor response to PNS is objective and less user-dependent than the interpretation of US images or a patient's (subjective) response of pain following needle-nerve contact (paresthesia). Nerve stimulation can also be used to confirm that the structure imaged by US is the nerve being sought when the ultrasound image is not clear. Figure 4-5 provides an algorithm for using nerve stimulation as a monitoring tool during ultrasound-guided blocks.

Limitations of Peripheral Nerve Stimulation

A motor response at a current intensity of ≤0.5 mA may indicate needle-nerve contact or intraneural needle placement (high specificity). Unfortunately, this response may not always be present (low sensitivity). In addition, multiple injection techniques during PNBs decrease PNS sensitivity due to the partial nerve blockade that occurs with these injections. Likewise, PNS is not reliable and should not be used in patients receiving neuromuscular blocking agents (relaxants).

The obvious disadvantages of PNS include the need for equipment (nerve stimulator and insulated needles), equipment maintenance, and multitasking during the nerve block procedure. The operator has to monitor the patient, physiologic parameters, ultrasound imaging, response to nerve stimulation, and functionality of the nerve stimulator.

CLINICAL PEARLS

- The occurrence of a motor response at at a very low current intensity (i.e., <0.5 mA; 0.1 ms) may indicate needle-nerve contact or intraneural needle placement, and further needle advancement should be stopped.
- PNS is not reliable in patients receiving muscle relaxants.
- The presence of spinal or epidural anesthesia does not affect the reliability of PNS.
- Multiple injection techniques increase the minimum current intensity necessary to elicit a motor response and decrease the sensitivity of PNS to detect needle-nerve contact.

Nerve Stimulation and Interference with Pacemakers and Defibrillators

Although highly unlikely, PNS can interfere with pacemakers or other implanted electronic devices. For that reason, in patients with a pacemaker or defibrillator, use the lowest practical current intensity and duration and low-frequency PNS settings (e.g., 1 Hz). Placing the nerve stimulator electrode away from the pacemaker components (i.e., pulse generator and lead system) decreases the possibility that the PNS current traverses those components. The absence of case reports suggests that defibrillation systems probably do not have to be disabled during PNS with low stimulus intensity and frequency. American Society of Anesthesiologists monitoring should be routinely used during PNBs in all patients, regardless of whether or not they have implanted electronic devices.

Stimulating Needles

In **noninsulated needles**, the current disperses in all directions along the shaft of the needle, requiring a larger current intensity to stimulate the nerve. On the other hand, **insulated needles** promote stimulation close to the injection point at the needle tip and are therefore the industry standard.

PNS needles should have the following characteristics:

- A fully insulated needle hub and shaft to avoid current leakage
- Depth markings for easy identification and documentation of the needle insertion depth

Figure 4-6 shows a comparison of the electrical characteristics of noninsulated and insulated needles with uncoated bevel (Figure 4-6A) and fully coated needles with the needle tip exposed only (Figure 4-6B). A noninsulated needle has no ability to determine the needle-nerve relationship once the needle tip has passed the nerve. Therefore, spatial discrimination near the nerve is more precise in needles with insulated shaft and exposed tip (Figure 4-6B) compared to needles without insulation (Figure 4-6A).

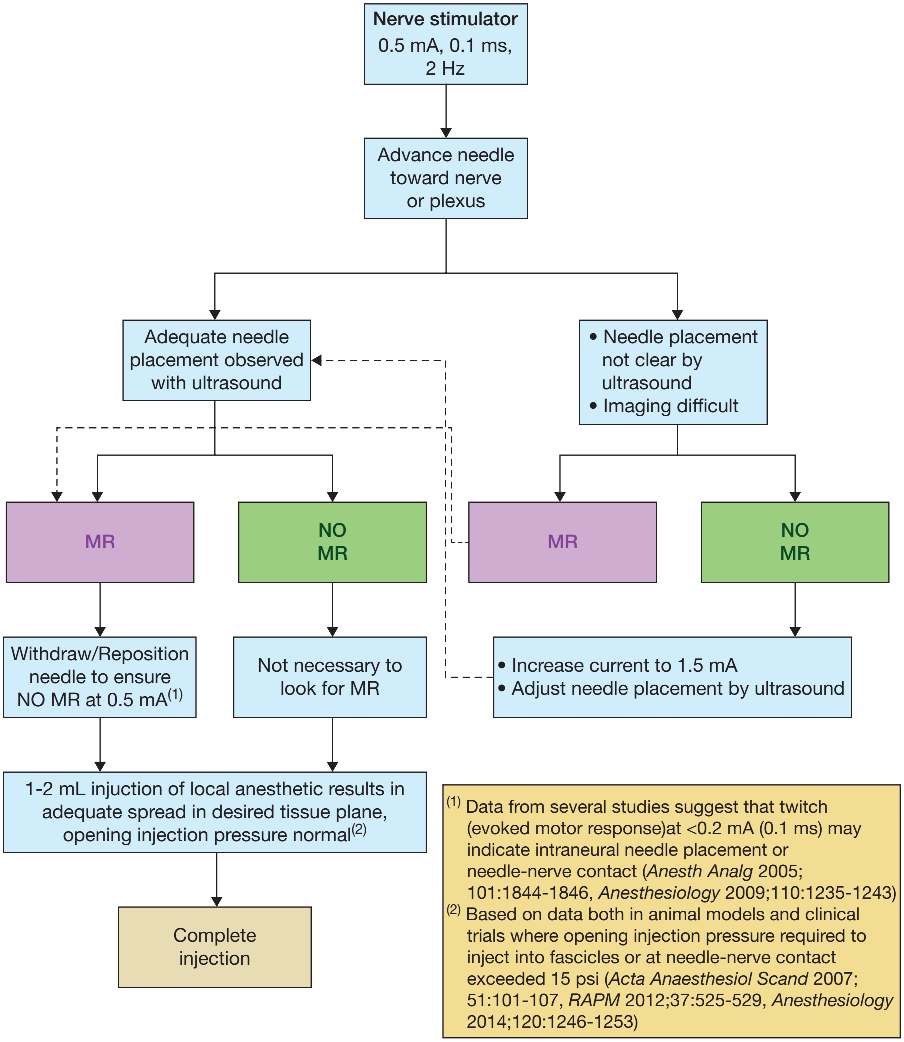

FIGURE 4-5. An algorithm for the use of nerve stimulation with ultrasound-guided nerve blocks where the nerve stimulator is used primarily as a safety monitoring tool, rather than a nerve localization tool. The stimulator is set at 0.5 mA (0.1 ms), and the current is rarely adjusted. The motor response is not sought, but when obtained, needle advancement is halted. The needle can be slightly withdrawn from the nerve until the response stops. A small amount of injectate can be used to determine the needle tip location while avoiding an opening pressure greater than 15 psi. MR, motor response.

Clinical Use of Peripheral Nerve Stimulation

Setup and Checking the Equipment

The following are a few important aspects for successful electro-localization of the peripheral nerves using PNS:

- Use only a nerve stimulator specifically manufactured for nerve blocks.
- Before starting the procedure, check for the proper functioning of the nerve stimulator and the connecting cables.
- Select between 0.1 and 0.3 ms of pulse duration for most purposes.
- With US guidance, select the current as 0.5 mA; it is rarely necessary to change the current as motor response with US guidance is not sought.
- Use insulated nerve stimulation needles.

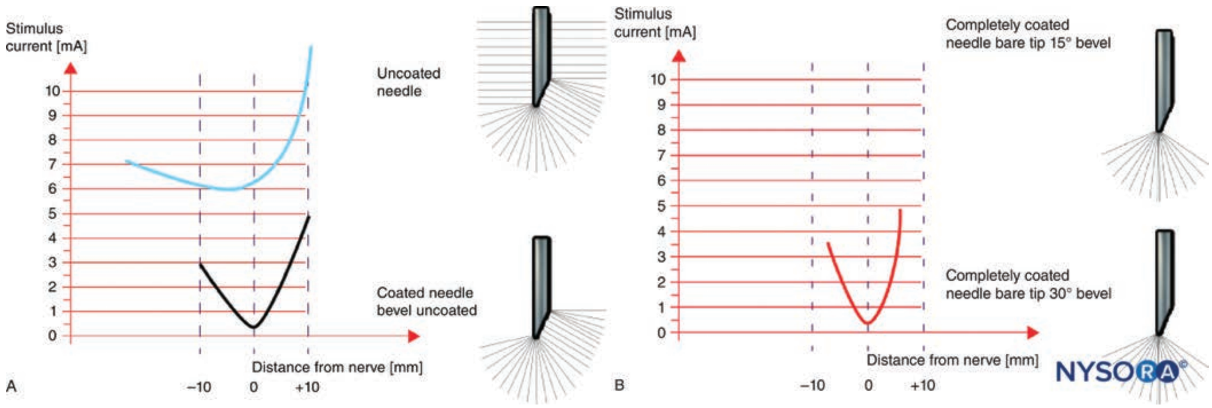

FIGURE 4-6. (A) Threshold amplitude achieved with an uncoated needle and coated needle with an uncoated bevel. (B) Threshold amplitude achieved with a fully coated needle and pinpoint electrode.

- Use high-quality skin electrodes with a low impedance. Some lower-priced ECG electrodes can have too high an impedance/resistance.

Basic Settings and Implications

- **Current intensity or amplitude** (stimulus strength): Use low current intensity nerve stimulation (0.5 mA) with ultrasound-guided nerve blocks. It is not necessary to change the current intensity during the procedure.
- **Pulse duration** (pulse width): Between 0.1 and 1.0 ms. Motor nerves are stimulated more easily with a current of shorter duration (0.1 ms), while sensory nerves require a longer stimulus duration (1.0 ms).
- **Stimulus frequency** (number of current pulses delivered from the nerve stimulator in 1 second): Between 1 and 3 Hz (meaning 1 to 3 pulses per second). At 1 Hz, the needle must be advanced slowly to allow time for the delivered pulse to evoke a motor response, whereas at 2 Hz the needle can be advanced at twice the speed. Furthermore, using the 2 Hz frequency allows more frequent feedback as the operator is advancing the needle, allowing more efficient and faster manipulation of the needle to the nerve. Therefore, the best compromise is 2 Hz, which should be the default.

Electrode Localization

Electrical polarity is the directional flow of electrons (i.e., current) from a negative to a positive pole (i.e., electrode). The stimulating needle and return electrode are the electrodes used during PNS. The orientation of these electrodes, negative and positive, affects the current necessary to elicit a motor response. The negative electrode (cathode) should be connected to the needle, while the positive electrode (anode) should be attached to the patient's skin. Current flowing from the needle acting as cathode alters the resting membrane potential of cells nearby, leading to nerve depolarization and the generation of an action potential. The return electrode location is not important because it can be placed anywhere on the skin when using a constant-current output nerve stimulator.

Using Peripheral Nerve Stimulation as a Localization Tool Without Ultrasound Guidance

The starting amplitude (i.e., current intensity) used for nerve stimulation depends on the local practice and the projected skin-nerve depth. An amplitude of 1 mA is often chosen to start in most cases for superficial nerves. For deeper nerves, it may be necessary to increase the initial current amplitude between 1.5 and 3 mA until a motor response is elicited at a safe distance from the nerve. Too high current intensity, however, can lead to direct muscle stimulation or discomfort for the patient, both of which are undesirable.

After obtaining the sought-after muscle response, the current intensity amplitude is gradually reduced, and the needle is slowly advanced further. Too rapid advancement may miss a response between two stimuli. Advancement of the needle and current reduction are continued until the desired motor response is achieved with a current of 0.2 to 0.5 mA. When the motor twitch is lost during needle advancement, increase the stimulus intensity first to regain the muscle twitch rather than move the needle blindly. Once the needle is positioned to obtain a motor response at around 0.3 mA (0.1 ms), 1-2 mL of local anesthetic (LA) is injected as a test dose, which abolishes the motor response. Solutions conducting electricity, such as saline and LAs, increase the conductive area at the needle tip, thereby reducing current density. In other words, to elicit an action potential (i.e., motor response) at the same distance, a higher threshold current is required. Injection of dextrose 5% in water, a less conductive solution, lowers the conductive area at the needle tip and, thus, increases current density, does not lead to loss of the muscle twitch, and can also be used to confirm the needle position.

Remember that the absence of the motor response with a stimulating current of up to 1.5 mA does not rule out intraneural needle placement (low sensitivity). However, the presence of a motor response with a low intensity current (≤0.2 mA, 0.1 ms) occurs only with intraneural and, possibly, intrafascicular needle placement. For this reason, if the motor response is still present at 0.2 mA or less (0.1 ms), the needle should be slightly withdrawn to avoid the risk of intrafascicular injection. Figure 4-7 depicts the principle of the needle-to-nerve approach and its relation to the stimulation.

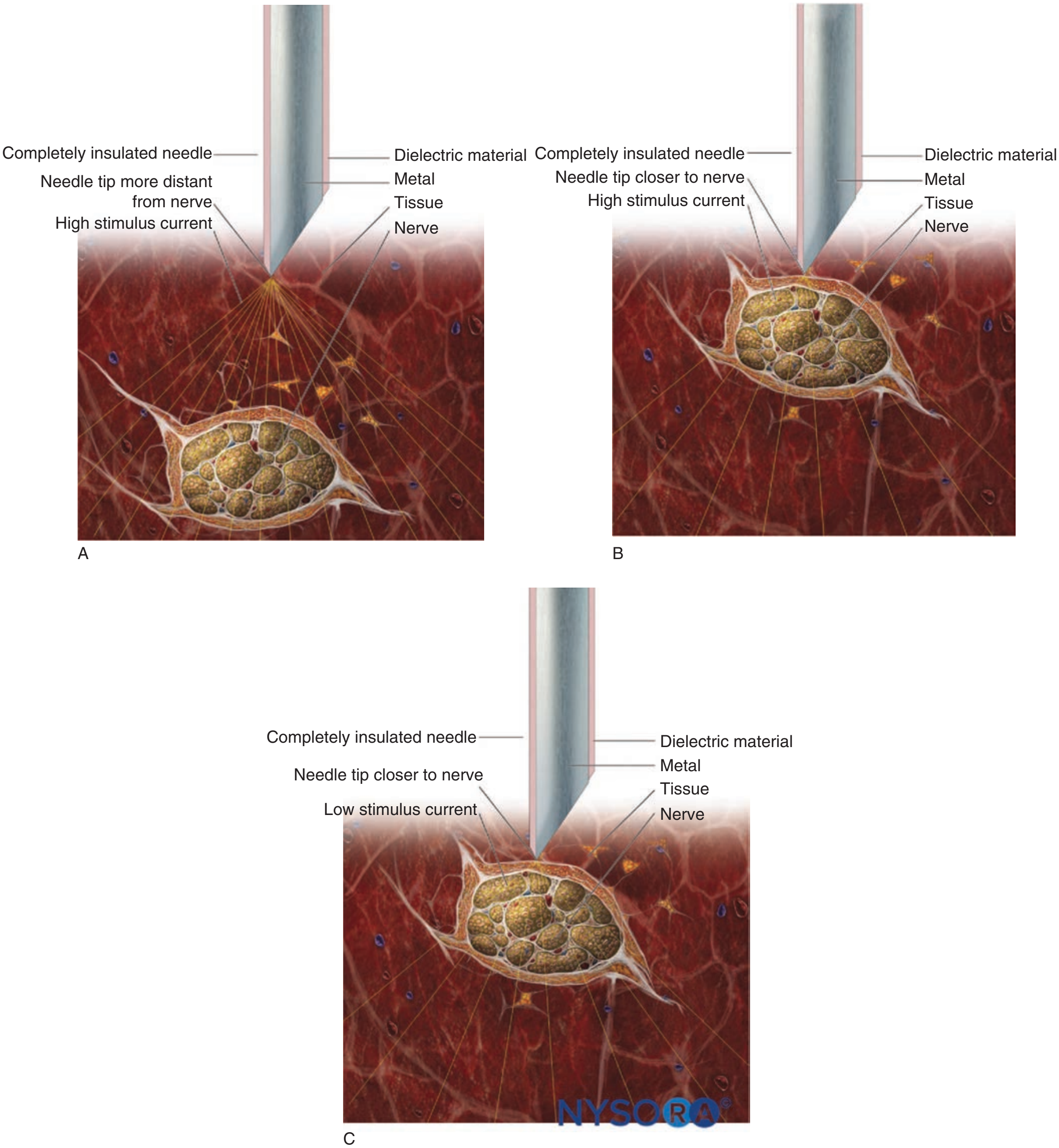

FIGURE 4-7. (A) An example of the needle placed at a distance to the nerve and high stimulus current eliciting a weak motor response. (B) Stimulation needle close to the nerve and high stimulus current eliciting a strong motor response. (C) Stimulation needle close to the nerve and low (near-threshold) stimulus current eliciting a weak motor response.

TABLE 4-1 Common Problems Encountered During Electro-localization of Peripheral Nerves and Corrective Action

PROBLEM	SOLUTION
Nerve stimulator does not work at all	Check and replace battery; refer to stimulator operator's manual
Nerve stimulator suddenly stops working	Check and replace battery
No motor response is achieved despite the appropriate needle placement	• Check connectors, skin electrode, cables, and stimulation needle for an interrupted circuit or too high impedance • Check and make sure that current is flowing – no disconnect indicator on the stimulator • Check the setting of amplitude (mA) and impulse duration • Check stimulator setting (some stimulators have a test mode or pause mode, which prevents current delivery)
Motor response disappears and cannot be regained even after increasing stimulus amplitude and duration	• Check for the causes listed previously • Can be caused by injection of local anesthetic

To prevent or minimize patient discomfort during the nerve location procedure, it is recommended to avoid using high stimulating currents. Again, the needle should be advanced slowly while observing the motor response. Too fast needle advancement may risk that the best needle position, producing a good near-threshold motor response, may be missed.

CLINICAL PEARLS

- When a motor response is unexpectedly elicited with 0.5 mA during ultrasound-guided PNS, stop needle advancement and determine the needle tip location using the following maneuvers:
  - Re-focus and improve the image.
  - Slightly shake the needle to facilitate its detection on ultrasound.
  - Inject a small amount of injectate while avoiding an opening injection pressure >15 psi.

Troubleshooting

Table 4-1 lists the most common problems encountered during nerve stimulation and the corrective action.

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5 Optimizing Ultrasound Image

Introduction

Optimization of the ultrasound (US) image is important to improve the visualization of the relevant anatomy during US-guided peripheral nerve blocks (PNBs). Because a nerve block is an injection of local anesthetic (LA) into a tissue space that contains the nerve, it is often more practical and easier to identify the interfascial tissue space containing the nerve than the nerve(s) to be blocked. Optimizing the US image requires knowledge of how the US machine operates and adequate training in image acquisition. In this chapter, we describe standardized scanning steps, including the selection of sonographic modes, adjustment of function keys, essential transducer maneuvers, and interpretation of artifacts to optimize the US view and guide the needle toward the target.

Ultrasound Machine Settings

Conventional, compound, and tissue harmonic imaging (THI) are common sonographic imaging and signal processing modes used for medical diagnostics, which can all be utilized to visualize the relevant anatomy during regional anesthesia.

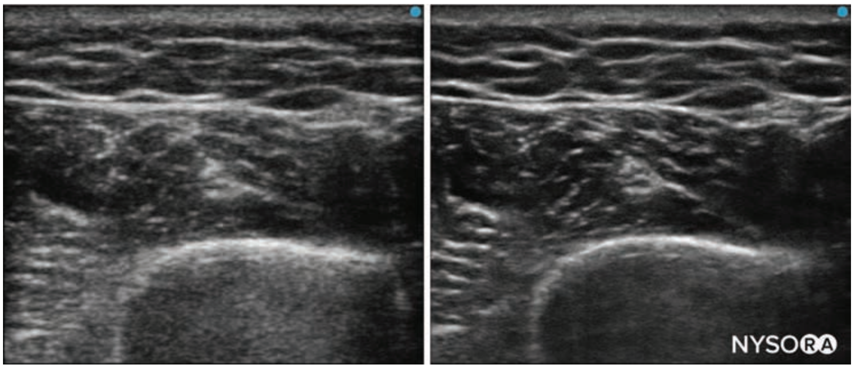
Conventional imaging is generated from a single angle beam at a primary frequency designated by the transducer.

Compound imaging acquires several overlapping frames from different frequencies or angles. Figure 5-1 demonstrates the difference between conventional and compound imaging applied to visualize the radial nerve proximal to the elbow. The contrast resolution between the muscle and the nerve is increased in comparison with conventional imaging. Compound imaging is automatically deactivated with the use of color Doppler, which cannot be applied with multiple angles of insonation.

Tissue harmonic imaging (THI) combines the information from harmonic frequencies, which are multiples of the primary frequency, generated by US beam transmission through tissue. As such, THI suppresses scattering signals from tissue interfaces, thereby improving the axial resolution and boundary detection. An example of its advantage is in obese patients where the anatomical structures may be situated deeper. All modern US manufacturers incorporate THI as the default mode, because of the better resolution images, improved tissue penetration, better detection of tissue interfaces, and margin enhancement compared with conventional sonography.

The following function keys on an US machine are essential to achieve the best possible resolution during the performance of PNBs:

1. ***Transducer frequency:*** US frequency determines the axial resolution or the ability of the US to distinguish two separate points along the axis of the US beam. Frequency and



A B

FIGURE 5-1. Ultrasound image of the radial nerve at the elbow with (A) conventional and (B) compound imaging.

depth, however, are interdependent and important in decision-making. The first step is to select the transducer with the optimal frequency range to visualize the target nerves at a certain depth. The second step is to adjust the best frequency within each transducer range according to the depth of the nerve. Some US machines display the full range of the transducer frequency, while others display several range options (e.g., high, middle, and low). US energy is attenuated and eventually absorbed by the imaged tissues. The higher the US frequency, the more rapid the absorption, and the less distance sound propagation. Therefore, lower frequency allows for better tissue penetration and better imaging for deep tissues but lower image quality for superficial structures. Higher frequencies have better resolution and image quality but shallower penetration. Consequently, high frequency can be used only for superficial blocks (structures). Of note, increasing the imaging frequency has a ceiling plateau with regards to image quality. Frequencies beyond 18 MHz do not further improve the image quality for use in most regional anesthesia techniques (Figure 5-2).

2. ***Depth of imaging:*** The depth controls increase or decrease the image field by predetermined depth increments. Increasing the depth reduces the resolution of the image; therefore, the minimum required depth setting typically provides a better image (Figure 5-3). The depth at which peripheral nerves and fascial planes are located varies greatly and also depends on the width of overlying subcutaneous tissue. Table 5-1 shows the recommended initial depth and transducer settings for common regional anesthesia blocks. The US machine manufacturers often incorporate software algorithms that optimize the resolution in the center of the image. This simplifies the use of the equipment and allows the visualization of other anatomical structures in the vicinity of the nerve or target point. For that reason, whenever possible the target nerve or fascial plane should be positioned at the center of the US screen.

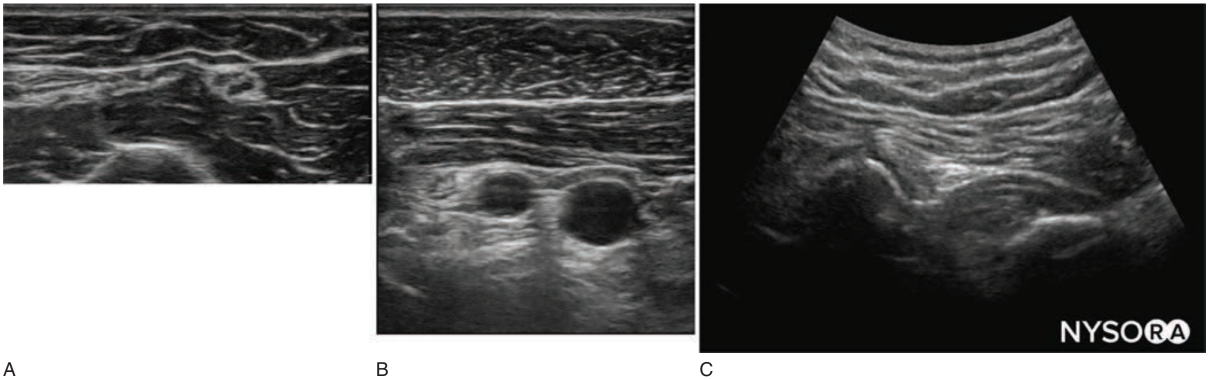


FIGURE 5-2. Examples of images with different transducer frequencies: (A) ulnar nerve, 13 MHz; (B) infraclavicular brachilal plexus, 10 MHz; and (C) sciatic nerve, 5 MHz.

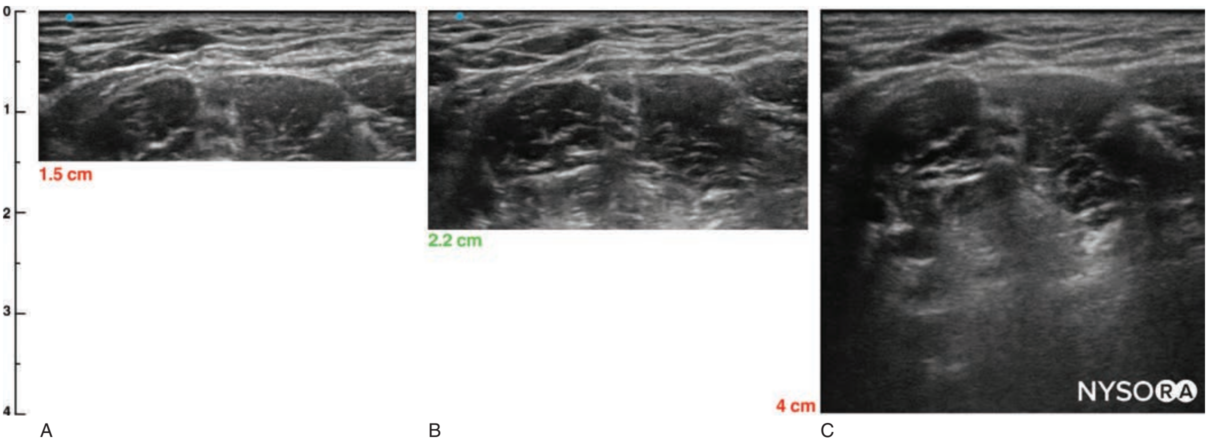


FIGURE 5-3. Images of the brachial plexus in the interscalene space with different depth settings: (A) insufficient, (B) correct, and (C) excessive.

TABLE 5-1 Suggested Optimal Imaging Depth and Frequency for Common Fascial Plane and Peripheral Nerve Blocks

FIELD DEPTH (cm)	TRANSDUCER	BLOCK TYPE
<2.0	High frequency	Cervical plexus, wrist, elbow, and ankle
2.0-3.0	High frequency	Interscalene, supraclavicular, axillary brachial plexus block, pectoralis and serratus, fascia iliaca
3.0-4.0	High frequency	Femoral nerve, TAP block, erector spinae
3.0-5.0	High or low frequency	Infraclavicular, adductor canal, popliteal, subgluteal sciatic nerve blocks
7.0-10.0	Low frequency	Pudendal, gluteal sciatic nerve, lumbar plexus blocks, quadratus lumborum
>10.0	Low frequency	Anterior approach to sciatic nerve, celiac ganglion block

3. ***Focus:*** The width of the US beam determines the lateral resolution or the ability of the US system to distinguish two points in the transverse plane (perpendicular to the axis of the US beam). The lateral resolution is maximal at the focal zone, where the beam width is at its narrowest. The number and position of the focal zones can be adjusted by modifying the US pulse. By choosing a higher frequency transducer (for shallow depths, typically 4-5 cm) and focusing the US beam at the level of the target (focal zone), the spatial resolution can be enhanced (Figure 5-4). Although many machines allow multiple focus zones, selecting no more than two focus zones can yield better image quality than multiple focal zones. This is because using multiple focus zones decreases the frame refreshment rate. This in return decreases the temporal resolution.
4. ***Gain:*** Gain is the amplification of US signals returning to the transducer after the reflection from the tissues at various depths. On US images, these signals are represented with white (bright) dots on the screen. The gain of these reflected signals can be adjusted as an overall gain (Figure 5-5) or at the desired depth (time-gain compensation, TGC) (Figure 5-6). The TGC compensates for

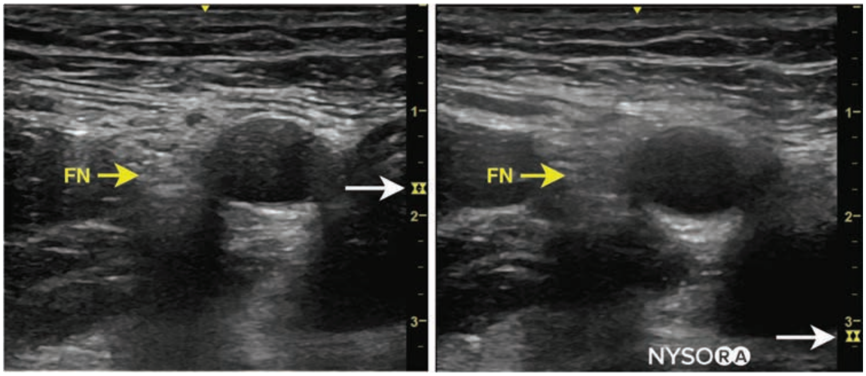


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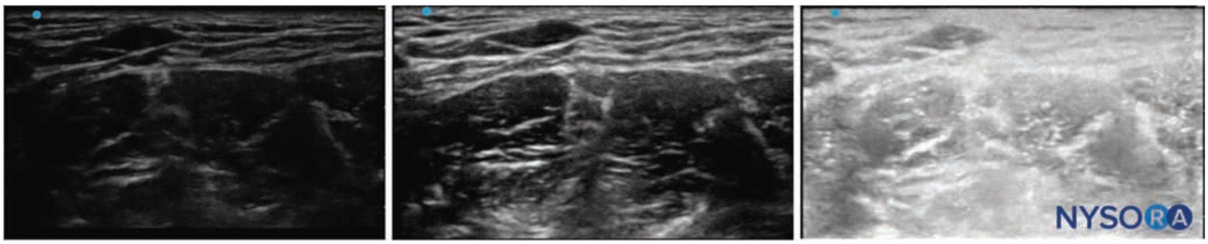
FIGURE 5-4. Focus adjustment (white arrow). (A) Imaging focus positioned at the level of the femoral nerve and (B) focus below the femoral nerve.



A B C

FIGURE 5-5. Effects of overall gain adjustments: (A) insufficient, (B) correct, and (C) excessive.

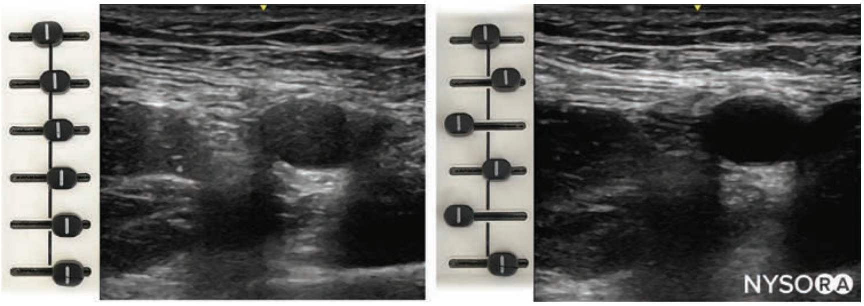


FIGURE 5-6. Effects of time-gain compensation adjustments on the view of the femoral nerve. Optimal (*left*) and suboptimal time-gain compensation (*right*).

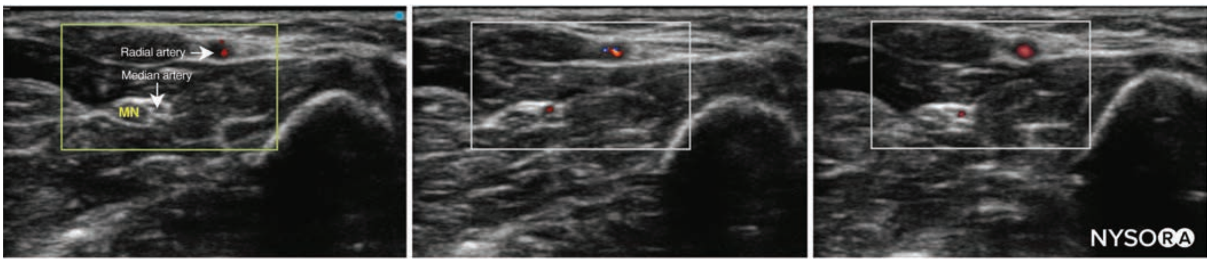
the attenuation (loss) of the signals as they reflect from and travel back through the tissues. Adjusting the TGC allows a more even, or selective, gain level at the desired depth of imaging. For simplicity, portable US systems made for point of care use often have an overall gain without TGC functionality. For imaging the peripheral nerves, the optimal gain is typically the gain at which the best contrast is obtained between the nerves and adjacent muscle and connective tissues. Excessive or inadequate gain causes blurring of tissue boundaries and loss of contrast. Incorrect TGC settings may accentuate artifacts and result in inferior image quality that interferes with image interpretation. Increasing gain below the focus works well to improve the image of both the target of interest as well as the anatomical structures at a greater depth. Technicians can obtain a more desirable image by using TGC with selectively applied gain for different depths.

5. ***Doppler imaging:*** Doppler mode is used to detect vascular structures in the vicinity of the targeted nerves and along the needle path. Color Doppler can also be used to identify the LA spread during the injection. To optimize the view of small vessels it is recommended to apply the following adjustments (Figure 5-7):
    a. Decrease the scale of Doppler velocity that is best set between 15 and 35 cm/s to reduce aliasing of color Doppler imaging and color artifacts. Aliasing is the inability to record the direction and velocity of flow accurately.
    b. Use power Doppler, as it is more sensitive than color Doppler for detecting blood flow. Power Doppler simply detects the flow, rather than its speed and direction, which are less important for application in regional anesthesia where the goal is to detect and avoid the vasculature.
    c. Adjust the gate to limit the size of the sample volume in the axial direction. For greater sensitivity, the sample volume should be small to overlay only the area of interest. This excludes distractive signals from adjacent tissues and improves the temporal resolution by allowing a greater frame refreshment rate.
    d. Note that applying excessive pressure to the transducer during imaging may collapse small- and medium-sized vessels and prevent their detection with Doppler imaging.

Ultrasound Artifacts

US artifacts occur commonly and are an intrinsic part of US imaging. By definition, an US artifact is any image aberration that does not represent the correct anatomic structures. Most artifacts are undesirable, and operators must learn how to recognize them when using US to practice regional anesthesia. The six most common artifacts in the practice of regional anesthesia are the following:

1. ***Anisotropy*** is seen as a change of the echogenicity of tissue at different angles of insonation. Anisotropy is a property of some fibrillar tissues, such as tendons and nerves, that



A B C

FIGURE 5-7. Examples of Doppler imaging of the small median artery: (A) high-flow color Doppler, (B) low-flow color Doppler, and (C) power Doppler.

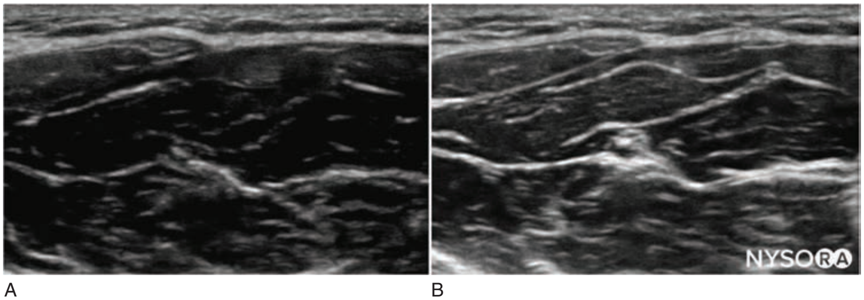


FIGURE 5-8. Anisotropy or changes of the tissue echogenicity at different angles of insonation. (A) Reduced echogenicity and (B) optimized echogenicity to visualize the median nerve at the forearm.

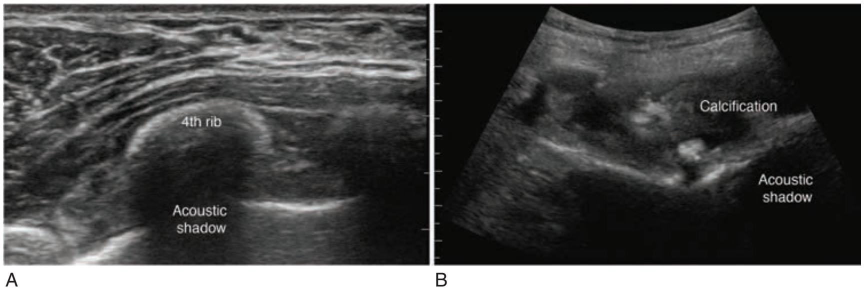


FIGURE 5-9. Examples of acoustic shadow with (A) deep to bone structures (B) deep to calcifications.

reflect most US waves in the same direction. The echogenicity is maximal when the US beam is perpendicular to the fibers, when the transducer receives most of the reflected waves and is progressively reduced as the angle of deviation increases, when most US waves are reflected away from the transducer (Figure 5-8).

2. ***Acoustic shadowing*** is the attenuation of US signals by structures that impede, absorb, or reflect US energy, such as bone, calcifications, or air. The result is a weak or absent echo image, which appears as a shadow below a bright, hyperechoic interface. Acoustic shadowing facilitates the diagnosis of calcifications, such as gallstones, scar tissues, or a presence of air. In regional anesthesia, acoustic shadowing is used to identify bony landmarks but may interfere with nerve visualization. Changing the scanning angle, alignment, or imaging plane to find an acoustic window is the best strategy to avoid shadowing when it interferes with imaging (Figure 5-9).
3. ***Acoustic enhancement or posterior enhancement*** manifests as an increase in echogenicity deep to a structure that transmits the sound better than the surrounding soft tissues (e.g., a fluid-filled structure such as a blood vessel or a cyst). This artifact occurs because the echo signals are overamplified, disproportionally to other echo signals at the same depth. Changing the angle or plane of imaging helps to decrease or eliminate enhancement artifacts when necessary. Correcting TGC can also be used to decrease enhancement artifacts (Figure 5-10).

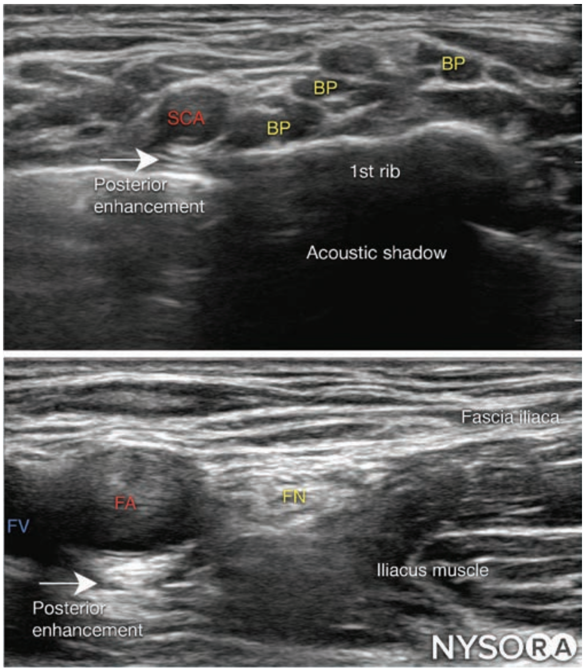


FIGURE 5-10. Example of a posterior enhancement: (A) below the subclavian artery and (B) below the femoral artery. BP, brachial plexus; FA, femoral artery; FN, femoral nerve; FV, femoral vein; SCA, subclavian artery.

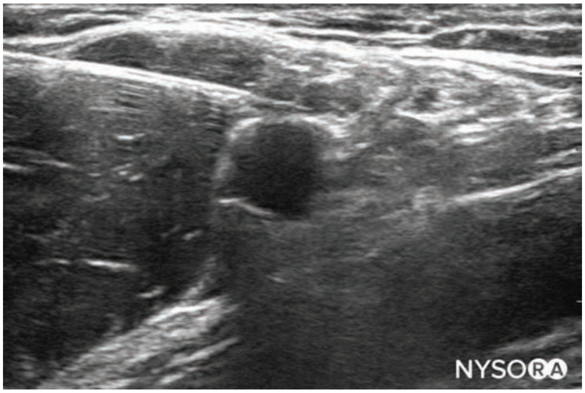


FIGURE 5-11. Reverberation of the needle during an axillary block.

4. ***Reverberation*** may occur between two highly reflective parallel interfaces or between the transducer and a strong reflector in parallel. Instead of the beam reflecting off a single surface and producing a strong echo that returns to the transducer, the US beam is reflected between the interfaces repeatedly. Reverberation is displayed as parallel, equally spaced, bright linear echoes that decrease in intensity with an increase in depth, deeper to the strong reflector. Because reverberation echoes take longer to return to the transducer, they appear to occur at increasing depth. Slightly changing the scanning direction or decreasing the US frequency can attenuate or eliminate reverberation artifacts (Figure 5-11).
5. ***Mirror image*** artifact results from a highly reflective linear boundary that acts like an acoustic "mirror." A structure located on one side of the interface repeats also on the other side at an equal distance. The transducer receives both direct echoes from the object and indirect echoes from the mirror (Figure 5-12). The duplicated artifactual image is less bright and deeper than the real image because indirect echoes transmit a longer distance and their energy is attenuated in that way. Changing the scanning direction may decrease the artifact.
6. ***Propagation velocity error*** is seen as a displacement or discontinuity of an interface caused by the difference of the actual velocity of US propagation in soft tissue compared with the calibrated speed, which is assumed to be a constant velocity of 1540 m/s set by the US system. Consequently, a reflector is erroneously displaced on the image closer to the transducer by the error in distance calculations (Figure 5-13).

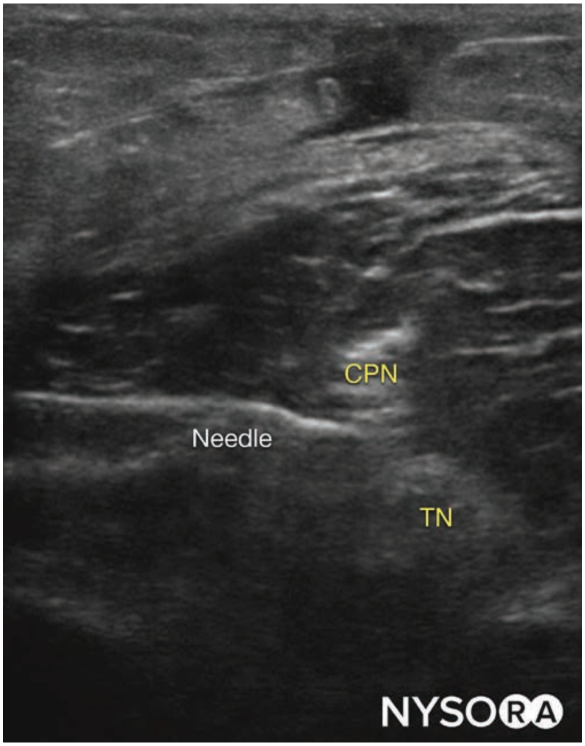


FIGURE 5-13. Propagation velocity error. "Bayonet effect" of the needle approaching the sciatic nerve at the popliteal fossa. CPN, common peroneal nerve; TN, tibial nerve.

The inherent artifacts in the process of scanning cannot always be entirely eliminated. However, recognizing and understanding US artifacts help the operator to avoid misinterpretation of images and use the machine settings to control and limit their effect on image quality.

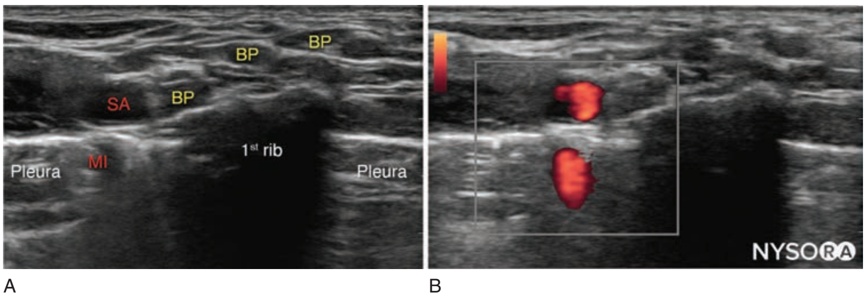


FIGURE 5-12. Ultrasound image of the subclavian artery at the supraclavicular level that shows an example of a mirror image (MI) above and below the pleura. BP, brachial plexus; SA, subclavian artery.

Needle Insertion Techniques

The two most common needle insertion techniques are the in-plane and out-of-plane techniques (Figure 5-14).

With the in-plane technique, the needle is placed in the plane of the US beam. As a result, the needle shaft can be monitored throughout the procedure in the longitudinal view in real-time as the needle is advanced toward the target nerve. When the needle tip is not seen on the image, needle advancement is stopped. The best course of action to bring the needle in-plane is *alignment* (sliding). Although tilting or rotating the transducer can also align the US beam with the needle, these maneuvers may result in a compromise in the image of the relevant anatomy. In addition, a subtle, fast needle shake and/or injection of a small amount of injectate may help detect the needle tip location.

The out-of-plane technique involves needle insertion perpendicular or at an oblique angle to the transducer. The needle shaft is imaged in a cross-sectional plane and is often identified as a bright white reflection in the image. Visualization of the needle tip with an out-of-plane technique, requires a high degree of skill. To track the needle with this technique, the needle is slightly shaken up to differentiate the needle reflection from that of the surrounding tissue. One common technique is, once the needle tip reflection encounters the US beam superficially to the target, the needle is then further advanced in a steeper angle under the continuous view of the tip toward the target. Also, the transducer can be aligned (sliding) with the advancing needle tip reflection as the needle is being inserted until the target is reached. The operator should stop needle advancement when the needle trajectory is lost visually and align the transducer to identify the needle. A small amount of injectate ("hydrodissection") can be used to estimate the needle tip position.

Catheter Visualization

Continuous PNBs are a common practice. Visualization of the catheter position can be challenging. Introducing the catheter in-plane at a short distance from the needle tip (e.g., 2 cm past the needle tip) can allow direct visualization of the catheter tip (Figure 5-15). However, inserting the catheter deeper (e.g., 3-5 cm beyond the needle tip) or

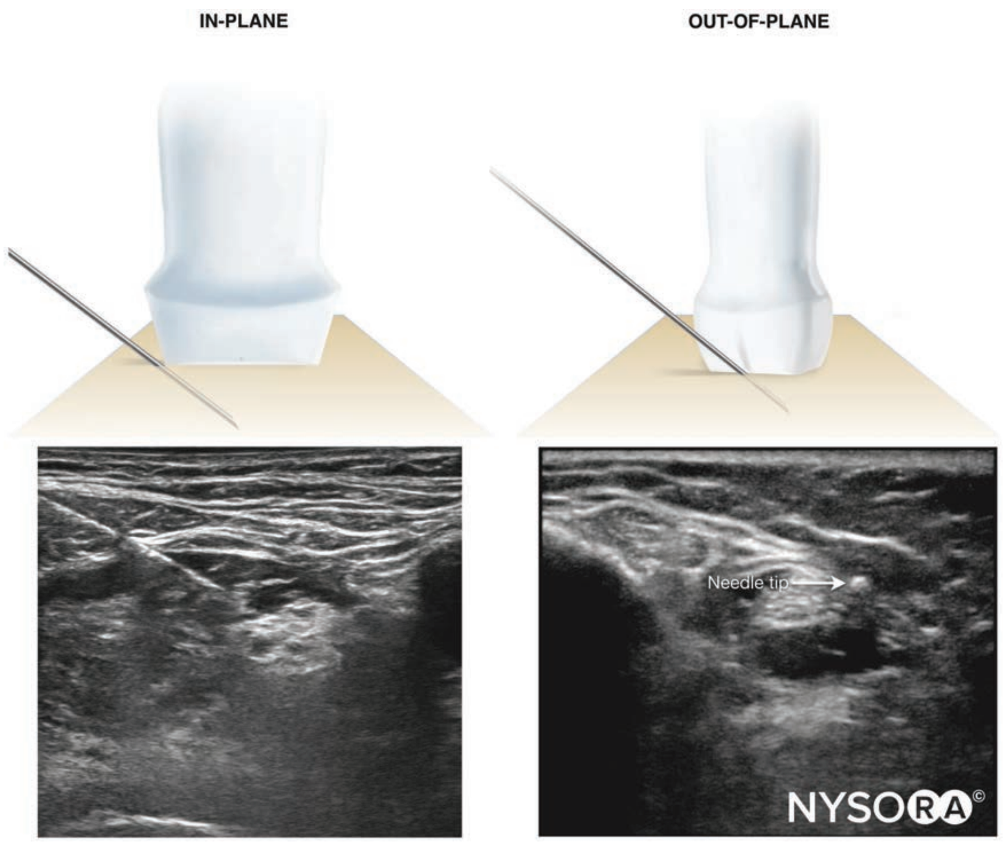


FIGURE 5-14. In-plane and out-of-plane needle insertion techniques and their corresponding appearance in an ultrasound image.

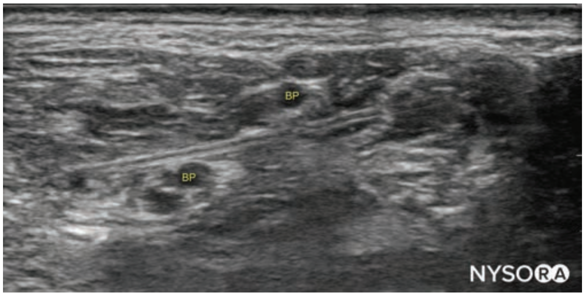


FIGURE 5-15. Catheter insertion in-plane for interscalene brachial plexus block. BP, brachial plexus.

out-of-plane results in the needle, nerve, and catheter being in different planes from the US beam, which challenges the imaging. Catheters may be difficult to visualize because they often coil within the space that contains the nerve. There are two ways to confirm the catheter tip location:

1. The operator can align (slide) the transducer to see a reflection of the catheter.
2. The position of the catheter tip can be detected by observing the spread of 1-2 mL of injectate through the catheter. The use of color Doppler may also help to visualize the spread (Figure 5-16). Visualization of the spread of injectate is the most convenient and important method to ascertain the position of the catheter tip in the therapeutic location, rather than visualization of the catheter.

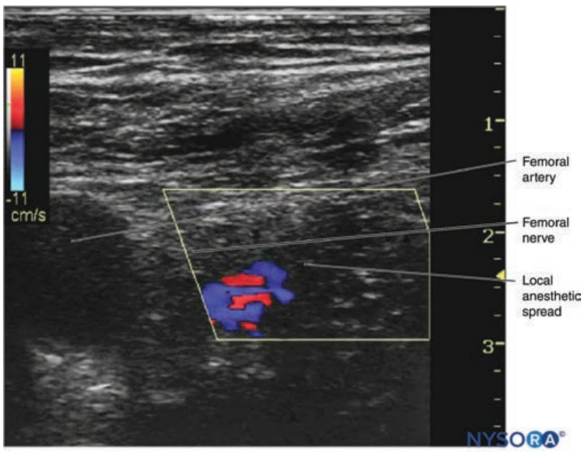


FIGURE 5-16. Catheter tip detection using the spread of the injectate and color Doppler imaging.

New Needle Tracking Technology

The use of guides attached to the transducer to mechanically guide the needle toward the target helps to align the needle and the US beam and may be useful to control the needle path. Recently, a variety of more advanced technologies have been introduced to facilitate the view of the needle tip during procedures. These include the modification of the needle tip, electromagnetism, magnetization of the needle tip, optical tracking, augmented reality, needle detection software, three-dimensional US, and robot assistance. These technologies may ultimately substantially facilitate the accuracy of interventional point of care US in the years to come.

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6 Monitoring and Documentation in Regional Anesthesia

Introduction

Just like in patients having general anesthesia, the practice of regional anesthesia requires comprehensive, organized preoperative assessment, patient education, preparation. Likewise, monitoring, and documentation of respiratory and cardiovascular parameters during the administration of regional anesthesia (e.g., oximetry, capnography, electrocardiography) for safety and guidance in therapeutic decision-making. In regional anesthesia, several needle and injection monitoring systems have become available to decrease the risk of nerve injury, local anesthetic (LA) toxicity, and inadvertent needle injury to adjacent structures.

The first part of this chapter describes needle and injection monitoring and the rationale for their use. The latter section focuses on the documentation of nerve block procedures or medical record-keeping of the objective information obtained by the monitors. Objective and robust documentation of *how* a nerve block is performed provides useful database information to inform on the matters of safety and efficacy and may have medicolegal implications.

SECTION I: MONITORING

Available Means for Monitoring Needle-Nerve Relationships

Monitors, as used in medical practice, are devices that assess a specific physiologic state, provide objective data, allow for trending of the provided information, and can warn the clinician of impending harm. In this chapter, we discuss the currently available clinical monitors, such as ultrasonography, nerve stimulation, and injection pressure, and remark on some emerging technology. Each monitor has its advantages and limitations, and each can be used in an additive, complementary fashion (Figure 6-1) to minimize the potential for patient injury, rather than relying only on the information provided by a single monitor alone. Evidence-based information suggests that a combination of monitors is likely to enhance the safety of peripheral nerve blocks (PNBs).

Epinephrine as a Monitor of Intravascular Injection

Some clinicians use epinephrine in the LA as a pharmacologic monitor to improve detection of an intravascular injection and contribute to the safety during PNBs. Intravenous injection of 10 to 15 μg epinephrine increases the systolic blood pressure more than 15 mmHg, even in premedicated patients or patients treated with β-blockers. This increase in blood pressure may help early detection of intravascular injection and prompt discontinuation of the injection. Epinephrine also decreases the absorption of the LA in perineural tissues or in local infiltration. This may decrease the peak plasma level of LA and lower the risk for systemic toxicity. Concerns regarding vasoconstriction and nerve ischemia with the addition of epinephrine have not been substantiated. Concentrations of 2.5 μg/mL (1:400,000) actually may increase intraneural blood flow due to the predominance of

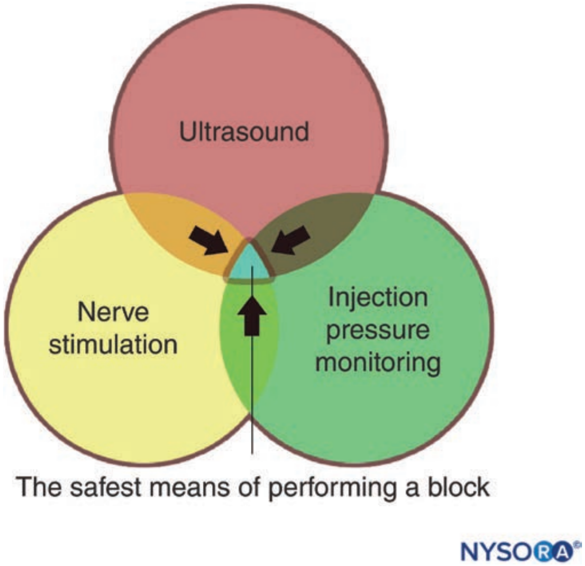


FIGURE 6-1. Three modes of monitoring peripheral nerve blocks for patient injury. The overlapping area of all three (*blue area*) represents the safest means of performing a block.

the β-effect of the drug in small doses. All in all, epinephrine may enhance safety during the administration of larger doses of LAs without increasing the risk of nerve ischemia and neuropathy.

Ultrasound Monitoring

Ultrasound (US) has revolutionized the practice of regional anesthesia and transformed the subspecialty from an art practiced by a few to a reproducible medical discipline. US provides real-time needle-target guidance and injection monitoring, resulting in a quicker and more accurate procedure. US makes it possible to accurately deposit additional injections of LA into tissue spaces for reproducible nerve block anesthesia or analgesia. US also makes nerve blocks feasible for patients in whom an evoked motor response (EMR) using nerve stimulation could not be elicited.

US guidance aids in visualizing and avoiding adjacent structures of importance thereby improving PNB safety. As an example, before the introduction of US, the supraclavicular block was rarely used to anesthetize the brachial plexus for fear of causing a pneumothorax due to the proximity of the pleura and chest cavity. Likewise, the ability to visualize tissue fasciae has allowed the development of new interventional regional analgesia procedures. However, US depends on the skill of the user and the quality of the image. Consequently, complications such as intravascular injections, nerve injury, or pneumothorax can still occur.

The ability to determine the distance from the skin to the target and the use of needles with ultrasound-detectable depth markings (Figure 6-2) confers an additional safety margin by warning the clinician of a "stop distance," a depth beyond which the operator should stop advancing the needle and reassess.

Real-time monitoring of the LA distribution is another advantage of US (Figure 6-3). For example, if tissue expansion with injection does not occur in the therapeutic area, the needle tip may have to be adjusted. Subsequently, the operator can reassess the needle tip location and adjust accordingly. This can be particularly useful in vascular areas, as the lack

FIGURE 6-2. Needles with 1 cm depth markings (or 0.5 cm markings on short length needles) and etched surface help to visualize and control the insertion depth.

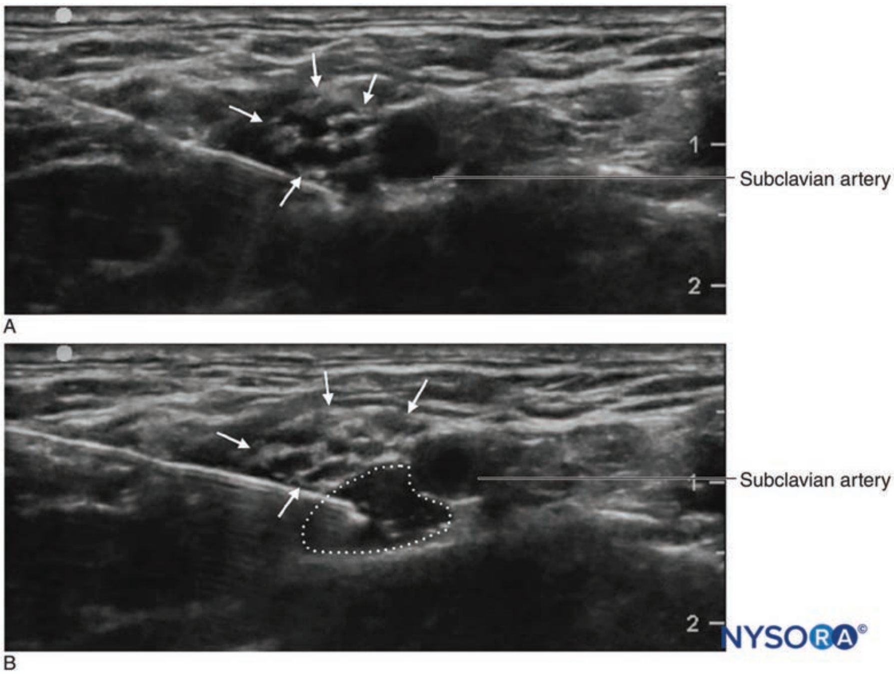


FIGURE 6-3. A supraclavicular brachial plexus block showing plexus (*arrows*) adjacent to the subclavian artery, (A) before and (B) after deposition of 10 mL of local anesthetic (*dotted outline*).

of LA visualization may be due to intravascular needle placement. US monitoring can detect intra-arterial needle tip placement, typically presenting as a "blush" in the arterial lumen.

The use of US guidance for PNBs has decreased the risk of severe local anesthetic systemic toxicity (LAST). An analysis of a large, multicenter registry of PNBs (>25,000 PNBs) showed a reduction of >65% for the risk of LAST when using US guidance. One of the reasons for the lower risk of LAST with US is the reduction of the LA volumes and doses to accomplish the blocks. Numerous reports documented a reduction in the volume required to achieve a successful nerve block, as compared to pre-ultrasound-guided regional anesthesia techniques. For instance, brachial plexus blocks can be performed with as little as <10 mL of LA, without a sacrifice in the effectiveness of anesthesia or analgesia. Furthermore, severe LAST is less likely to result from accidental injection of 7 mL of 0.5% ropivacaine in an adult of average size, for example. In addition, observation of the needle path on US, avoidance of intravascular placement, and confirmation of the LA spread in the tissues all decrease the risk of LAST.

Unfortunately, the use of US guidance during PNBs has not decreased the risk of nerve injury. The reason for this discrepancy is multifactorial. The ability to discern the needle-nerve relationship is anatomy- and operator-dependent. Studies suggest that practitioners miss intraneural needle placement and injection in 1 or 2 out of 10 injections. The resolution of an US image may also not be adequate to recognize intraneural or intrafascicular injections. However, it may already be too late to prevent the injury when the gross swelling of the nerve following an intraneural injection is detected. This is because even a small amount of LA (e.g., 0.1-0.5 mL) can result in neurologic injury if injected into the fascicle.

Nerve Stimulation

Nerve stimulation replaced paresthesia as the primary means of nerve localization in the 1980s. Nevertheless, motor response to nerve stimulation may be absent even when the needle is in contact with the nerve with current intensities of 1.0 mA or higher. In some instances, even with intraneural needle placement, an EMR can be obtained with only a current intensity of >1 mA. As such, nerve stimulation has relatively low sensitivity (i.e., approximately 70%). Nonetheless, when a motor response is present with 0.5 mA or less, it is always indicative of a very close needle-nerve distance, nerve contact, or an intraneural needle placement (i.e., 100% specificity). Multiple factors conspire to decrease the sensitivity of nerve stimulation to detect needle-nerve contact: (1) The electrical current may not flow toward the nerve and may shunt away from the nerve alongside the path of least resistance to exit via the (return) skin-electrode, even when the needle is near the nerve; (2) the variability in the organization of the motor and sensory fibers of nerves.

However, the electrical stimulation of peripheral nerves is not obsolete in an era of US guidance. Data from several animal and human studies suggest that the presence of a motor response at a very low current (i.e., <0.2 mA) is associated with intraneural needle tip placement and intraneural inflammation after injection in this condition (Table 6-1). Voelckel et al. reported that nerve tissue showed no signs of an inflammatory process after injection of LA at currents between 0.3 and 0.5 mA. Injections at less than 0.2 mA resulted in lymphocytic and granulocytic infiltration in 50% of the nerves. In a similar study, Tsai et al. investigated the effect of nerve distance on the required current. While a range of currents was recorded for a variety of distances, a motor response at less than 0.2 mA was only obtained with intraneural needle tip placement.

Bigeleisen et al. studied 55 patients scheduled for upper limb surgery, receiving ultrasound-guided supraclavicular brachial plexus blocks. The authors determined the minimum current threshold for a motor response inside and outside the first encountered trunk. They reported a median minimum stimulation threshold of 0.60 mA outside the nerve and 0.3 mA inside the nerve. EMRs were not observed with stimulation currents of 0.2 mA or less outside the nerve, whereas 36% of patients had an EMR twitch at currents less than 0.2 mA with intraneural needle placement.

Wiesmann et al. applied an electrical current to the brachial plexus of pigs at three different positions (i.e., intraneural, with the needle contacting the epineurium, and at 1 mm from the nerve) while varying the pulse duration (i.e., 0.1, 0.3, and 1.0 msec). The minimum threshold current to elicit a motor response was identical between the intraneural and needle-nerve contact positions, and both were significantly lower than the position 1 mm away. Pulse duration did not affect the minimal threshold current. The authors concluded that a motor response at less than 0.2 mA, irrespective of pulse duration, indicated *either* intraneural or needle-nerve contact. This is important because, in the absence of epineurium puncture, even forceful needle-nerve (epineurium) contact results in inflammation and potential nerve injury. Likewise, Gadsden demonstrated that current intensity of 0.5 mA (0.1 msec) detects needle-nerve contact in >70% of instances.

Taken together, the available data suggest that a "low current" sensitivity to elicit an EMR is approximately 75% in a potentially dangerous needle-nerve relationship (intraneural or epineural placement). However, the specificity of the EMR when present at less than 0.5 mA nears 100%. In other words, the needle tip is always intraneural or intimately related to the epineurium when a motor response is elicited by a low-intensity stimulating current. Therefore, the utility of the nerve stimulator is obvious. The unexpected appearance of an EMR at 0.5 mA indicates an intimate needle-nerve relationship (e.g., needle-nerve contact) and may allow the operator to stop needle advancement before entering the nerve.

Extraneural deposition of LA constitutes a safer practice because the injection of LA into the nerve carries a high risk of injury. While unquestionably useful, ultrasonography is far from an infallible monitor of the needle-nerve relationship. Therefore, the addition of electrical monitoring of the needle tip position is useful for safety, particularly in patients with challenging US anatomy when imaging proves to be difficult,

TABLE 6-1 Studies of Nerve Stimulation Current and Needle-Tip Position

STUDY	SUBJECT	METHOD	FINDINGS
Voelckel et al. (2005)	Pigs (n = 10)	• Bilateral posterior sciatic nerve blocks • Two groups: (1) injection after EMR at 0.3 0.5 mA; and (2) injection after EMR at <0.2 mA • Sciatic nerves were harvested 6 h postinjection for histologic analysis	• Normal, healthy appearance of nerve in high current group • 50% of nerves in low current group showed evidence of lymphocyte and polymorphic granulocyte sub-, peri-, and intraneurally • One specimen in low current group showed gross disruption of perineurium and multiple nerve fibers
Tsai et al. (2008)	Pigs (n = 20)	• General anesthesia • Bilateral exposure of sciatic nerves • Current applied with needle at various distances from 2 cm away to intraneural • Two blinded observers agreed on minimal current required to obtain hoof twitch • 40 attempts at each distance	• Sciatic nerve twitches were only obtained at 0.1 cm or closer • Wide range of currents required to elicit motor response • Only when intraneural did a motor response result from current <0.2 mA
Bigeleisen et al. (2009)	Patients for hand/wrist surgery (n = 55)	• Supraclavicular block • Minimum current (mA) recorded: (1) with needle outside nerve trunk (but contacting nerve); and (2) inside trunk • "Intraneural" position sonographically confirmed with 5 mL injection of local anesthetic	• Median minimal current threshold outside the nerve was 0.60 ± 0.37 mA • Median minimal current threshold inside the nerve was 0.30 ± 0.19 mA • No EMR observed at any time with <0.2 mA when needle placement outside nerve
Wiesmann et al. (2014)	Pigs (n = 6	• Open brachial plexus model • Stimulation at three positions: intraneural, needle nerve contact, and 1 mm away from nerve • Three pulse durations tested (0.1, 0.3, and 1 ms)	• Current intensity cannot distinguish between intraneural and needle nerve contact • Motor response <0.2 mA (irrespective of pulse duration) indicated intraneural or needle nerve contact

EMR, evoked motor response.

or when the image quality is poor. Overall, nerve stimulation adds little to the cost of a nerve block procedure in terms of time or cost but can add a meaningful safety electrophysiologic confirmation of the anatomical image shown on US (e.g., "Is that the median or ulnar nerve?"). For these reasons, nerve stimulation should be used routinely in conjunction with US as a valuable additional monitor of the needle tip position.

Injection Pressure Monitoring

Intrafascicular injection of lidocaine in canine sciatic nerves was associated with a high OIP (>20 psi), followed by a return of injection pressure tracing to normal (i.e., <5 psi) after fascicular rupture. In contrast, perineural and intraneural extrafascicular injections yielded low OIPs. The limbs in which sciatic nerve injections were associated with high OIPs experienced clinical signs of neuropathy (e.g., muscle wasting, weakness) as well as histological evidence of neurologic injury (e.g., inflammation, disruption of the nerve architecture). The implication is that injection into a low-compliance compartment, such as within perineurium-bound fascicles, requires a high OIP before the injection can be initiated. Therefore, detection of high injection pressure before injection can help to avoid injection into the fascicle or other low compliant tissues.

An intraneural needle tip position was also associated with high OIPs in human cadavers. Orebaugh et al. placed needles into cadavers' cervical roots using US and quantified the pressure for a 5 mL injection of ropivacaine and ink over 15 sec. In contrast to the control needles placed outside the roots (peak pressure <20 psi), the intraneural injections resulted in a mean peak pressure of 49 psi (range 37-66 psi). Similarly, Krol et al. performed ultrasound-guided intraneural and perineural injections in fresh human cadavers in more distal nerves (i.e., median, ulnar, and radial nerves). They reported that intraneural OIPs were more than 15 psi, while extraneural OIPs were less than 10 psi.

In studies by Gadsden et al., needle-nerve contact during interscalene brachial plexus and femoral blocks were associated with an OIP greater than 15 psi in 16 patients undergoing shoulder surgery. The flow of injectate did not commence at pressures of less than 15 psi when there was needle-nerve contact or just before needle entry into the roots of the brachial plexus. In 97% of subjects, halting the injection when the required OIP reached 15 psi avoided injection in this hazardous needle position. In contrast, a needle position 1 mm away from the nerve was associated with a flow initiation at OIPs less than 15 psi. Therefore, an OIP greater than 15 psi, as a monitor of needle-nerve contact, was far more sensitive than a minimum threshold current of either 0.5 or 0.2 mA, or occurrence of paresthesia.

These data suggest that when the pressure in the syringe-tubing-needle system approaches 15 psi without the ability to commence the flow of injectate, this high OIP may signal a dangerous needle-nerve relationship or needle placement in the wrong tissue plane. Therefore, when the opening pressure approaches 15 psi, the clinician should halt the injection and reevaluate the needle position.

Unfortunately, the use of "hand feel" to avoid a high injection pressure is not reliable. Studies of experienced practitioners, blinded to the injection pressure, who performed mock injections using standard equipment, revealed wide variations in applied pressure, some grossly exceeding the established safety thresholds. Similarly, anesthesiologists performed poorly when asked to distinguish between intraneural injection and injection into other tissues (e.g., muscle or tendon) in an animal model. As such, using an objective and quantifiable method is the only reproducible way to monitor the OIP.

While the practice of injection pressure monitoring during PNBs is relatively new, there are several monitoring options. Tsui et al. described a "compressed air injection technique" by which 10 mL of air is drawn into the syringe along with the LA. Holding the syringe upright allows only the gas portion of the syringe contents to compress to half of its original volume (i.e., 5 mL) and avoids a maximum threshold of 1 atm (or 14.7 psi) (Figure 6-4). This is based on Boyle's law, which states that pressure × volume must be constant. A pressure of 20 psi or less is considered to be a safe threshold for initiating injection during PNBs. Boyle's law

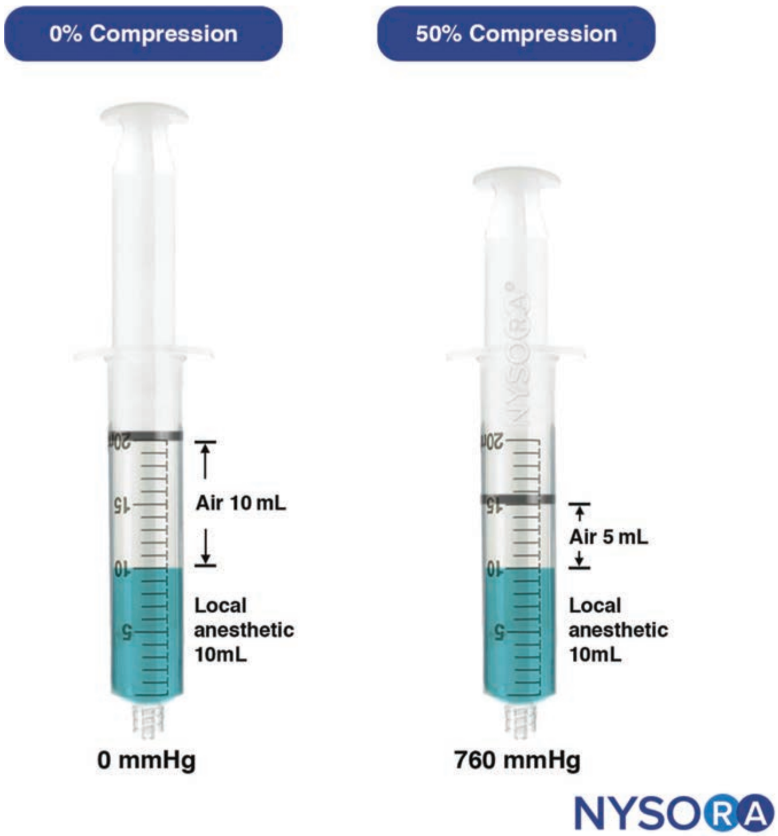
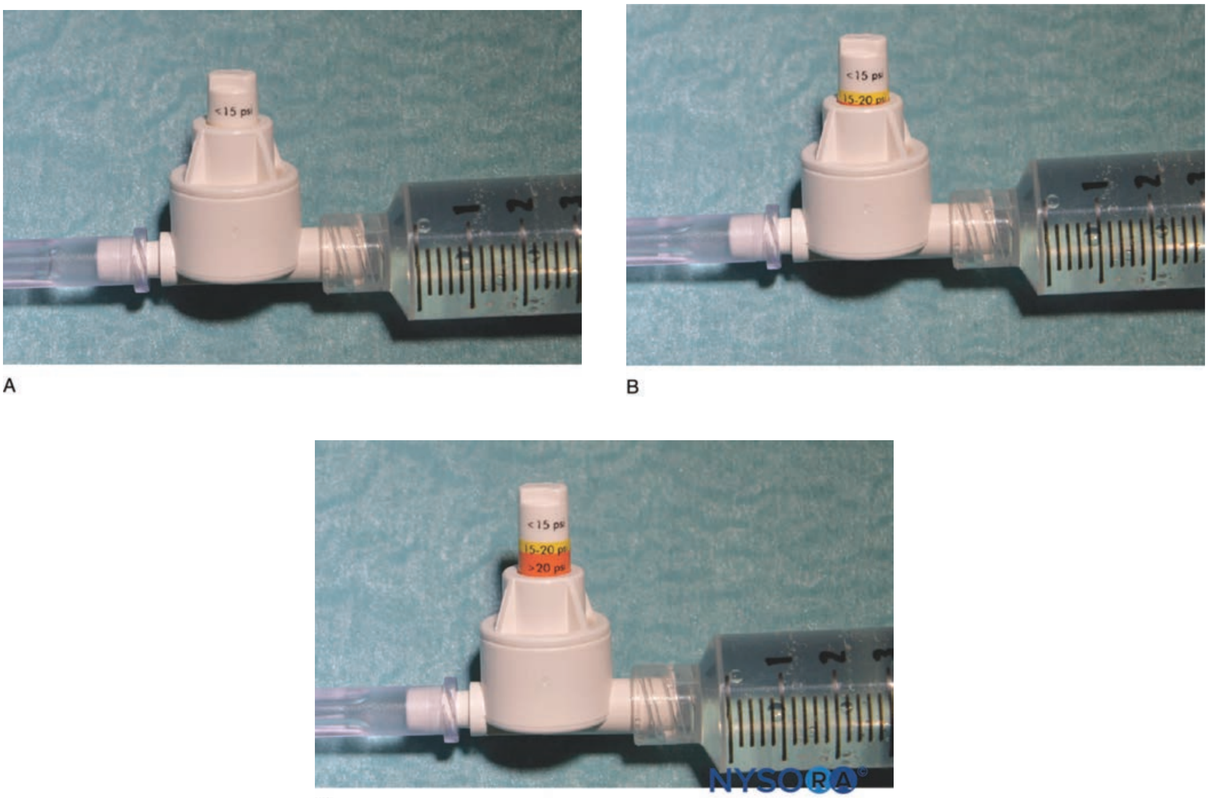


FIGURE 6-4. The compressed air injection technique. A 10 mL bubble of air is placed in the syringe filled with local anesthetic, which is then inverted. Compression of that bubble in a closed system to half of its original volume (i.e., 5 mL) will increase the pressure in the system by 1 atm (i.e., 14.7 psi).

has also been employed in another simple apparatus, using a four-way stopcock and a 1 mL air-filled syringe. If the fluid meniscus reaches the halfway point in the 1 mL syringe (i.e., 0.5 mL) during the initiation of injection, this indicates a doubling of the pressure in the system (i.e., another atm or 14.7 psi). These are both inexpensive and ubiquitously available ways to limit high OIP during PNBs. Practical limitations include the need to either hold the syringe upright or to periodically turn off the stopcock to the 1 mL syringe when aspirating to avoid the introduction of air in the injection tubing.

Another option to monitor injection pressure is the use of in-line, disposable pressure manometers manufactured explicitly for this purpose. These devices bridge the syringe and needle tubing and allow the clinician to continuously monitor the pressure in the syringe-tubing-needle system via a spring-loaded piston. Markings on the piston's shaft delineate three different pressure thresholds: less than 15 psi, between 15 and 20 psi, and more than 20 psi (Figure 6-5). This method offers the advantage that the assistant performing the injection can monitor and communicate the attained pressures and objectively document the injection pressure during a PNB procedure. Other designs include a pressure limiter within the syringe tubing system (NerveGuard, Pajunk GmbH) and various automated injection pumps with built-in pressure monitoring systems.

Importantly, the opening pressure (pressure at which the flow begins) is independent of the size of the syringe, tubing, needle, and injection speed (Pascal's law) (Figure 6-6). Although fast injection speed may result in higher injection pressures, the opening pressure at which the flow begins is independent of the injection speed or size of the fluid passages for standard syringe-tubing-needle sizes (i.e., 18-25 gauge). Nevertheless, when the injection begins, these factors will influence the attained injection pressure. Therefore, slow, steady injection speed (i.e., 10-15 mL/min) is suggested for all nerve block procedures. The OIP becomes relevant with every consequent needle reposition and injection.



A B C

FIGURE 6-5. An example of a commercially available in-line pressure manometer (B-Smart, B. Braun Medical, Bethlehem, PA). As seen in (A-C), respectively, the monitor displays pressure ranges in color on the movable piston: 0-15 psi (white), 15-20 psi (yellow), and more than 20 psi (orange). In clinical use, the exact opening injection pressure is less important than the prevention of exceeding the range of opening injection pressure associated with fascicular injury (>15 psi). Practically, this is avoided by aborting the injection with the appearance of any color on the piston throughout the injection cycle (>15 psi). At the time of this publication, several additional injection pressure monitoring systems have been introduced (NerveGuard by Pajunk, Safira by Medovate).

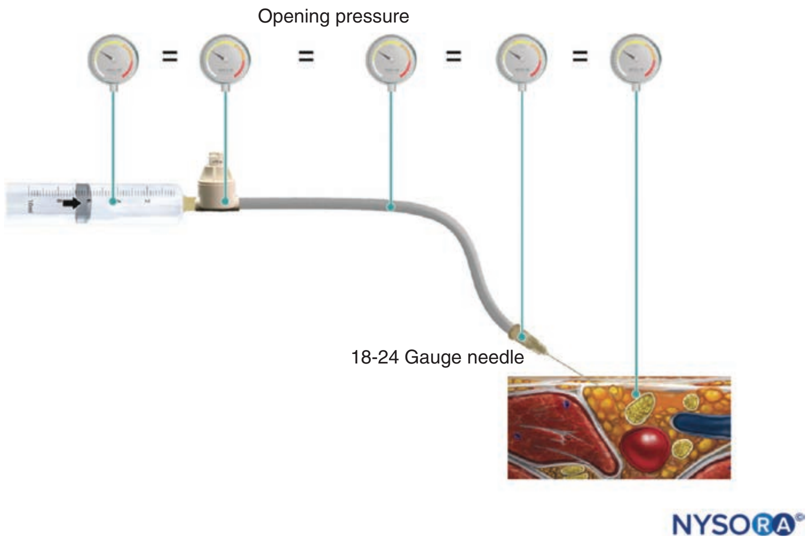


FIGURE 6-6. Opening injection pressure (pressure at which the flow begins) is independent of the size of the syringe, tubing, and needle or injection speed, and is equal throughout the injection system (Pascal's law).

Pressure monitoring is important for several aspects of patient safety and comfort during the practice of PNBs. Gadsden et al. demonstrated that 60% of patients receiving high-pressure lumbar plexus blocks (>20 psi) developed a bilateral epidural block and a high thoracic epidural block. Similarly, Gautier et al. showed that when volunteers were randomized to low (<15 psi) versus high (>20 psi) injection pressures during interscalene brachial plexus blocks, cervical epidural spread occurred in 11% of high-pressure injections (vs. 0% in the low-pressure group). In addition, all subjects requested to halt the injection due to discomfort during the high-pressure condition, but not during the low-pressure injection.

Summary

Regional anesthesia has made a transition from an art to a reproducible clinical discipline. The standardization of the monitoring of PNBs with ultrasonography, neurostimulation, and injection pressure monitoring together provides a complementary set of objective data for greater consistency and safety. Figure 6-7 is a flowchart outlining how these monitors are used in our practice.

SECTION II: DOCUMENTATION

Block Procedure Notes

Documentation of nerve block procedures has lagged behind the documentation of general anesthesia. The increasing regulatory and billing requirements mandate efforts to improve the documentation for PNBs. Examples of PNB documentation forms that incorporate all of the monitoring elements mentioned previously in this chapter are shown in Figures 6-8 and 6-9. These can be adopted and modified to suit individual practices. Institutions attempting to formulate their procedure notes should consider several features of these forms (Table 6-2).

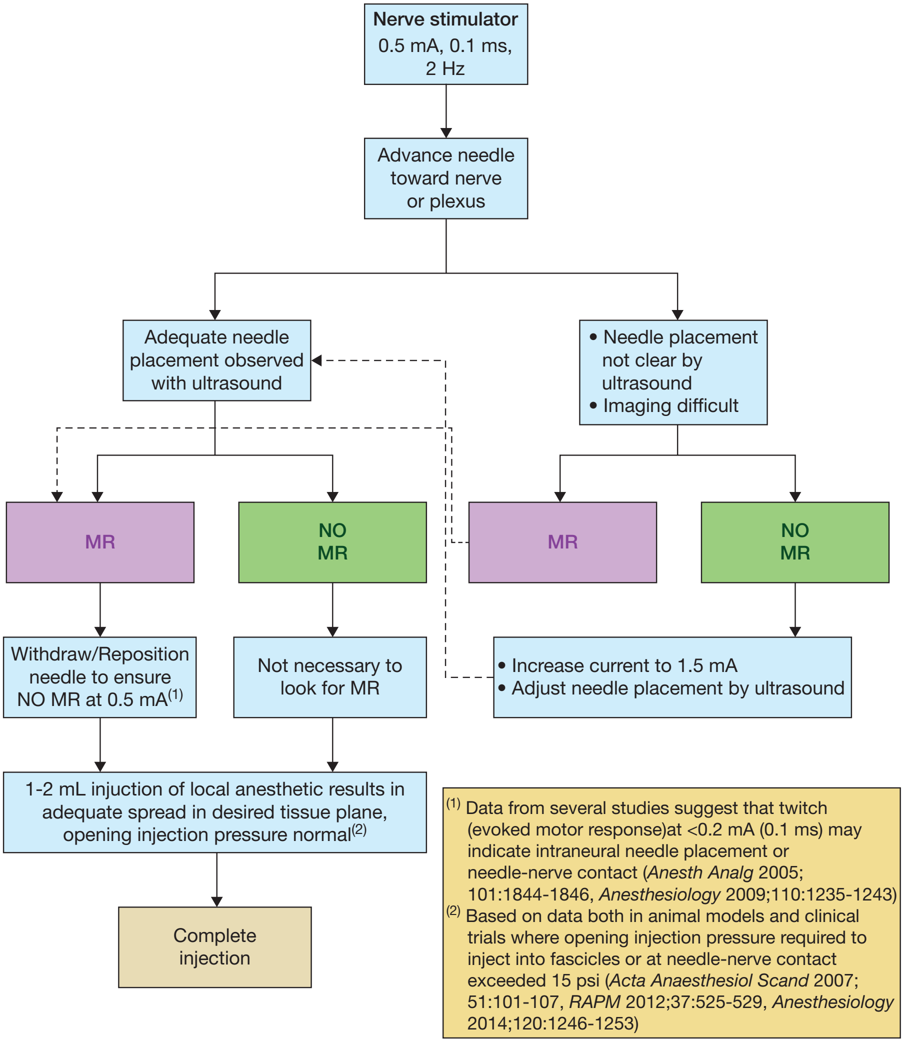


FIGURE 6-7. Flowchart depicting the order of correctly monitoring nerve block procedures by combining ultrasound, nerve stimulation, and injection pressure monitoring (triple monitoring). MR, motor response.

Paper records are increasingly being replaced with electronic medical record-keeping systems. Block documentation is simple with computerized systems as the block variables can be selected quickly from a list by indicating relevant documentation items. Moreover, any narrative element can be rapidly typed using a keyboard.

Another useful aspect of PNB documentation is the recording of an US image or video clip to be stored either as a hard copy in the patient's chart or as a digital copy in the electronic health record or separate secure hard drive. Any hard copies should have a patient identification, the date, and any pertinent findings highlighted with a marker, such as LA

Regional Anesthesia Procedure Form

Date		**Time Out (time)**		Patient Identification Sticker
Consult/Block Requested By				
Pre-op Diagnosis				
Surgical Procedure				
Purpose of Block	☐ Surgical ☐ Postop Pain			
Block Procedure Location				Side:

Monitors	**Premedication**	**Level of Sedation/Anesthesia**
Full ASA monitoring: ☐	Midazolam (mg)	No sedation ☐
Oxygen by:	Fentanyl (mcg)	Sedated, easily arousable, conversant ☐
Other:	Alfentanil (mcg)	Deep sedation/general anesthesia ☐
	Other:	Neuraxial Anesthesia in situ ☐

Block Procedure:	Ultrasound Guidance ☐ **[76942]**
Technique: ☐ single injection ☐ continuous ☐ nerve-stimulator guided ☐ landmark-based	

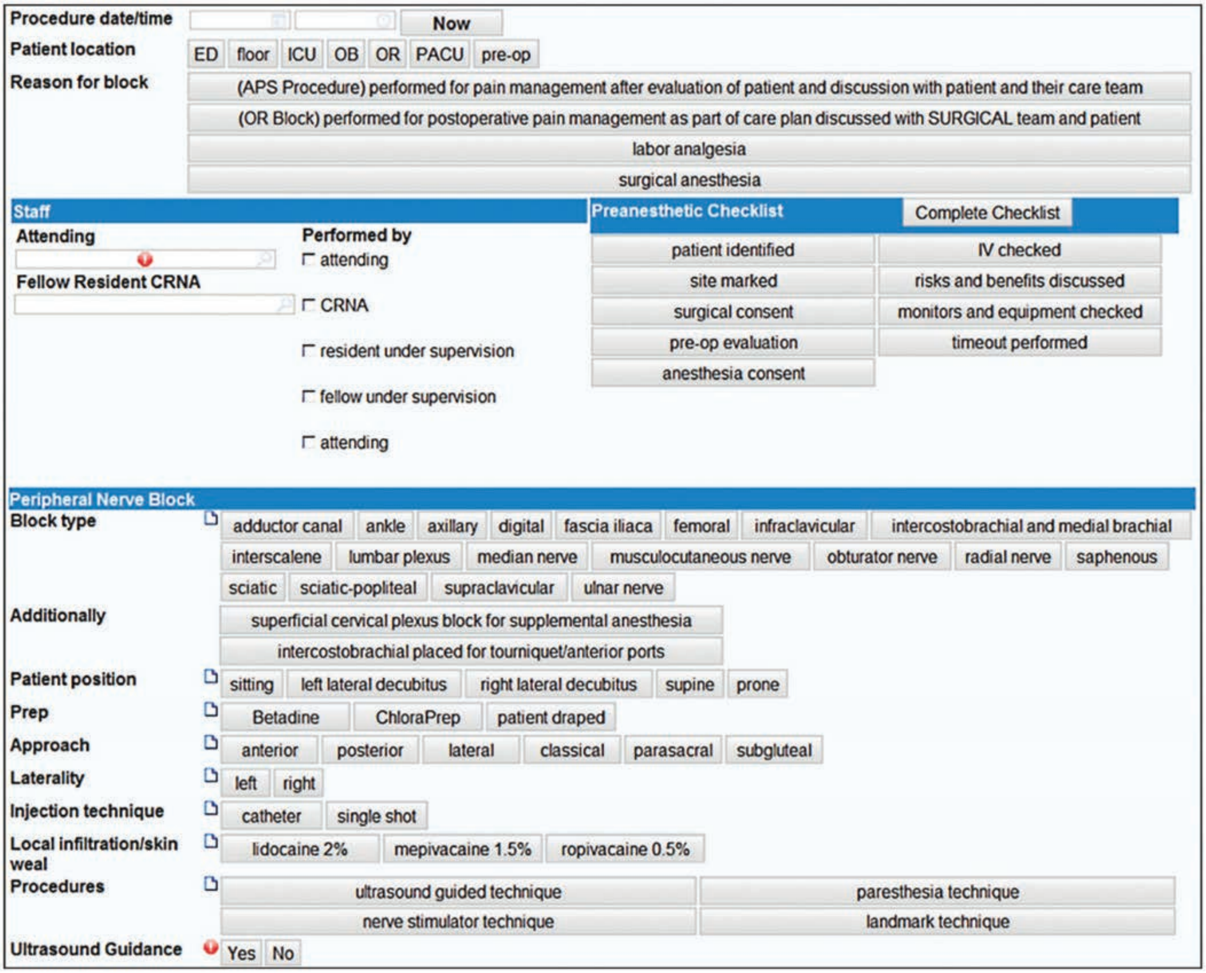
Needle/Catheter	**Sterility**
Type/Size:	☐ Aseptic skin prep ☐ Sterile drape(s) ☐ Sterile gloves ☐ Sterile transducer cover

Local Anesthetic & Additives	
Type/Concentration:	☐ Epinephrine (concentration:)
Volume: mL	☐ Bicarbonate (0.1 mEq/ml) ☐

Procedure Notes	
☐ Skin anesthetized with local anesthetic	Patient Position:
Needle depth: cm Minimal current: mA Motor response:	☐ No response <0.2 mA
If ultrasound guided: ☐ In-plane ☐ Out-of-plane ☐ Local anesthetic directly observed spreading adjacent to nerve	
Catheter tip location confirmed by: ☐ Ultrasound ☐ Motor stimulation	Depth at skin: cm
Blood aspirated:	Action taken:
Pain on injection:	Action taken:
Injection pressure <15 psi:	Action taken:
Other notes:	

Resident/Fellow:	Signature:	NYSORA©	
Attending:	Signature:	Date:	Time:

FIGURE 6-8. Example of a block documentation form.


Procedure date/time Now

Patient location ED floor ICU OB OR PACU pre-op

Reason for block

(APS Procedure) performed for pain management after evaluation of patient and discussion with patient and their care team

(OR Block) performed for postoperative pain management as part of care plan discussed with SURGICAL team and patient

labor analgesia

surgical anesthesia

Staff

Attending

Fellow Resident CRNA

Performed by

attending

CRNA

resident under supervision

fellow under supervision

attending

Preanesthetic Checklist Complete Checklist

patient identified | IV checked

site marked | risks and benefits discussed

surgical consent | monitors and equipment checked

pre-op evaluation | timeout performed

anesthesia consent

Peripheral Nerve Block

Block type: adductor canal, ankle, axillary, digital, fascia iliaca, femoral, infraclavicular, intercostobrachial and medial brachial, interscalene, lumbar plexus, median nerve, musculocutaneous nerve, obturator nerve, radial nerve, saphenous, sciatic, sciatic-popliteal, supraclavicular, ulnar nerve

Additionally: superficial cervical plexus block for supplemental anesthesia; intercostobrachial placed for tourniquet/anterior ports

Patient position: sitting, left lateral decubitus, right lateral decubitus, supine, prone

Prep: Betadine, ChloraPrep, patient draped

Approach: anterior, posterior, lateral, classical, parasacral, subgluteal

Laterality: left, right

Injection technique: catheter, single shot

Local infiltration/skin weal: lidocaine 2%, mepivacaine 1.5%, ropivacaine 0.5%

Procedures: ultrasound guided technique, paresthesia technique, nerve stimulator technique, landmark technique

Ultrasound Guidance: Yes No

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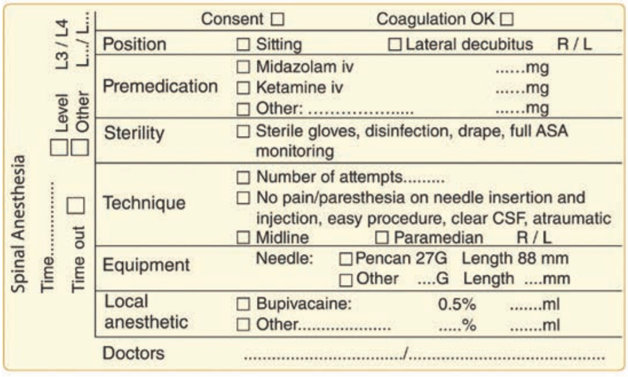
FIGURE 6-9. Screenshot from a block documentation page taken from an electronic medical record.

TABLE 6-2 Useful Features of a Peripheral Nerve Block Procedure Note

SUGGESTED PERIPHERAL NERVE BLOCK PROCEDURE NOTE	EXAMPLES
Details that guide the practioner to meet a given standard of care	A space to indicate the use of additives
A compromise between time-efficiency and individualization	Information provided with ticking boxes and blank line spaces for descriptions as needed
Documentation to safeguard against common medicolegal challenges	Patient's level of sedation during procedure
Documentation of compliance with regulatory agencies (e.g., Joint Commission)	Tick boxes with indication of the laterality
Details to facilitate billing	Language required by insurance carriers indicating when block was "requested by surgeon"


Spinal Anesthesia
Time............
Time out ☐
Level ☐ L3 / L4
Other ☐ L.../ L...
Consent ☐ Coagulation OK ☐
Position: ☐ Sitting ☐ Lateral decubitus R / L
Premedication: ☐ Midazolam iv ......mg; ☐ Ketamine iv ......mg; ☐ Other: ....mg
Sterility: ☐ Sterile gloves, disinfection, drape, full ASA monitoring
Technique: ☐ Number of attempts.........; ☐ No pain/paresthesia on needle insertion and injection, easy procedure, clear CSF, atraumatic; ☐ Midline ☐ Paramedian R / L
Equipment: Needle: ☐ Pencan 27G Length 88 mm; ☐ Other ....G Length ....mm
Local anesthetic: ☐ Bupivacaine: 0.5% ....ml; ☐ Other.................... .....% ....ml
Doctors ..../...

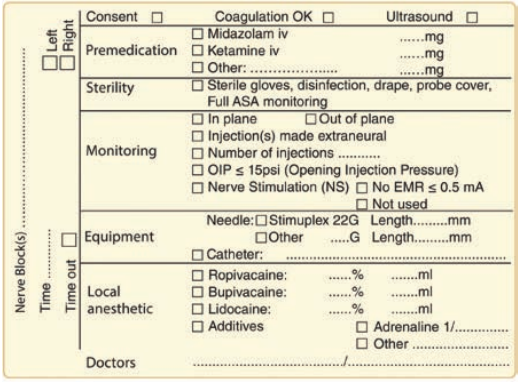

Nerve Block(s) ....
Left ☐ Right ☐
Time ....
Time out ☐
Consent ☐ Coagulation OK ☐ Ultrasound ☐
Premedication: ☐ Midazolam iv ......mg; ☐ Ketamine iv ......mg; ☐ Other: ....mg
Sterility: ☐ Sterile gloves, disinfection, drape, probe cover, Full ASA monitoring
Monitoring: ☐ In plane ☐ Out of plane; ☐ Injection(s) made extraneural; ☐ Number of injections ....; ☐ OIP ≤ 15psi (Opening Injection Pressure); ☐ Nerve Stimulation (NS) ☐ No EMR ≤ 0.5 mA ☐ Not used
Equipment: Needle: ☐ Stimuplex 22G Length.........mm; ☐ Other .....G Length.........mm; ☐ Catheter: ....
Local anesthetic: ☐ Ropivacaine: ......% ....ml; ☐ Bupivacaine: ......% ....ml; ☐ Lidocaine: ......% ....ml; ☐ Additives ☐ Adrenaline 1/............ ☐ Other ....
Doctors ..../...

FIGURE 6-10. Essential elements of documentation of peripheral nerve block procedures used at NYSORA-Europe CREER (Center for Research, Education, and Enhanced Recovery From Orthopedic Surgery) at ZOL (Ziekenhuis Oost-Limburg), Genk, Belgium.

spread around the nerve. Figure 6-10 illustrates additional examples of practical implementation of the documentation of regional anesthesia procedures.

Informed Consent

Documentation of informed consent is an important aspect of the practice of regional anesthesia. Practice patterns vary widely on this issue, and specific written consent for nerve block procedures is often not obtained. However, the written documentation of this process can be important for several reasons:

- Patients are often distracted and anxious on the day of surgery and may not remember the details of a discussion with their anesthesiologist. A written record of the informed consent process improves patients' recall of risks and benefits.
- A written consent establishes that a discussion of risks and benefits occurred between the patient and physician.
- A specific document for regional anesthesia can be tailored to include all common and severe risks; this allows the physician to explain them to the patient as a matter of routine and reduce the chance of omitting important risks.

The following tips can be utilized to maximize the consent process:

- Be brief. A simple, short explanation helps recall of the risks and benefits more than lengthy paragraphs.
- Include not only severe and major risks but also benefits and expected results of the proposed regional anesthetic procedure. It is difficult for patients to make an informed choice if only risks are discussed.
- Use the consent process as a means to educate the patient simultaneously.
- Offer a copy of the form to the patient. This has been shown to aid in the recall of consent-related information.

Checklists

Checklists have been introduced as a solution for patient safety and a number of other quality issues in health care. They are considered to be an inexpensive and simple method to avoid common human errors, applicable across a wide range of processes. Although checklists are routinely used in medicine to prevent mishaps and errors, continuing publications of case reports describing the occurrences of wrong-side (also called wrong-site) procedures illustrate that there is no simple solution to this problem and that checklists alone are not a cure-all solution. The checklists in health care are intended specifically to improve communication and teamwork (e.g., a discussion of patient risk factors) and accomplishment of straightforward categorical checks (e.g., hands washed, informed consent obtained). However, the successful completion of procedure-related checklists requires training in their implementation in a multidisciplinary environment.

Time-Out

A time-out should be completed before needle insertion for each new block site if the position is changed or separated in time or performed by another team. Practitioners should verify the patient's identity, planned surgical procedure and site, whether informed consent was obtained, and laterality of the block site before performing the nerve block. However, the most common culprit in clinical practice is forgetting to implement the checklist or time-out. Subsequently, wrong-side procedures continue to occur at the point of care. NYSORA has developed a "time-out" US transducer

FIGURE 6-11. An example of the probe cover with the removable reminder to perform the checklist before the point of care block placement ("STOP" before your block!).

cover (Figure 6-11). The cover features indicia "STOP" that requires removal of the "STOP" sticker before the transducer can be applied.

NYSORA's RAPT Checklist

Apply the RAPT method before every LA injection to rule out a motor response (R; absent at 0.5 mA) to nerve stimulation; and confirm negative aspiration (A) and low OIP (P; <15 psi) to avoid intravascular needle placement and prevent intraneural injection, respectively. The T refers to the total mL injected, which should be documented.

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7 Indications for Peripheral Nerve Blocks

Introduction

Peripheral nerve blocks (PNBs) are an important component in multimodal strategies for acute pain management. PNBs can be used as a sole anesthetic modality or as an adjunct to neuraxial or general anesthesia. The use of regional anesthesia confers many well documented clinical benefits. The wide availability of point-of-care ultrasound in clinical practice and the ubiquitous use of rapid recovery protocols increased the indications and utility of PNBs. A number of new regional anesthesia techniques have been introduced to facilitate early mobilization after surgery. The newer techniques tend to target specific distal sensory branches to decrease motor blockade. As an example, several truncal fascial plane blocks have been proposed as an alternative to epidural analgesia to avoid unwanted effects after thoracic and abdominal procedures (e.g., postural hypotension, motor weakness).

The proper choice of nerve blocks for specific procedures is essential for success. This chapter aims to provide guidance in decision-making for common clinical indications. Contraindications to PNBs are discussed in Table 7-1. Perioperative management protocols for patients having orthopedic surgical procedures are listed as an example for clinical context.

Upper Extremity Blocks

Regional anesthesia can be used as the main anesthesia and analgesia modality for many surgical procedures on the upper extremity because the brachial plexus innervates the entire upper extremity. The level (proximal-distal) at which the brachial plexus is blocked can be tailored to the specific surgeries from the cervical roots to the distal peripheral nerves. Table 7-2 lists common nerve block procedures and their indications.

Choosing a PNB technique for the upper extremity requires consideration of the intraoperative and perioperative needs germane to the surgical procedure. For example, the anatomical site of the planned surgical procedure, the need, and position of the tourniquet (arm or forearm) determines selection of the regional anesthesia technique with the optimal sensory-motor block. Likewise, for tendon repair or other functional restoration surgery where intraoperative functional monitoring is important, distal peripheral nerve blocks that are devoid of motor block can be very useful to monitor and ensure the desired functional outcome.

Hemidiaphragmatic paralysis is one of the most common, transient adverse effects of proximal brachial plexus techniques, such as interscalene or supraclavicular blocks. It causes a transient decline in respiratory function of approximately 20%, which is caused by the spread of local anesthetic under the cervical fascia and toward the phrenic nerve, and/or proximal spread of the LA towards C3-C5. Alternative approaches to proximal brachial plexus blocks should be selected in patients with severe pre existing respiratory dysfunction who could not tolerate such a decline in respiratory function.

Lower Extremity Blocks

Achieving complete anesthesia of the lower extremity with nerve blocks is more challenging than with the upper extremity. This is because the innervation for the lower extremity is provided by both lumbar and the sacral plexuses. Therefore, a combination of blocks is often required for complete anesthesia or analgesia. Table 7-3 lists common

TABLE 7-1 Contraindications to Peripheral Nerve Blocks

ABSOLUTE	RELATIVE
Patient refusal	Uncooperative or agitated patient
Documented allergy to multiple local anesthetics	Vague history of allergy to local anesthetic (typically dental procedure)
Nerve/plexus trauma or evolving neuropathy	History of neurologic deficits along the block distribution
Coagulopathy with deep blocks, especially blocks close to the neuraxis	Coagulopathy or use of anticoagulants for peripheral perivascular blocks
Infection at the site of injection	

TABLE 7-2 Common Upper Extremity Blocks and Their Indications

PERIPHERAL NERVE BLOCK	INDICATIONS	ADVANTAGES	DISADVANTAGES
Interscalene brachial plexus block	• Shoulder surgery • Frozen shoulder mobilization • Upper arm and humerus surgery	• Distal spread toward the supraclavicular nerves • May spare the lower trunk and partially preserve the mobility of the hand	• Hemidiaphragmatic paralysis due to spread toward the phrenic nerve • Complex plexus architecture carries a higher risk of transient neuropathies compared to more distal blocks • Spares the lower trunk, therefore not recommended for surgery at the elbow and below • Side effects: Horner syndrome, recurrent laryngeal nerve block
Supraclavicular brachial plexus block	• Shoulder surgery (if the upper trunk is blocked) • Surgery of the arm, forearm, and hand	• Anesthesia of the whole arm including the shoulder with a single block • Fast onset	• Hemidiaphragmatic paralysis due to rostral spread of the local anesthetic toward the phrenic nerve (volume-dependent) • Risk of pneumothorax and vascular puncture
Shoulder block (suprascapular nerve + axillary nerve block)	• Shoulder surgery • Frozen shoulder mobilization	• Phrenic nerve-sparing block • Effective analgesia to the anterior and posterior shoulder capsule	• Adequate US imaging may be challenging in obese patients • The pectoral, musculocutaneous, and subscapular nerves are not covered
Costoclavicular block	• Shoulder surgery (suprascapular block may be also needed) • Surgery of the arm (intercostobrachialis block may be needed) • Surgery of the forearm and hand	• Consistent block of the three cords of the brachial plexus • Phrenic nerve-sparing block	• Adequate US imaging may be challenging in obese patients • Requires a greater degree of expertise
Infraclavicular brachial plexus block	• Surgery of the arm distal to the axilla	• Convenient for catheter placement • Less incidence of phrenic nerve block • Less risk of pneumothorax than with supraclavicular approaches	• Adequate US imaging may be challenging in obese patients • Deep block • Requires a higher volume of LA to block the three cords of the brachial plexus • Intercostobrachial nerve block may be needed

TABLE 7-2 Common Upper Extremity Blocks and Their Indications (*Continued*)

PERIPHERAL NERVE BLOCK	INDICATIONS	ADVANTAGES	DISADVANTAGES
Axillary brachial plexus block	Surgery on the arm, elbow, or below	• Superficial block • Compressible area in case of anticoagulation • Suitable for bilateral blocks	• Requires abduction of the arm to access the axilla • Requires more than one injection • Higher infection risk
Median, ulnar, and radial nerve block (at the level of the elbow)	Forearm, hand, and wrist surgery	• Preserves the function of the elbow • Selective nerve blocks are possible • Superficial blocks • Requires less LA dose and volume in comparison with other brachial plexus blocks	• Separate blocks of each nerve required • Requires changes in arm positioning to block the radial, median, and ulnar nerves • For complete anesthesia of the forearm, additional cutaneous nerve blocks may be necessary • Not suitable if the procedure requires arm tourniquet
Wrist block (distal block of the median, ulnar, and radial nerves)	Hand surgery	• Motor sparing (wrist and partially that of the fingers) • Allows functional intraoperative monitoring • Superficial block • Low volume of LA • Fast onset	• Multiple needle insertions needed • Cutaneous infiltration is needed for incisions at the level of the wrist

Abbreviations: LA, local anesthetic; US, ultrasound.

lower extremity blocks and practical considerations for their selection.

Many surgical interventions involving the hip and knee joints are performed under neuraxial anesthesia, combined with nerve blocks for postoperative analgesia. This approach combines the best of the two worlds, where spinal anesthesia is associated with better outcomes compared to general anesthesia, whereas motor-sparing specific nerve blocks facilitate early mobilization and recovery. As an example, an ankle block has become a technique of choice in enhanced recovery after surgery (ERAS) protocols for ankle and foot surgery and is increasingly performed by blocking distal branches of the sciatic and saphenous nerves selectively. This provides complete and consistent surgical anesthesia and often prolonged postoperative analgesia.

Thoracic and Abdominal Wall Blocks

Ultrasound guidance increased the accuracy of thoracic and abdominal landmark-based techniques, such as intercostal and paravertebral blocks. The use of ultrasound allows objective and precise identification of fascial planes, which led to the development of a number of new, fascial plane analgesia techniques. As a result, the use of truncal blocks is growing in multimodal analgesia protocols, particularly in patients having thoracic and abdominal procedures (Table 7-4).

TABLE 7-3 Common Lower Extremity Blocks and Their Indications

PERIPHERAL NERVE BLOCK	INDICATIONS	ADVANTAGES	DISADVANTAGES
Lumbar plexus block	• Postoperative analgesia for hip or knee surgery • Combined with a proximal sciatic nerve block: surgical anesthesia for procedures on the hip, thigh, and knee	• Blocks all branches of the lumbar plexus innervating the anterior aspect of the hip, knee, and thigh • Can be combined easily with spinal anesthesia with patients in the lateral or sitting position	• Deep block, close to the neuraxis, and technically complex • Risk/benefit ratio must be carefully considered • Potential complications: epidural spread, vascular puncture, toxicity of LA, and peritoneal or renal puncture
Fascia iliaca block	• Analgesia for hip fractures and hip surgery • Analgesia for procedures on the anterior thigh	• Consistent block of femoral and lateral femoral cutaneous nerves • Superficial and technically easy to perform • Low risk for direct nerve injury	• Requires high volumes of LA • Results in motor block with quadriceps weakness
Hip pericapsular block	• Analgesia for primary hip replacement or hip fractures	• Targets sensory branches innervating the anterior capsule of the hip joint • Preserves hip and quadriceps function allowing early mobilization • Technically easy to perform, with no need to identify the nerves	• Quality and duration of analgesia inferior to that of fascia iliaca • Risk of intra-articular injection • More evidence is needed to define technical aspects of the block (minimum effective volume, injection site with respect to the psoas tendon, etc.) • Insufficient evidence of efficacy
Femoral nerve block	• Analgesia for hip fractures • Postoperative analgesia for hip or knee surgery • Surgical anesthesia for superficial procedures of the anterior thigh, quadriceps tendon, and patella • Analgesia for tourniquet pain on the thigh	• Superficial block • Consistent analgesia.	• Results in motor block with quadriceps paresis
Femoral triangle/adductor canal block	• Analgesia for knee surgery • Anesthesia and analgesia for procedures on the medial side of ankle/foot	• Reduces motor block associated with a femoral nerve block • Provides effective analgesia of the anteromedial side of the knee	• Risk of partial quadriceps weakness (volume- and spread-dependent)

TABLE 7-3 Common Lower Extremity Blocks and Their Indications (*Continued*)

PERIPHERAL NERVE BLOCK	INDICATIONS	ADVANTAGES	DISADVANTAGES
Genicular nerves block	• Analgesia for the knee	• Selective sensory block of the knee without motor block	• Incomplete analgesia • Requires multiple injections around the knee • Unpredictable spread • Insufficient evidence of efficacy
Posterior (transgluteal or subgluteal sciatic block)	• Surgical anesthesia for procedures on the posterior thigh and below the knee • Supplementary analgesia for procedures on the hip and knee	• Complete block of the sciatic nerve and the posterior cutaneous nerve of the thigh with the transgluteal approach • Unilateral anesthesia of the lower extremity in combination with a femoral nerve block	• Deep blocks; adequate US imaging may be challenging • Uncomfortable for patients • Requires lateral /prone position • Extensive motor block (knee, foot, and ankle) • Posterior cutaneous nerve of the thigh not blocked with the subgluteal approach
Anterior sciatic block	• Supplementary analgesia for procedures involving the posterior aspect of the knee • Anesthesia for procedures on the lower limb below the knee	• No need for lateral/prone position for block placement • Convenient to combine with femoral block	• Deep block; adequate US imaging may be challenging • Uncomfortable for patients
Popliteal sciatic nerve block	• Surgical anesthesia for procedures on the leg below the knee, foot, and ankle • Supplementary analgesia for procedures involving the posterior aspect of the knee	• Single injection • Complete anesthesia/analgesia below the knee in combination with the saphenous nerve block • Superficial block, technically easy to perform • Preserves the function of the knee compared to proximal sciatic blocks • Can be done in the supine, oblique, and prone positions	• Motor block below the knee (ankle and foot)
iPACK	• Analgesia for the posterior compartment of the knee	• Selective sensory block of the posterior knee without motor block	• Long needle trajectory • US imaging of popliteal vessels and the sciatic nerve can be difficult in obese patients
Ankle block	• Foot and toe surgery	• Superficial location of the nerves around the ankle • Preserves the function of the ankle allowing early ambulation without walking aids	• Multiple injections needed that can be uncomfortable for the patient

Abbreviations: LA, local anesthetic; US, ultrasound.

TABLE 7-4 Common Thoracic and Abdominal Wall Blocks and Their Indications

PERIPHERAL NERVE BLOCK	INDICATIONS	ADVANTAGES	DISADVANTAGES
Paravertebral block	• Analgesia for breast, thoracic, and upper abdominal surgery • Analgesia for rib fractures	• Complete unilateral block of the anterior and posterior divisions of the targeted spinal nerve(s) • Sympathetic chain block	• Deep block close to the neuraxis and pleura • Technically challenging • Risk for complications: pneumothorax, epidural spread, vascular puncture • Multiple level punctures may be required
Intercostal nerve block	Analgesia for breast, thoracic, and upper abdominal surgery	• Complete block of a segmental spinal nerve (anterior and lateral branches) • Landmarks are easy to find	• Requires multiple injections • Risk of pneumothorax • Risk of LA systemic toxicity with injections in multiple levels • Abdominal visceral pain is not covered
Pectoralis plane (Pecs) block	• Surgical anesthesia for small breast surgery and axillary lymph node dissection • Supplementary analgesia for breast surgery and surgery on the anterolateral thoracic wall	• Superficial fascial plane block, technically easy to perform • Can be performed in the supine position • Reduced risk of pneumothorax	• Does not include the anterior branch of the intercostal nerve • Unpredictable metameric extension of the block
Serratus plane block	• Supplementary analgesia for breast, thoracic, or cardiac surgery • Analgesia for rib fractures	• Superficial fascial plane block • Reduced risk of pneumothorax	• Does not block the anterior cutaneous branch of the intercostal nerve • Variable metameric extension of the block • Not adequate for posterior rib fractures
Erector spinae block	• Analgesia for rib fractures • Supplementary analgesia for thoracic and upper abdominal surgeries	• Paraspinal fascial plane block, technically easy to perform • Effective analgesia of the posterior thoracic wall	• Mechanism of action unclear • Insufficient evidence supporting efficacy for procedures on the anterolateral thoracoabdominal wall and lower extremities • Injection in multiple levels or a high volume of LA may be required
Transversus abdominis plane (TAP) block	• Supplementary analgesia for abdominal procedures	• Superficial plane block • Easy to perform in the supine position • The upper, middle, and lower abdominal wall can be specifically blocked with different approaches	• Variable metameric extension of the block • Multiple injections and a high volume of LA may be required depending on the areas of the abdominal wall to be blocked

TABLE 7-4 Common Thoracic and Abdominal Wall Blocks and Their Indications (*Continued*)

PERIPHERAL NERVE BLOCK	INDICATIONS	ADVANTAGES	DISADVANTAGES
Rectus sheath block	• Supplementary analgesia for midline or periumbilical abdominal incisions	• Superficial fascial plane block • Reliable block of the perforating anterior cutaneous branches of the thoracoabdominal nerves	• Variable metameric extent of the block • Requires bilateral injections for effective midline analgesia • Duration, extent, and quality of analgesia can vary • Risk of puncture of the epigastric vessels can lead to hematoma formation in the rectus sheath.
Quadratus lumborum block (QLB 1,2, TQLB)	• Analgesia for the antero-lateral abdominal wall and parietal peritoneum • Some variations of the block aim to provide analgesia for lower extremity procedures	• Block of the anterior rami of spinal nerves supplying the abdominal wall • Different approaches result in different analgesic patterns	• Variable metameric extent of the block • Duration, extent, and quality of analgesia can vary • Adequate ultrasound images are often challenging to obtain (most commonly with deep variations of the block, i.e., TQLB) • Risk of kidney, liver, and/or spleen injury

Rational and realistic selection of thoracoabdominal block techniques for specific surgical indications based on evidence or institutional experience is essential for clinically relevant analgesia. The site of the surgery is the most relevant consideration as it determines the area required for analgesia (posterior, lateral, or anterior wall) as well as the number of dermatomal levels that need to be covered by the analgesic intervention. Additional factors that should be considered include any presence and location of drains and dressings and the need for the patient positioning for the analgesic procedure. Bilateral multilevel blocks require attention with regard to the total dose of LA. The frequent publications of novel fascial plane injections and their numerous modifications require careful consideration, experience and scrutiny with regards to the efficacy, duration, and risk/benefit ratio of the different approaches. This is because the mechanism of action and realistic analgesic benefit of some new techniques have not been established.

Perioperative Management Protocols

Effective analgesia is best accomplished with perioperative management pathways, designed to provide standardized and, wherever available, evidence-based care. Protocols should consider patient and surgical factors as well as practical aspects such as departmental and hospital policies. Efficient communication among the multidisciplinary team members (i.e., surgeons, anesthesia practitioners nursing staff, physical therapy) is key to establish and evaluate the effectiveness of such pathways. The protocols for the common major orthopedic procedures outlined in this section are a few examples that are based on the current recommendations and accepted clinical practices in perioperative management (Figures 7-1 and 7-2).

Table 7-5 lists some common surgical procedures with the PNBs that are suitable for anesthesia and analgesia, as well as other common analgesic options.

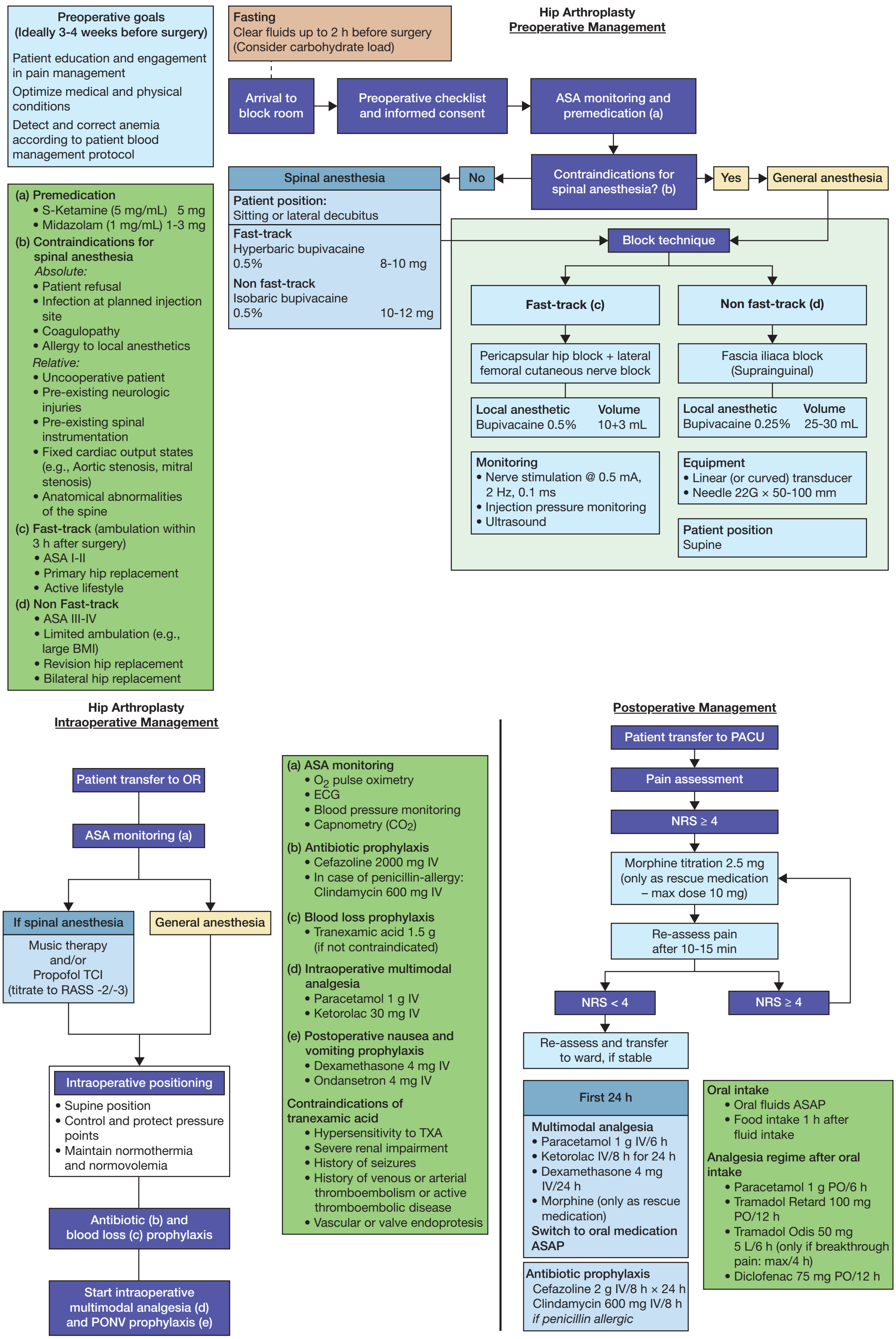

FIGURE 7-1. Perioperative protocol for hip arthroplasty used at NYSORA's practice.

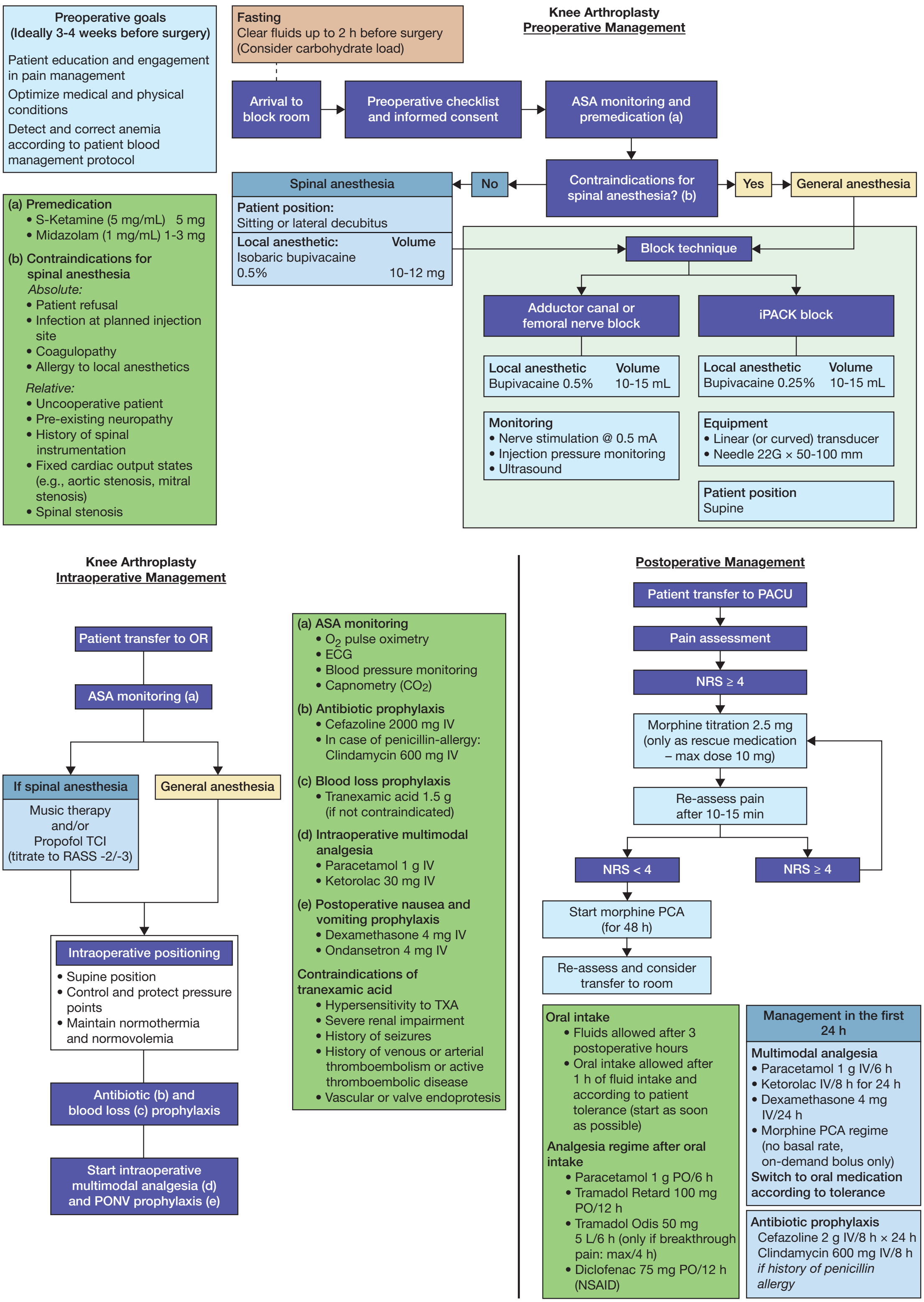

FIGURE 7-2. Perioperative protocol for knee arthroplasty used at Nysora's practice.

TABLE 7-5 Summary of Block Indications for Common Surgical Procedures

ANATOMICAL AREA	COMMON PROCEDURES	BLOCK TYPE
Shoulder	Total shoulder prosthesis Frozen shoulder mobilization Rotator cuff repair	• Interscalene block (single shot or catheter) • Supraclavicular block • Shoulder block • Costoclavicular block
Elbow	Fractures Tendon repair	• Supraclavicular block • Costoclavicular block • Infraclavicular block • Axillary block • +/– Cutaneous infiltration
Forearm	Fractures Protheses Osteotomies	• Supraclavicular block • Infraclavicular block • Costoclavicular block • Axillary block
Wrist **Hand**	Carpal tunnel Tendon repair Prostheses Fractures	• Supraclavicular block • Axillary block • Selective peripheral nerve block at the level of the elbow
Hand **Fingers**	Carpal tunnel Trigger finger	• Axillary block • Selective peripheral nerve blocks at the level of the forearm • +/– Local infiltration
Thorax	Mastectomy Thoracotomy Device implantation Rib fractures	• Paravertebral block • Intercostal block • PECS block • Serratus anterior block • Erector spinae block
Abdomen	Abdominal procedures Gynecological procedures	• Transversus abdominis plane (TAP) block • Quadratus lumborum (QLB) block • Rectus sheath block
Hip	Total hip Hip fracture Hip revision	• Fascia iliaca block • Pericapsular hip block • Lumbar plexus block
Knee	Total knee **Anterior cruciate ligament (ACL)**	• Femoral nerve block • Femoral triangle/adductor canal block • Genicular nerves block • iPACK
Ankle	Arthrodesis Arthroscopy Fractures Tendon repair	• Popliteal block (single shot or catheter) • +/– Saphenous nerve block
Forefoot **Toes**	Hallux valgus	• Popliteal block • +/– Saphenous nerve block • Ankle block

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8 Continuous Peripheral Nerve Blocks

Introduction

The analgesic efficacy of single-injection peripheral nerve blocks (PNBs) is limited to 8 to 24 hours. A longer duration of analgesia is often desirable, but the options are limited. For the interscalene brachial plexus block, liposome bupivacaine (Exparel) has been approved by the US Food and Drug Administration (FDA) as single-injection analgesia for up to 72 hours. As of April 2021, Exparel is now also approved in EU for interscalane and femoral nerve blocks as well. A longer duration of analgesia can also be accomplished with a continuous infusion of local anesthetic (LA) via a perineurally placed catheter. This method requires a high degree of skill and management, but the equipment is usually available worldwide. Continuous peripheral nerve blocks (CPNBs) are utilized for a wide variety of indications, most typically for anesthesia or analgesia in an increasing number of clinical indications, also as fascial sheath catheters (e.g., pectoralis, erector spinae infusions). The majority of reported applications of CPNBs relate to the treatment of perioperative pain. While there are reports on their new applications, many of the increasing numbers of proposed catheter infusions lack clear evidence-based information on their efficacy.

History and Background of Continuous Peripheral Nerve Blocks

The practice of continuous perineural analgesia has developed in parallel with technological advances over nearly 70 years' time. Methods for identification of the catheter target have included anatomic landmarks, paresthesias, electrical stimulation, fluoroscopy, and ultrasound (US). Continuous peripheral nerve blockade was described as early as 1946 by Ansbro. A series of patients having upper extremity surgeries received a cork-stabilized needle at the supraclavicular level of the brachial plexus. Other early reports include a similar practice in 1950 by Humphries. In 1951, Sarnoff et al. reported placement of a polyethylene tube advanced through an insulated needle placed adjacent to a peripheral nerve using electrical stimulation. By 1995, continuous perineural catheters were being inserted using multiple modalities. Pham-Dang et al. described fluoroscopy-guided catheter placement adjacent to the brachial plexus within the axilla. Guzeldemir reported using US to place an axillary brachial plexus catheter. By the late 1990s, ambulatory CPNBs gained popularity. Relatively small, light, and inexpensive portable infusion pumps permitted infusion of local anesthetics through the perineurally placed catheters in hospital and outpatient settings.

Equipment for continuous perineural infusion has evolved from a simple cork stabilizing a delivery needle, to a catheter sheath advanced over a needle stylet, to epidural-type catheters threaded through stimulating needles. Stimulating catheters were introduced in an attempt to improve the accuracy of the placement of the catheter tip, although this technology has been largely phased out with the wider use of ultrasound to document the catheter tip placement and local anesthetic spread.

Whatever the technique or method of insertion, catheters are always placed within a tissue space that contains the plexus or nerve(s) of interest (Figure 8-1). Patient selection

FIGURE 8-1. The general concept of catheter insertion: After successful needle placement into the tissue plane that contains the nerve, the catheter is inserted through the needle tip for infusion and/or boluses of local anesthetic.

for perineural catheters has also evolved from hospitalized patients only to perineural infusions on outpatient basis at patients' homes to facilitate earlier discharge from the hospital. Continuous techniques are nowadays used in a wide variety of patient populations, ranging from pediatric, pregnant, geriatric patients, to otherwise healthy ambulatory patients to critically ill.

Klein et al. at Duke University were among the first investigators to objectively quantify the benefits of LA infusion. In a randomized double-blind placebo-controlled study of patients having open shoulder surgery, an interscalene catheter was placed under electrical stimulation guidance and the patients received a postoperative infusion of either ropivacaine 0.2% or normal saline at 10 mL/h via a disposable elastomeric pump for up to 23 hours. Pain scores were lower in the ropivacaine infusion group, averaging 1 (of 10) compared with 3 for subjects receiving perineural saline. Their results suggested benefit conferred by continuous perineural infusion in the hospital postoperative setting. A report of a series of 70 outpatient catheter infusions by Rawal in 1998 sparked an interest in outpatient catheters. Data from multiple follow-up, randomized, controlled studies involving CPNBs in the outpatient setting subsequently affirmed their efficacy. Consequently, outpatient catheters became a common practice.

Patient Selection for Continuous Peripheral Nerve Blocks

Indications

Perineural catheters are typically indicated for management of acute perioperative pain of greater than 12 to 24 hours' duration that is expected to be difficult to control by traditional methods such as systemic analgesics. A perineural catheter may also be valuable in patients who do not tolerate other analgesic regimens. Frequently reported indications are in patients with vascular pathology and include sympathectomy/vasodilation after vascular accidents or embolism, digit replantation, limb salvage, and treatment of the Raynaud phenomenon. In the combat trauma setting, continuous perineural infusions have been described during transport to a treatment center. Continuous infusions have also been described for chronic painful conditions such as phantom limb pain, complex regional pain syndrome, cancer pain, preoperative pain control, and trigeminal neuralgia.

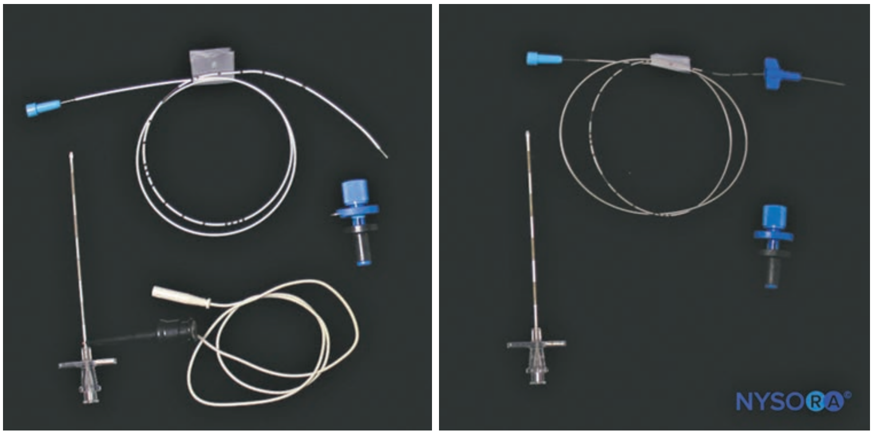
Contraindications

Contraindications to CPNB include infection at the catheter insertion site and allergy to LAs. Additional relative contraindications are coagulopathy, preexisting neuropathy, need for postoperative neurovascular examination, risk of falls, and inability to follow instructions for the infusion at home. Additional contraindications may be specific to the catheter location, for example, diaphragmatic paresis with interscalene and supraclavicular catheters.

Catheter Insertion and Management

Whatever the technique of insertion, catheters are always placed within a tissue space that contains the plexus or nerve(s) of interest (see Figure 8-1). US guidance facilitates catheter placement and, especially, confirmation of the catheter location in the therapeutic location by detecting the spread of the local anesthetic injection in the therapeutic space.

Several types of catheters are available for perineural use. Two main designs are stimulating and nonstimulating catheters (Figure 8-2). A stimulating catheter conducts an electrical current to its tip, for confirmation of its location when US



A B

FIGURE 8-2. Examples of two perineural catheter designs: (A) an insulated needle and stimulating catheter (StimuCath, Teleflex/Arrow, Reading, PA) and (B) an uninsulated needle and nonstimulating catheter (FlexBlock, Teleflex/Arrow, Reading, PA).

TABLE 8-1 Management Strategies and Local Anesthetics for Most Catheters

Management Strategies
1. Bolus 5-10 mL
2. Continuous infusion 5 mL/h
3. Patient-controlled bolus 5 mL/qh
Common Local Anesthetics
1. Bupivacaine 0.075-0.125%
2. Ropivacaine 0.1-0.2%

is not used or available. Nonstimulating catheters are typically advanced either "blindly" or under US monitoring.

The insertion of a perineural catheter under US guidance consists of five steps:

1. Placement of the needle in the perineural (therapeutic) space
2. Injection of LA to confirm the location of the needle tip and "open the space" for the catheter
3. Insertion of the catheter about 5 cm beyond the catheter tip
4. Injection of LA to confirm the therapeutic location of the catheter tip
5. Securing the catheter to prevent withdrawal

While it is important to insert the catheter deep enough to prevent its withdrawal, too deep insertion of a catheter may increase the risk of catheter knotting requiring surgical excision. Most reports of difficulties with catheter removal are reported with stimulating catheters. This is because the coiled wire tip may be prone to fibrin fixation to the tissues, resulting in adhesion. The risk of catheter knotting may be higher with insertion deeper than 5 cm beyond the needle tip.

Common catheter management strategies are outlined in Table 8-1. More recently, an automatic, pump-programmed bolus of LAs has been introduced. Such programmed injections are suggested to reduce the need for patient participation and the need to activate the bolus function. Essential to the understanding of the need for a bolus is the fact that the catheter location cannot be controlled and can change during the treatment. Therefore, the use of a bolus function is for the purpose of assuring that the LA reaches the target nerves through the tissue planes with a large volume even when the catheter is not in an ideal therapeutic position.

Benefits

Well-documented benefits from perineural catheters are mostly related to better analgesia and opioid sparing, which decreases opioid adverse effects. Studies have also documented earlier achievement of joint mobilization goals, higher patient satisfaction, and earlier discharge from the hospital. However, the use of the catheter should not exclude the concurrent multi-modal analgesia regimens. This is because many surgical sites such as the knee or hip are innervated by multiple nerves; thus even with a functional CPNB, multimodal analgesia is required.

The location of the catheter and surgical site will influence the degree of the analgesia and opioid-sparing benefit. Coverage of the entire surgical site within the sensory distribution of the target nerve typically provides the most complete analgesia. For this reason, shoulder (interscalene catheter) and foot procedures (popliteal sciatic catheter) are particularly amenable to regional anesthesia. Infraclavicular catheters have also been validated by randomized controlled trials. However, providing adequate analgesia at this location often requires a relatively high dose of LA, which may lead to an insensate arm or fingers.

Risks

When compared to single-injection blocks, continuous techniques appear to have a similar frequency of complications. Most of the side-effects and complications are relatively minor and include hematoma formation, infection, or neurologic injury. Also, catheters may be unintentionally inserted into the intravascular, epidural, intrathecal, or intraneural spaces. Although infectious complications are not common, catheter colonization is common and occurs in 29% to 58% of patients. Neurologic complications are a rare but serious complication of any regional technique. It is difficult to attribute the contribution of the surgical procedure, patient positioning, the single-injection block, or the catheter/infusion. The incidence of transient neurologic symptoms after a continuous technique has been reported from 0% to 1.4%. Long-lasting (greater than 6 weeks) neurologic symptoms have been reported at a rate of 0.2% in one large study of 3500 catheters.

Catheters may unintentionally dislodge, occlude, break, or be retained and difficult to remove. Catheter dislodgement from the therapeutic location is relatively common, and the most limiting factor to their clinical utility. The dislodgement is dependent on the insertion site (superficial location more common), insertion technique, and length of the indwelling catheter in the therapeutic space. A recent study in healthy volunteers reported that up to 25% of femoral catheters may dislodge from their original intended location. Troubleshooting of catheters with suspected dislodgement is explained in Figure 8-3.

Generally, catheter failure can be classified as: (1) primary failure where the catheter is not placed in the therapeutic position during the procedure, or (2) secondary failure where the properly placed catheter eventually dislodges and migrates from the therapeutic position.

Falls can occur, especially with CPNBs of the lower extremity, so prevention strategies are required. A pooled analysis of

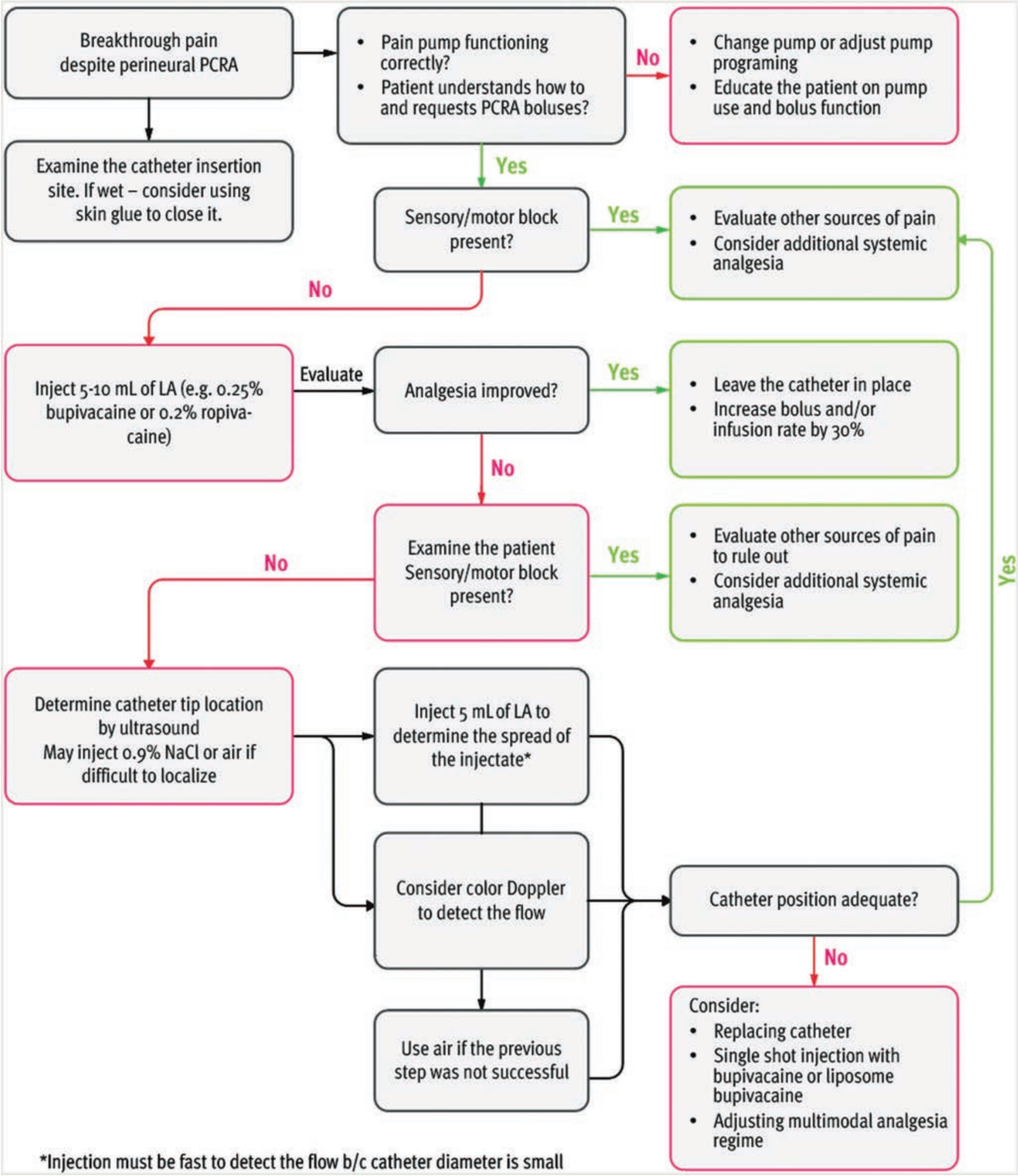


FIGURE 8-3. Management of a catheter with suspected dislodgement. LA, local anesthetic; PCRA, patient-controlled regional analgesia.

several studies suggests an increased association of falls with continuous femoral/psoas compartment blocks after knee or hip arthroplasty.

SUMMARY

A CPNB or perineural LA infusion is an effective and well established method to extend the effects of a single-injection technique by the placement of a perineural catheter and LA infusion. Accurate indications and careful patient selection and education are crucial for both inpatient and ambulatory cases. Different techniques are used for accurate catheter tip placement. Multiple patient benefits have been documented by randomized controlled trials, most of which result from improving analgesia and opioid-sparing effects. The adverse effects are minor and easily remedied, whereas serious complications are rarely reported.

It is likely that the use of the catheters in the future will be increasingly be replaced by delayed-release local anesthetics that provide extended analgesia with a single injection and without the need for catheters, pumps, patient management, and additional expertise required for insertion of the catheters.

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9 Local Anesthetic Systemic Toxicity and Allergy to Local Anesthetics

Introduction

Local anesthetic systemic toxicity (LAST) and allergy to local anesthetics (LAs) are potentially life-threatening complications of regional anesthesia.

The most common causes of LAST are the administration of an excessive dose of LAs, accidental intravascular injections, and the rapid absorption from tissue injection sites. Fortunately, incidence of LAST has decreased in recent years. This can be attributed to the use of ultrasound (US) to monitor the administration of nerve blocks, lower doses of LAs with ultrasound-guided regional anesthesia, and the implementation of safety checklists. It is estimated that approximately 1.8/1000 of the patients receiving a peripheral nerve block (PNB) may develop LAST. However, in one report, no severe cardiac toxicity was reported in 12,666 patients who received an ultrasound-guided PNB.

Allergy to LAs is uncommon. Most symptoms after LA injection are misintrepreted as an allergic reaction. Sympathetic stimulation, vasovagal syncope, or even LAST may be confused for an allergic reaction. True allergy occurs in less than 1% of all LA adverse reactions and is an immune-mediated response triggered by the LA molecule and/or its preservative compounds (metabisulphite or methylparaben). Both allergic and nonallergic adverse reactions require appropriate treatment.

This chapter will focus on the prevention, mechanisms, and treatment of LAST and allergy to LAs. The chapter includes also a practical algorithm for the evaluation and management of patients with suspected allergy to LAs.

Mechanisms of LAST

LAs are generally safe and effective in therapeutic doses for tissue infiltration, fascial planes, or near a nerve/plexus of nerves. However, supratherapeutic plasma levels of LAs can result in LAST. High plasma concentration of LAs can be the result of accidental venous/arterial puncture, intravascular injection, or rapid vascular absorption from the injection site. Plasma levels of LAs are proportional to the rate of systemic absorption from the site of therapy. The rate of absorption varies among tissues, and it is often determined by the size of the absorptive surface and vascularization of the tissue planes where the injection is made. Clearly, higher doses of LA will yield higher plasma levels of LAs, independent of where the injection takes place.

LAs exert their inhibitory action on nerve conduction by inhibiting the movement of ions through voltage-gated ionotropic channels at the level of the cell membrane (refer to Chapter 2). The primary therapeutic target of LAs is the voltage-gated sodium channel where inhibition alters the transmission of sensory and motor signals in axons. In addition to the voltage-gated sodium channel, LAs also inhibit voltage-gated Ca^{2+} channels, K^{+} channels, the Na-K ATPase, and other channels and enzymes. This inhibition occurs from the intracellular side and requires LAs to cross the lipid bilayer first as unbound, non-ionized free molecules. At lower concentrations, LAs block protein kinase signaling induced by tumor necrosis factor α. At higher concentrations, LAs can inhibit other channels, enzymes, and receptors, including the carnitine-acylcarnitine translocase in the mitochondria.

Cardiovascular toxicity is likely caused by the combination of electrophysiologic and contractile dysfunction. Bupivacaine is lipophilic and has a greater affinity for the voltage-gated sodium channels, resulting in its uniquely high cardiotoxic profile. With bupivacaine, toxicity can occur at lower serum concentrations because it can accumulate in the mitochondria and cardiac tissue at a ratio of about 6:1 (or greater) relative to plasma.

Special Populations and the Risk of Local Anesthetic Systemic Toxicity

In this section, we discuss the populations at higher risk of LAST, underlying pathophysiology, and suggested dosing modifications.

Newborns

LA molecules unbound to plasma proteins diffuse freely through membranes and are responsible for the toxic effect of LAs. Therefore, low plasma protein level states (i.e., malnutrition, or patients with lower levels of alpha-1-acid glycoprotein such as infants) are at higher risk for LAST. The elimination half-life of amide LAs in neonates is prolonged by two- to three-fold. Compared to adults, newborns may not completely metabolize some LAs and have a higher unchanged drug excretion in urine.

For example, in premature neonates, 43% of mepivacaine is excreted unchanged in the urine, compared to 3.5% in adults. Lidocaine also has a prolonged elimination half-life in neonates; 20% of lidocaine is excreted unchanged in the urine (4% in adults). This is due to the immature hepatic enzyme system unable to fully metabolize mepivacaine and lidocaine in the newborn. A dose reduction of 15% in infants below 4 months of age receiving large doses of LAs is therefore recommended.

Elderly Patients

Aging is associated with many physiological changes in tissues and organ systems, affecting the metabolism and pharmacokinetic profile of LAs. Neuronal sensitivity is increased, resulting from an age-dependent decline in neuron population within the spinal cord and a slower conduction velocity in the peripheral nerves.

Elderly patients have a higher proportion of body fat with decreases in total body water, muscle, and lean body mass. As a result, lipophilic drugs have a higher volume of distribution (Vd). The implications of these changes in body composition are extensive re distribution and a longer elimination half-life of lipophilic drugs. A greater pharmacological effect, especially after repeated or continuous dosing, is expected. These changes in patients with advanced age make them prone to unexpectedly higher peak drug concentrations following rapid bolus injections or infusions.

Elderly patients may also have low albumin concentrations and suboptimal nutritional states. Alpha 1-acid glycoprotein (α1-AG) is the most important plasma protein involved with the binding of circulating weak bases such as LAs. In contrast, acidic drugs more likely bind to albumin in serum; however, albumin has a greater binding capacity than α-1AG. At lower LA plasma concentrations, α1-AG is the main binding protein, whereas albumin plays the major binding role at high concentrations, such as would be with cardiovascular system (CVS) toxicity. Therefore, hypoalbuminemia in the elderly reduces the plasma binding capacity of highly protein-bound LAs such as bupivacaine. Unlike albumin, α1-AG concentration is normally not affected by advanced age. In addition, a decline in glomerular filtration rate (GFR) and renal function with age is an important factor in pharmacokinetics. As a consequence, metabolites that are primarily eliminated via the renal system have a longer half-life and reach higher peak levels.

A reduction of hepatic blood flow and a steady decline in liver weight and enzyme activity are also common in the elderly. Age-related effects on phase I reactions reduce the metabolic rate of many drugs, such as amide LAs, that depend on the liver for elimination. The aforementioned changes warrant a reduction in 10% to 20% of LA doses in the elderly.

Renal Disease

LAs and their metabolites are excreted primarily by the kidneys. A decline in renal function may alter LA pharmacokinetic profile. Although renal excretion of lidocaine is a minor part of its elimination, renal failure also indirectly influences LA disposition kinetics. Ropivacaine and its metabolites, 3-hydroxyropivacaine and pipecoloxylidide, are mainly excreted in urine, leading to reduced plasmatic clearance of ropivacaine. Enhanced LA absorption and increased binding to serum α1-AG along with reduced urinary excretion of the metabolites also increase total plasma concentrations in patients with renal failure. Patients who are also uremic with metabolic acidosis may have higher free lidocaine and bupivacaine plasma concentrations.

Liver Disease

Hepatic dysfunction decreases the clearance of aminoamide LAs. After intravenous (IV) administration, ropivacaine has been found to have a 60% lower clearance in liver transplantation candidates. Interestingly, these patients may have lower peak plasma concentrations of LAs than their healthy counterparts due to an increased Vd. Hepatic insufficiency does not appear to affect the peak ropivacaine plasma concentration after single-shot regional anesthesia techniques. Therefore, a reduction in LA doses for single-shot techniques does not appear to be necessary. However, steady-state plasma ropivacaine concentrations are more than doubled in end-stage liver disease, and the half-life is significantly prolonged (up to four times that of healthy subjects). Despite larger volumes of distribution for lidocaine, mean plasma clearance has been found to be reduced and slower phase half-life appears longer in advanced alcoholic liver disease patients. Caution should be exerted when using intermittent bolus/infusions of LAs for continuous regional anesthesia in end-stage liver disease. A reduction of up to 10% to 50% is recommended to decrease the accumulation of LAs and its metabolites in the blood.

Heart Failure

Patients with heart failure are at increased risk for LAST due to reduced hepatic perfusion, reduced clearance, and elevated LA tissue concentrations due to the slower circulation time. Not surprisingly, higher LA plasma levels, reduced Vd, and reduction in plasma clearance of IV lidocaine has been reported. Hepatic dysfunction due to passive congestion/increased central venous pressure is common in patients with right-sided heart failure; congestive hepatomegaly may further impair liver function. Moreover, decreased albumin synthesis and hypoalbuminemia increase the free fraction of LAs in plasma. Patients with heart failure have a higher risk of LA-toxicity-related arrhythmias partly as a result of action potential prolongation along with altered calcium and potassium channel function. The choice of less-cardiotoxic LAs where possible is recommended. The dosages used for repeated doses or continuous infusion of LAs should be reduced by 10% to 20%.

Pregnancy

Physiological changes during pregnancy account for an increased risk of LAST. Pregnancy is associated with hormonally mediated increased sensitivity of Na^+ channels to LA blockade. Increased cardiac output in pregnancy can alter systemic uptake of LAs from the injection sites. Epidural venous plexus engorgement may increase the risk of an intravascular needle or catheter placement. Vascular puncture occurs in as many as 15% of epidural anesthetics in parturients. Pregnancy-related decreases in protein binding corresponding to decreases in α-1-glycoprotein and albumin increase the free fraction of LAs progressively throughout gestation and may further increase the sensitivity of LAs in the parturient, especially in the third trimester. Increased levels of beta-estradiol and progesterone increase the risk of cardiotoxicity of LAs through alterations in the rate of depolarization. Increased susceptibility to LAST due to the aforementioned changes during pregnancy warrants a risk-benefit evaluation and dose reduction for high volume blocks.

Symptoms and Diagnosis

To effectively diagnose and treat an event of LA toxicity, it is important to maintain a high degree of suspicion during the performance of any procedure that involves the use of LAs. Likewise, noninvasive blood pressure, electrocardiography, and pulse oximetry should be used to monitor all patients during and after completing any regional anesthetic procedure. An episode of LAST can occur immediately at the time of injection (accidental intravascular injection) or up to an hour after it (due to delayed tissue absorption). When large volumes or toxic doses of LAs have been used, monitoring must be continued for at least 30 to 45 minutes after the injection. Additionally, in patients who present any signs of LAST, prolonged monitoring (2-6 hours) is recommended because cardiovascular depression due to LAs can persist or recur after treatment.

Another fundamental recommendation for the diagnosis of LAST is to maintain frequent communication with the patient for early detection of toxicity symptoms (perioral paresthesia, metallic taste, tinnitus, or altered mental status). The central nervous system (CNS) is more sensitive to LA toxicity than the CVS . Consequently, the CNS symptoms typically precede the CVS symptoms. LAs affect the balance between inhibitory and excitatory pathways in the CNS, leading to variable neurological signs/symptoms. Rapid blockade of the voltage-gated sodium channels of inhibitory cortical neurons in the CNS occurs first and accounts for the excitatory manifestations initially characterizing LAST. Neurological symptoms include seizures (68%), agitation (11%), or loss of consciousness (7%). Many patients report prodromal symptoms such as perioral paresthesia, metallic taste, and tinnitus. As plasma levels increase, excitatory cortical neuron blockade occurs, leading to overall CNS depression that can progress to coma and respiratory arrest. It is important to understand that the aforementioned symptoms can be present in any combination and can progress very rapidly. Almost 40% of LAST cases present as a sudden, rapid-onset seizure, progressing to cardiac arrest. With large LA doses or direct intravascular injection, the CNS symptoms may be absent and the first manifestation could be CVS toxicity (11%).

CVS toxicity during LAST is characterized by cardiac conduction anomalies, cardiac contractility impairment, and a reduction in systemic vascular resistance. Early-onset electrocardiographic alterations include PR and QTc prolongation. Alterations in QRS (bundle branch blocks) and ST intervals can also be observed, with/without refractory brady/tachyarrhythmias. Depression of spontaneous pacemaker activity can rapidly lead to high-degree AV blocks or even asystole. Cardiogenic shock and refractory hypotension may ensue as a result of cardiac contractility impairment and vasomotor control disturbances, caused by peripheral vascular ion-channel alterations. Early cardiovascular toxicity at low concentrations may increase systemic vascular resistance and hypertension, although with higher concentrations a significant decrease in systemic vascular resistance is predominant.

Prevention

Prevention is the most important aspect and should include the systematic implementation of a checklist for each regional anesthesia procedure. At NYSORA we use the mnemonic RAPT as the checklist for safety during the block procedure: **R**esponse (motor), **A**spiration, **P**ressure (low), and **T**otal LA volume injected. These steps, when combined, may increase the safety of nerve block techniques. Additionally, it is important to be mindful of the high-risk population for LAST.

Limiting Intravascular Injection and Systemic Uptake

Current recommendations to reduce the risk of LAST are summarized in Table 9-1. US guidance during PNBs has significantly decreased the risk of LAST by monitoring the deposition of the LA and allowing a reduction in the volume of LA used. In addition, US is used to identify and avoid vascular structures during block performance.

Epinephrine is used as a marker for intravascular injection and to reduce peak plasma levels of LAs. An IV injection of 10 to 15 μg epinephrine produces detectable changes in heart rate and blood pressure. An increase in heart rate greater than 10 beats per minute is suggestive for intravascular injection which should prompt the clinician to halt the injection. Using epinephrine in LA solutions can be particularly useful with fascial plane blocks that require larger volumes and doses of LAs (i.e., pectoralis or transversus abdominis plane blocks).

TABLE 9-1 Recommendations for Decreasing the Risk of LAST

Use ultrasound guidance for regional anesthesia procedures where the equipment is available.	The injection should be paused when the spread of the local anesthetic is not detected on ultrasound, as it may indicate an intravascular injection.
Use the lowest effective dose of local anesthetics.	
When performing large volume blocks (e.g., truncal blocks), lower the concentrations of local anesthetics and calculate the dose based on the lean body weight.	
Inject local anesthetic incrementally and use NYSORA's mnemonic RAPT to prompt attention to aspiration and total local anesthetic volume injected.	Administer local anesthetic in 3-5 mL aliquots, pausing 15-30 seconds between each injection to re-ensure RAPT checklist: • Motor **R**esponse absent • **A**spiration negative for blood • Opening injection **P**ressure <15 psi • Be aware of the **T**otal volume needed
Consider using epinephrine-containing local anesthetic mixtures (i.e., if large volumes of local anesthetics will be used).	Intravascular injection of epinephrine 10-15 μg/mL in adults produces an increase in heart rate (≥10 beat/min) or increase in systolic blood pressure (≥15 mm Hg). Note: Assumes the absence of β-blockade, active labor, advanced age, or general/neuraxial anesthesia.
Be extra cautious (conservative) with the local anesthetic dose in patients with high risk of LAST (e.g., elderly, ill, lean body mass).	
Be aware of the additive nature of local anesthetic toxicity when redosing.	
Include local anesthetic dosing parameters as part of the pre-incisional surgical pause.	

Management

As with most crisis scenarios in perioperative medicine, airway management and oxygenation are paramount in the management of LAST (Figure 9-1). Oxygen administration should be started early because hypoxia potentiates LA toxicity. Likewise, to ensure oxygenation and prevent respiratory acidosis, airway management is crucial. Seizures should be rapidly controlled with the administration of a first-line agent such as a benzodiazepine. A small dose of propofol, titrated to avoid hypotension, is also acceptable. Muscle relaxants may be used for intubation and to stop the muscle contractions of the convulsions. Convulsions cause metabolic acidosis and hypoxemia and increase LA toxicity.

Block of inotropic and cardiac conduction ion channels by LAs can result in cardiovascular collapse, which should be addressed promptly after securing oxygenation and ventilation. The impending cardiovascular collapse can initially manifest as worsening tachycardia, bradycardia, or new heart block. If the progression continues to cardiac arrest, cardiopulmonary resuscitation (CPR) with chest compressions should immediately start, because the reduction of toxic tissue concentrations of LAs in the brain and heart is dependent on cerebral and coronary blood flow. Maintaining cardiac output by CPR is also important for lipid emulsion therapy to reach the brain and heart.

Early treatment of LAST with an intravascular infusion of a 20% lipid emulsion is suggested to reduce peak levels of LAs and decrease the chance of progression to cardiovascular collapse. Lipid emulsion therapy should be started at the very first sign of arrhythmia, prolonged seizures, or rapid clinical deterioration. The doses and administration of the lipid emulsion therapy are described in the LAST management algorithm shown in Figure 9-1.

LAST-Specific Cardiopulmonary Resuscitation

LAST is a medical emergency that must be managed somewhat differently from conventional CPR because toxic cardiomyopathy is pathophysiologically different from other causes of cardiovascular system collapse. During LAST-specific CPR, the initial priority is immediate airway management to prevent hypoxia and respiratory and metabolic acidosis, which potentiate and increase toxicity. Secondly, taking into account that potentiation mechanisms are related to an increased free fraction of LAs and/or

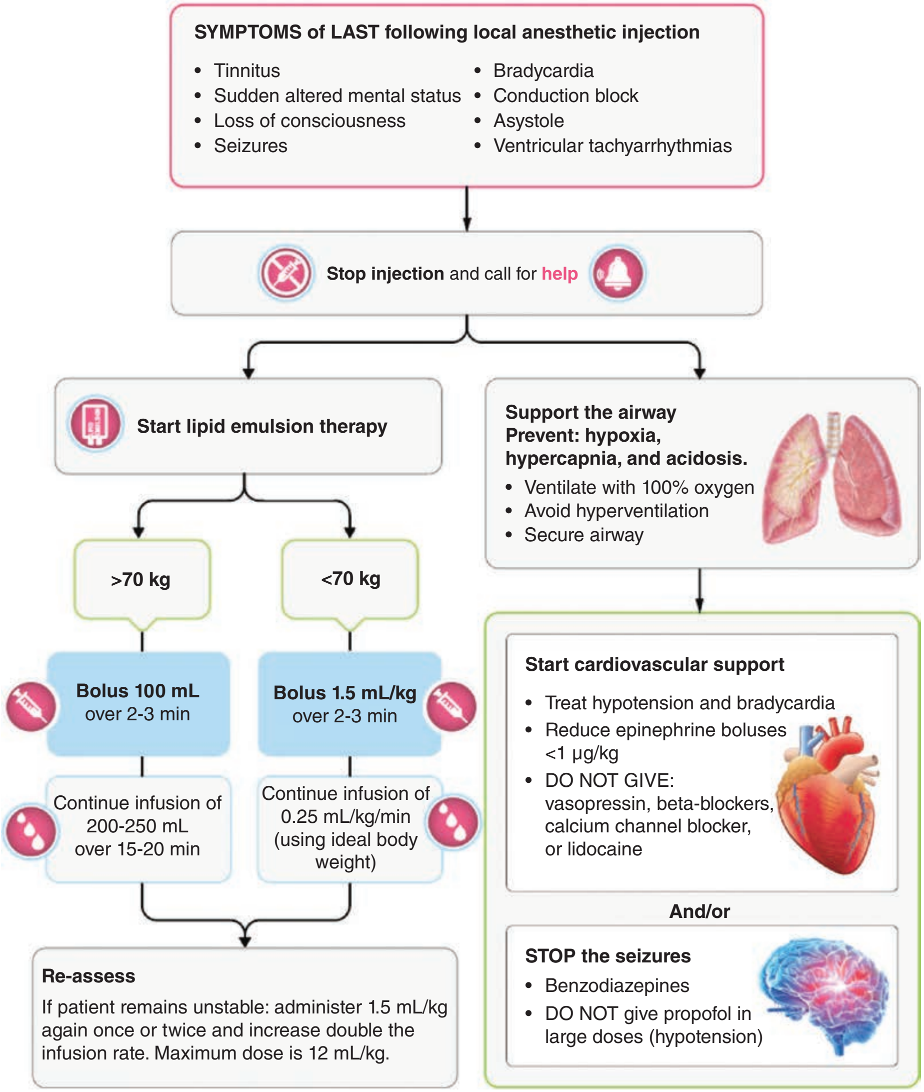


FIGURE 9-1. Algorithm for the management of local anesthetic systemic toxicity.

worsening of the cardiac function, successful treatment seeks to effectively moderate or reverse the mechanisms underlying the LA toxicity. This means reducing the free LA concentration below a threshold that corresponds to ion channel blocking concentrations. The importance of effective CPR in this setting is then to ensure that coronary perfusion is sufficient to reduce LA tissue levels and ensure the maximum benefit of lipid infusion.

When indicated, epinephrine may be used but in smaller doses (≤1 μg/kg) than in a generic CPR to avoid impaired pulmonary gas exchange and increased afterload. Also, lidocaine should be avoided as antiarrhythmic therapy in LAST. Instead, amiodarone is the first choice for ventricular fibrillation/pulseless ventricular tachycardia that is unresponsive to CPR, defibrillation, and vasopressor therapy. Procainamide is not recommended for the treatment of stable, wide-QRS tachycardia. Vasopressin is not recommended for use as it has been associated with adverse outcomes and pulmonary hemorrhage in animal models. Likewise, calcium channel blockers and beta-blockers should also be avoided.

LAST may require prolonged CPR because LAST is a reversible cause of cardiac arrest when proper management is followed. Depending on availability, venoarterial extracorporeal membrane oxygenation during cardiac arrest (including extracorporeal membrane oxygenation and cardiopulmonary bypass) may be indicated in cases of refractory cardiac arrest to decrease the levels of LAs through redistribution, metabolism, and elimination.

Lipid Therapy: Mechanism

Intravascular lipid infusion may work through scavenging and non scavenging effects. Scavenging effects occur after the initial IV administration of a large lipid emulsion therapy bolus, which creates a lipid-soluble compartment in the blood. This compartment provides a medium for the redistribution of lipophilic LAs from the sensitive-to-toxicity organs, such as the brain, heart, and kidney, to organs that serve as storage and metabolizers (i.e., muscle, adipose tissue, liver). This mechanism has been considered by some authors as a dynamic or “shuttle” effect (lipid sink).

The non scavenging effects relate to the direct hemodynamic effects of lipid infusion therapy through actions on the vasculature and heart. For example, lipid emulsion and elevated free fatty acids increase blood pressure by vasoconstriction of the smooth muscle of the peripheral vasculature. Additionally, there is an important volume effect (dilution and preload), direct cardiovascular benefits, and activation of cardioprotective pathways.

Allergy to Local Anesthetics

Mechanisms

Less than 1% of all adverse reactions where LAs are administered can actually be attributed to allergy to LAs. Epinephrine-driven sympathetic effects, LAST, vasovagal syncope, and psychogenic reactions are frequently confused with an allergic reaction by patients and healthcare practitioners.

True allergic reactions to LAs are most commonly the type I and type IV responses. A type I allergic reaction is a generalized hypersensitivity reaction where the first exposure to the LA (allergenic agent) causes immunoglobulin E (lgE) antibody production from B cells and no allergic symptoms occur (the sensitizing dose). The IgE antibodies then bind to basophils and mast cells, and when the allergenic agent is administered for the second time, the binding of the allergenic agent to the IgE complex will immediately result in degranulation of vasoactive substances from basophils and mast cells.

Type IV reactions are the most common type of allergic reaction mediated by LAs. This involves cellular immunity where T cells are sensitized to the LAs during the first exposure, and no antibodies are produced. The second exposure to the LAs will make the T-lymphocytes release lymphokines that induce inflammatory reactions and activate macrophages to release inflammatory mediators. This process will result in contact dermatitis.

As described in Chapter 2, LAs can be classified, based on their chemical structure, as esters or amides. The p-aminobenzoic acid (PABA), a metabolite formed during the degradation process of ester LAs in plasma, has strong allergenic properties, and, therefore, esters (i.e., chloroprocaine and tetracaine) are more likely to cause allergic reactions than amides. However, preservative compounds such as methylparaben used in amides and esters, have structural similarities to para-aminobenzoic acid and can elicit allergic reactions. Sulfites, stabilizing agents used in the presence of vasoconstricting additives, can also trigger hypersensitivity reactions. When an allergic reaction to LAs is detected, it is important to test for cross-reactivity with the other type of LAs (ester or amide). True cross-reactivity between esters and amides does not exist and is therefore related to preservative compounds or stabilizing agents.

Symptoms and Diagnosis

As previously mentioned, the clinical presentation of an allergy to LAs can vary depending on the type of allergic reaction that develops (type I or type IV). Likewise, the severity of the symptomatology can be classified into different grades (from I-IV) or according to their onset time, which will further guide management (Table 9-2).

Type I allergic reactions can occur with generalized urticaria and/or anaphylactic symptoms that will appear within seconds to 1 hour after the administration of the LA. Symptoms can be divided into various grades (I to IV) depending on the severity of the presentation, which may include pruritus, urticaria, bronchospasm, wheezing, angioedema, rhinitis, hypotension, and cardiovascular collapse due to distributive shock. Type IV reactions manifest as allergic contact dermatitis that will present as local swelling at the site of administration 24 to 72 hours after injection. The affected area that was in direct contact with the LA may develop an eczematous and pruritic rash with blistering, swelling, and peeling of the skin.

Allergic reactions to other eliciting allergens used during the procedure (e.g., latex, antibiotics, nonsteroidal anti-inflammatory drugs, povidone, or chlorhexidine) also need to be considered. Symptoms related to epinephrine-driven sympathetic effects, LAST, vasovagal syncope, or psychogenic reactions may mimic symptoms of allergic reactions, which can make the diagnosis difficult. The next paragraph will focus on these misleading symptoms for diagnostic purposes.

TABLE 9-2 Clinical Presentation of an Allergy to Local Anesthetics

By Symptoms (Four Degrees of Severity):	
Grade I	Mucocutaneous symptoms: erythema, urticaria, angioedema
Grade II	Non-life-threatening symptoms: mucocutaneous symptoms ± hypotension, tachycardia ± mild bronchospasm
Grade III	Life-threatening symptoms: mucocutaneous symptoms (laryngeal edema) ± cardiovascular collapse ± bronchospasm
Grade IV	Cardiac/respiratory arrest
By Time:	
Acute/rapid onset (immune reaction type I)	• Urticaria • Anaphylaxis (urticaria, angioedema, bronchospasm, hypotension) →Affected tissues are NOT contiguous with LA injection site.
Delayed (immune reaction type IV)	• Contact dermatitis • Swelling →At site of LA injection.

Symptoms and diagnosis of LAST are extensively discussed earlier in this chapter. LAST symptoms usually present as a result of interactions with the CNS (perioral paresthesia, metallic taste, tinnitus, or altered mental status) and the cardiovascular system (hypotension, arrhythmias). More severe presentations of LAST are seizures, depression of the CNS, respiratory arrest, and cardiovascular collapse. Epinephrine is frequently added to the LA to extend the duration of the block and is the most common cause of nonallergic symptoms such as tachycardia, hypertension, and palpitations when injected intravascularly. Stressed patients can also release endogenic epinephrine with similar outcomes. Psychogenic reactions are anxiety driven and can involve catecholamine release and hyperventilation (dyspnea, tachypnea, paresthesia of the digits or mouth, dizziness, palpitations, tachycardia, and nausea). Vasovagal syncopes can be elicited by pain, unpleasant experiences, or anxiety. They will happen as a result of sympathetic imbalance (bradycardia, hypotension, nausea, sweating, or loss of consciousness).

A correct anamnesis is essential for the correct diagnosis of an allergy or for deciding on further diagnostic testing (Figure 9-2). Positive anamnesis for allergic reactions implies the need for further testing procedures. Initially, skin prick testing and intradermal testing will be performed. Positive skin tests should be interpreted as possible allergy, however, false-positive results are likely for intradermal tests and therefore some practitioners will prefer to immediately perform subcutaneous challenge tests. A negative skin test always needs further subcutaneous challenge tests with incremental concentrations of LA. Wheal and flare, acute rash, wheezing, decreased blood pressure, and/or decrease in pulmonary function within 20 minutes after administration are considered positive for challenge tests. For positive testing, other LAs should be evaluated in search of safe alternatives for future procedures to be performed under regional anesthesia. If the LA contains preservative compounds and the test is positive, a compound-free solution should be included to trace if the reaction is caused by the LA itself or by the preservative compounds.

For diagnosing psychogenic reactions, clinicians may perform a reverse challenge test. Here, the clinician explicitly tells the patient that he or she is injecting a placebo while actually injecting the LA; if no symptoms are present, the adverse effects can be psychogenic in origin.

Epicutaneous or patch tests are used to determine the presence of LA-related contact dermatitis or type IV reactions. Different substances are applied to the skin for 48 hours to determine which substances cause allergic reactions.

Management

Because it is difficult to determine the exact cause of the symptoms at the time of presentation (i.e., differentiate between LAST, vasovagal syncope, or allergic reactions), treatment should be primarily supportive (Figure 9-3). It should be kept in mind that type I allergic reactions are the most severe and that timely administration of epinephrine is crucial. Epinephrine doses can be guided according to the severity of

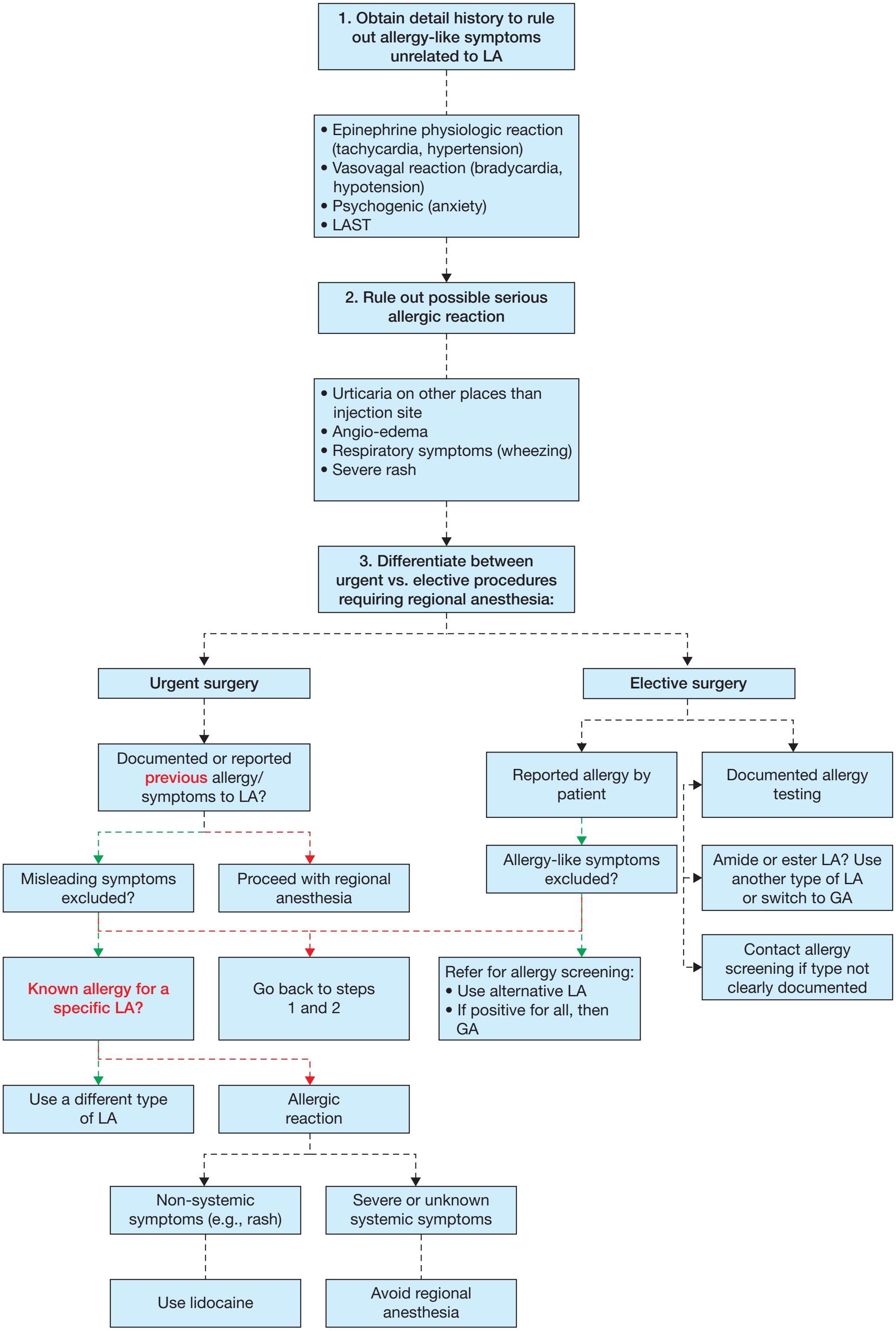
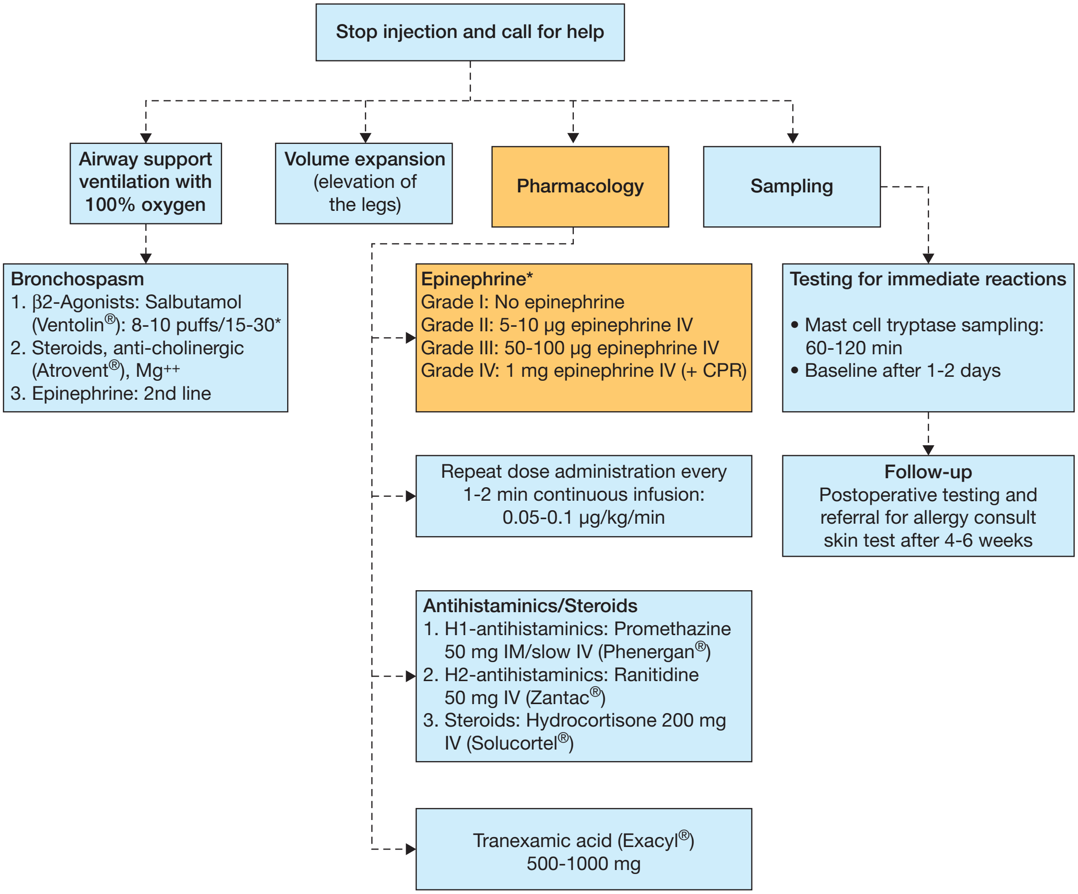


FIGURE 9-2. Evaluation of the patient with history of allergy to local anesthetics.



*Degrees of severity are described in Table 9-2.

FIGURE 9-3. Management of an allergic reaction to local anesthetics.

the symptoms (grades I-IV). Other pharmacologic treatments are described in the literature but should not be considered in the acute phase.

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10 Neurologic Complications of Peripheral Nerve Blocks

Introduction

Nerve injury is a potentially serious complication of peripheral nerve (PN) blocks, which can lead to permanent disability. Fortunately, many neurologic deficits are reversible. This chapter will outline mechanisms, clinical course, and treatment of patients with neurologic injury after nerve blocks.

Classification and Mechanisms of Injury

Perhaps the most practical classification of neurologic injury is that of Seddon. The classification proposes three types of PN injury, ranging from mild to severe (Figure 10-1).

- **Neuropraxia**: The mildest of the three types, it consists of damage to the myelin sheath. A common clinical example is transient nerve dysfunction that may occur after nerve stretching or its compression. With this injury, axons and supporting connective tissue of importance to the nerve function (i.e., endoneurium, perineurium, and epineurium) remain intact. The prognosis is favorable, with complete recovery of nerve function in a few weeks to months.
- **Axonotmesis**: Axonal injury associated with fascicular disruption, crush, or toxic injury. Damage to the endoneurium and perineurium occurs. Recovery may be prolonged and incomplete, depending on the extent (partial or complete) of perineurium disruption.
- **Neurotmesis**: The complete transection of the nerve. These injuries typically require surgical intervention and the prognosis is poorer.

Most nerve injuries are mixed, with different fascicles exhibiting different degrees of injuries. Often all three different degrees of injury will be present in different fascicles.

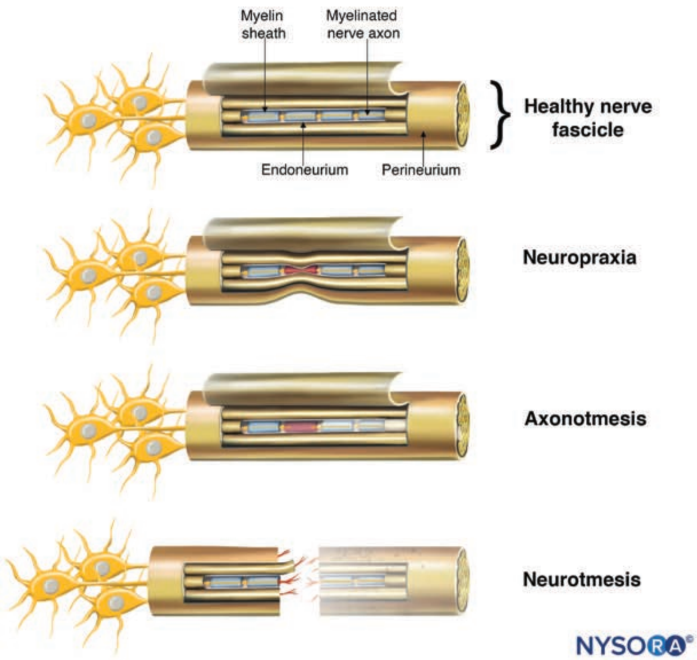

FIGURE 10-1. Seddon's classification of nerve injury.

The mechanisms of PN block-related injury fall into one of four broad categories:

- **Mechanical or traumatic injury**: Includes compression, stretching, laceration, or injection injury. The leading cause of block-related nerve injury is an injection into a fascicle, causing a direct needle and injection trauma, rupture of the perineurium, and loss of the protective environment within the fascicle with consequent myelin and axonal degeneration.
- **Vascular injury**: Damage to the nerve vasculature during nerve blocks can result in local or diffuse ischemia. It occurs when there is direct vascular injury, acute occlusion of the arteries, or hemorrhage within a nerve sheath.
- **Chemical injury**: Results from tissue toxicity of injected solution (e.g., local anesthetic [LA], alcohol, or phenol) or its additives. The toxic solution may be injected directly into the nerve or adjacent tissues, which causes an acute inflammatory reaction or chronic fibrosis that indirectly involves the nerve.
- **Inflammatory injury**: Nonspecific inflammatory responses targeting PNs can occur either remote from the site of the surgery or within the operative area. Distinguishing inflammation from other causes of PN injury may be difficult.

Risk Factors

The etiology of PN injury is difficult to discern in many instances. The injury is often multifactorial. Possible etiologies include mechanical needle-nerve trauma, intraneural hematoma, perineural and intraneural inflammation, and neurotoxicity of the injectate (both LAs and adjuvants). Confounding factors that may play a role in nerve injury or delay the diagnostic include pre-existing neuropathies (e.g., diabetes mellitus), intraoperative injury, tourniquet pressure, and compression from postoperative casting. Table 10-1 summarizes the commonly cited etiologies and their respective confounding factors, making it difficult to discern block-related injury from the preexisting (subclinical) neuropathy or perioperative injury.

TABLE 10-1 Mechanisms of Peripheral Nerve Injury and Their Respective Confounding Factors

MECHANISM OF INJURY	CONFOUNDING FACTORS
Mechanical trauma from the needle	Pre-existing neuropathies
Nerve edema or hematoma	Surgical manipulation
Pressure effects of the LA injectate	Prolonged tourniquet pressure
Neurotoxicity of the injected compression	Compression from postoperative casting
Post nerve block injection inflammation and tissue scarring	Postoperative inflammatory neuropathy

Practical Management of Postoperative Neuropathy

A postoperative neurologic deficit that outlasts the expected duration of the PN block may occur even with all monitoring utilized. Fortunately, the vast majority of neurologic deficits resolve spontaneously. Patient reassurance is important while processes that may be evolving (i.e., compartment syndrome) or are repairable (i.e., surgery-related nerve injury) should be ruled out. Figure 10-2 displays a practical approach to the management of patients with neurologic deficits after PN blocks.

These principles should be kept in mind when managing a postoperative neuropathy:

- Good communication before, during, and after the procedure is essential. This is important both for patient care and from a medicolegal standpoint.
- Approximately 95% of postoperative sensory changes will resolve within 4 to 6 weeks, and most of these will occur during the first week.
- Early diagnosis of postoperative PN injury can be challenging due to:
  - Residual sedation and or PN block
  - Postoperative pain that limits the examination
  - Casts, dressings, splints, and slings
  - Movement restrictions
- Prolonged tourniquets, casting, excessive intraoperative traction, or a misplaced surgical clip can all cause neuropathies. Therefore, the early involvement of the surgical team and a multidisciplinary approach are also important.
- In general, the presence, or persistence, of a motor deficit may be associated with a less favorable outcome and warrants early consultation with a neurologist and/or neurosurgeon.
- A neurologic deficit that is progressing, severe, or complete should be seen immediately by a neurologist and a neurosurgeon.

Referral for electrophysiologic testing may be indicated when the symptoms are not purely sensory or when neuropathy is long-lasting. It is recommended to perform the following:

- **Electromyography (EMG)**: This is undertaken to determine which muscle units are affected by a denervation lesion. Small needle electrodes are placed in various muscles, and the pattern of electrical activity, both at rest and with contraction, is analyzed. The test can be used to localize a lesion. The electrical activity pattern can also determine a time frame for the injury. In other words, it

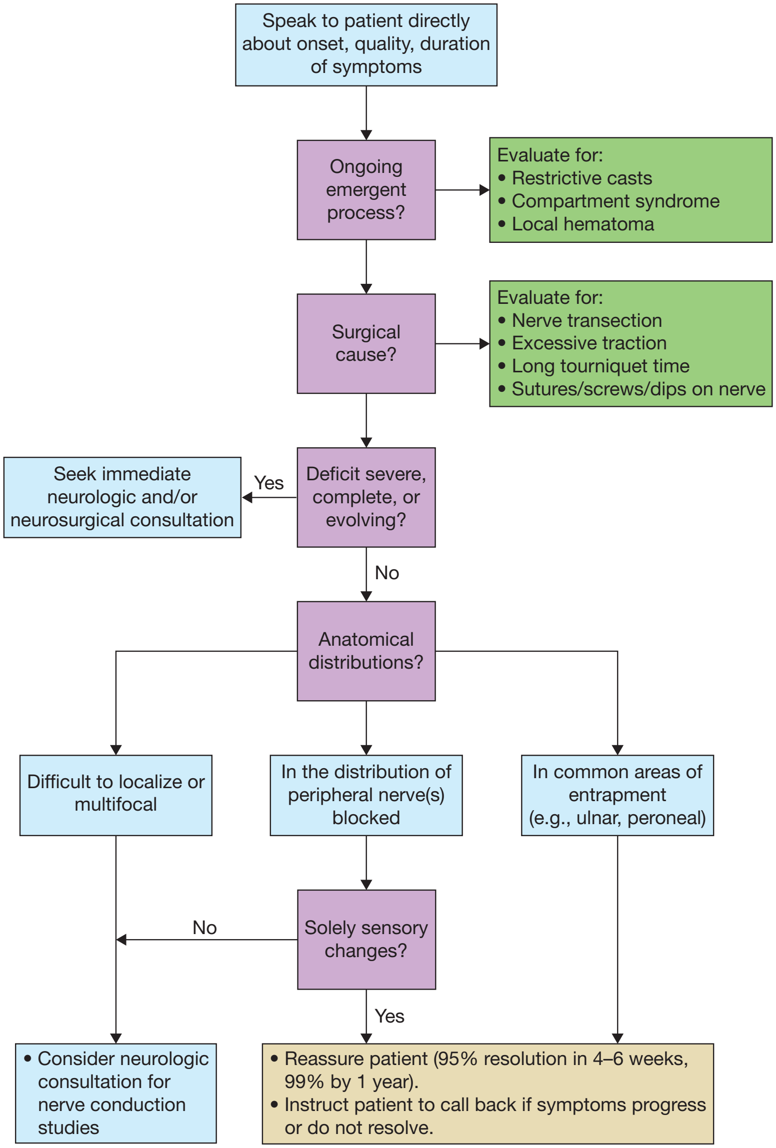

FIGURE 10-2. Flowchart of the practical approach of the management of a patient with a neurologic deficit after a peripheral nerve block.

can determine whether a preexisting injury existed that may have unmasked and worsened the current, clinically apparent neuropathy.

- **Nerve conduction tests**: A device similar to the PN stimulator is attached over various nerves in the affected area. Stimulation of a nerve generates a characteristic waveform, which allows the neurologist to pinpoint a conduction block. It can be used to determine the likely level at which the injury occurred, which can be used to decipher the possible reversible cause, such as compression by bone fragment, etc.

The optimal timing of electrophysiologic testing depends on the indication. When performed 2 to 3 days after the onset of injury, EMG can also yield information regarding the completeness of the lesion (prognosis), as well as information about the duration of the lesion, which may have medicolegal ramifications, particularly if the lesion is deemed to predate the nerve block or surgical procedure. As such, this can be seen as a "baseline" examination. More information is obtained at approximately 4 weeks postinjury when the electrophysiologic changes have had an opportunity to fully evolve.

Prevention

Preventing nerve injury during the practice of nerve block is paramount. Refer to Chapter 6. Below are several practical recommendations used in NYSORA teaching.

- Avoid blocks in patients with existing neurologic deficit, unless clear patient benefit is evident.
- Use triple monitoring: ultrasound (US) guidance (confirm extraneural injection), nerve stimulation (no motor response at <0.5 mA), and injection pressure monitoring (opening injection pressure <15 psi), and always fully document the procedures (Figure 10-3).
- Stop the injection when the patient experiences severe pain during needle advancement or LA administration. However, most patients experience some degree of discomfort during needle advancement and LA injection, making the pain on injection nonspecific. Objective monitoring is recommended, instead.
- Stop needle advancement when an evoked motor response occurs (0.5 mA; 0.1 ms). A distal motor response at this current intensity indicates intimate needle-nerve relationship, needle-nerve contact, or intraneural needle placement.
- Neither the presence or absence of paresthesia is entirely predictive of nerve injury.
- Avoid high opening injection pressure during injection. An injection pressure monitor may detect injection into poorly compliant tissue spaces, such as a nerve fascicle.

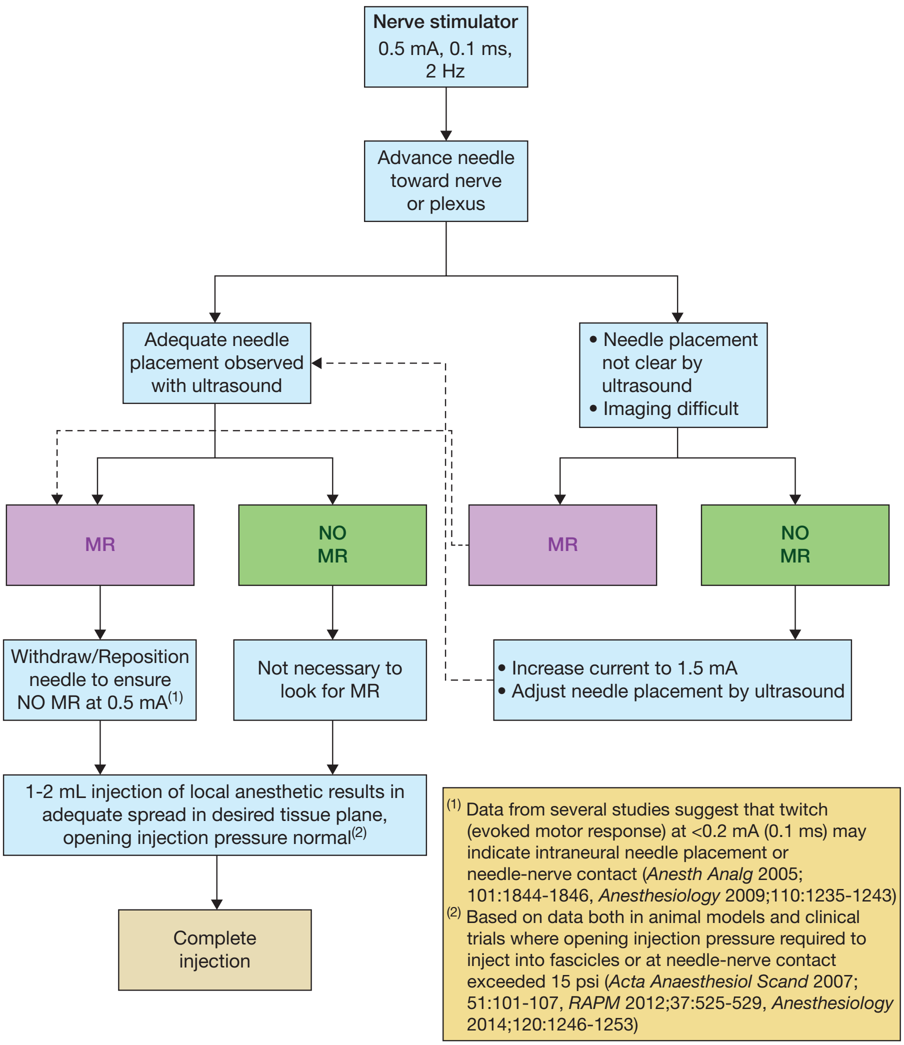

FIGURE 10-3. Flowchart depicting the order to correctly monitor nerve block procedures by combining ultrasound, nerve stimulation, and injection pressure monitoring (triple monitoring). MR, motor response.

- Use US to avoid needle-nerve contact and detect an intraneural injection. Note that by the time that US detects an intraneural injection, it may already be too late to prevent injury (i.e., even a small amount of injectate is sufficient to rupture the fascicle and injure the axons).

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11 Preparation for Regional Anesthesia and Perioperative Management

Introduction

The practice of regional anesthesia involves a preoperative assessment, patient information, adequate preparation, objective monitoring of block administration, and monitoring of respiratory and cardiovascular parameters. These activities should be standardized and recorded as standardized documentation where applicable.

This chapter describes the suggested steps for the perioperative management of patients receiving regional anesthesia. While the suggestions here apply to all regional anesthetics, more detail, uniquely applicable to the specific procedures, will be detailed in their respective chapters.

Preanesthetic Evaluation and Information

- Assess comorbidities relevant for anesthesia and the specific blocks (e.g., pre-existing neurologic symptoms, respiratory insufficiency for proximal brachial plexus blocks, coagulation disorders/anticoagulants).
- Discuss indications and specifics of the regional anesthesia technique with the patient and obtain informed consent, if applicable.
- Evaluate the anatomical area of regional anesthesia for potential contraindications or limitations that would require alternative approaches (e.g., scars, infections, osteosynthesis material, inability to adequately position or expose the area of interest).
- Apply similar fasting guidelines as for general anesthesia. In the absence of contraindications, allow the intake of clear fluids up to 2 hours prior to the surgical procedure.
- As opposed to general anesthesia, removal of the dentures etc., is typically not necessary for patients receiving regional anesthesia.

Patient Preparation

- Ensure patient privacy and comfort.
- Perform a checklist (a) on patient arrival and (b) just before the intervention.
- Confirm the surgical procedure, regional anesthesia procedure, and side to be anesthetized.
- Explain to the patient the planned procedure and what to expect post-procedure (i.e., the duration and distribution of the sensory-motor block).
- Apply the standard American Society of Anesthesiologists (ASA) monitoring.
- Initiate intravenous (IV) access.
- Position the patient for the planned procedure (refer to the techniques chapters).
- Administer supplementary oxygen.
- Administer IV analgesia and anxiolysis as necessary, best as a routine protocol.

Equipment and Personnel

- Establish and train a dedicated block room nursing personnel team.
- Establish standardized protocols for equipment for each commonly used regional anesthesia procedure.
- Block nurses are essential for regional anesthesia service. Their service functions best also when patient care, regional anesthesia techniques, equipment, indications, and perioperative care are standardized within the entire service.
- In addition to the patient preparation, establish and train the nursing team to prepare the equipment for regional anesthesia and assist in the block performance:
    - Prepare ultrasound (US) machine and position it correctly, standardized ergonomics.
    - Help with the general setup of the US machine (transducer, mode, frequency, time gain compensation, initial depth).
    - Prepare the nerve stimulator with the correct settings.
    - Prepare the regional anesthesia tray with the protocoled medication, needle, injection pressure monitoring (where used), etc. (See Figure 11-1.)
    - Prepare sterile gloves, sterile US transducer cover and, for catheter placement, a sterile gown.

FIGURE 11-1. Setting for nerve block including a regional anesthesia tray with the protocoled medication, stimulating needle, injection pressure monitoring, and transducer cover.

FIGURE 11-2. Arm protected with a blanket to avoid inadvertent malposition after an interscalene brachial plexus block.

Block Procedure

- Whenever possible, maintain meaningful verbal contact with the patient while explaining the steps throughout the procedure.
- Develop a clear instructions protocol for the block nurse to ensure assistance during the block procedure.
- Consider using the mnemonic **RAPT** for monitoring and reporting during regional anesthesia injection:
    - **R**esponse: Motor response absent at 0.5 mA, 0.1 ms, 2 Hz
    - **A**spiration: Negative for blood
    - **P**ressure: Opening injection pressure <15 psi
    - **T**otal volume of local anesthetic (LA) administered
- Once the injection is completed, ensure that the blocked extremity is protected (Figure 11-2).
- Designate one single person for the responsibility of safely removing sharp objects from the block tray to avoid accidental needle sticks to the personnel.
- Assess the sensory and motor block before the surgical procedure (Figure 11-3).
- For incomplete blocks, consider administering rescue, or repeat block, or additional analgesia, sedation, or general anesthesia.
- Document the block procedure (refer to Chapter 6 for details on monitoring and documentation).

Intraoperative Management

- Apply the ASA monitoring.
- Administer supplementary oxygen.
- Ensure a comfortable position for the patient during surgery.
- Ensure that the patient's temperature is maintained by warming (i.e., forced air, warm blankets).
- Start titrated sedation, as necessary; this is best done using a protocoled approach (e.g., target-controlled infusion [TCI] of propofol).
- Protect the patient's ears from the operating room (OR) noise with earplugs, blankets, and/or headphones with music. This can substantially add to the patient's comfort and experience of the perioperative care, as well as decrease the need for intraoperative sedation (Figure 11-4).

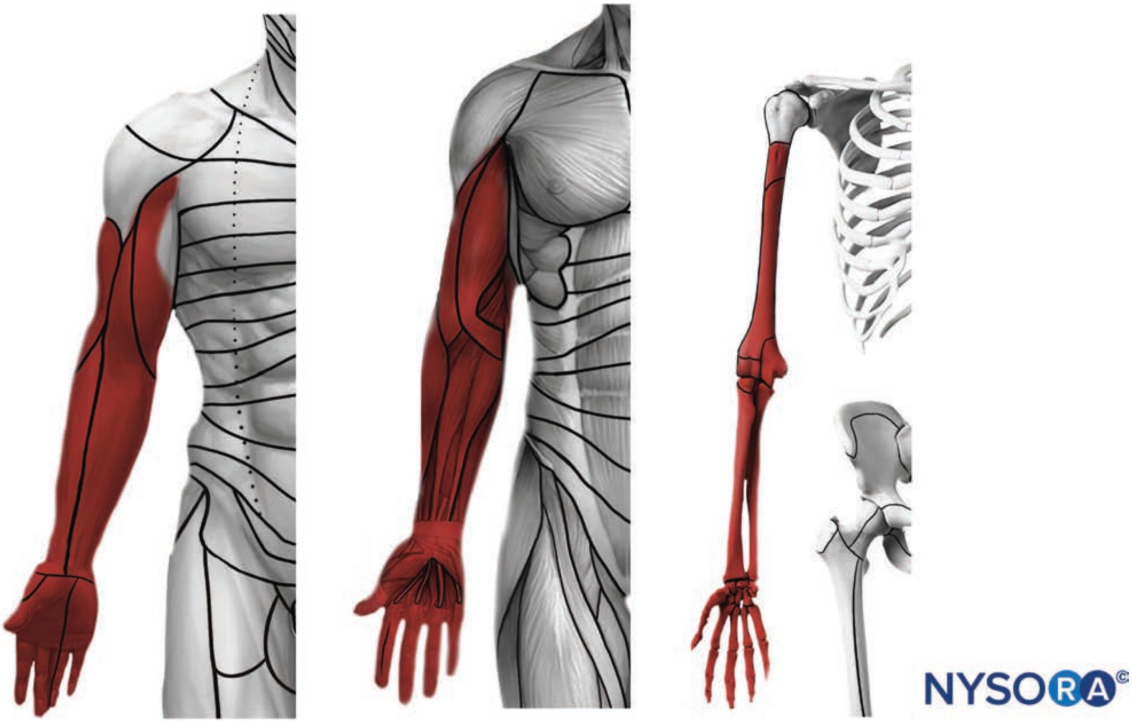

FIGURE 11-3. Example of the standardized sensory and motor evaluation for block completeness. Expected block distribution after an axillary block.

FIGURE 11-4. Example of an intraoperative setting, including standard monitoring, titrated sedation, supplementary oxygen, noise protection, and warming system.

- Establish a routine protocol for intraoperative administration of fluids.
- Develop and apply a standardized multimodal analgesia protocol for all common surgical procedures (Figure 11-5).

Postoperative Management

- Accompany the patient during the transport from the OR to the post-anesthesia care unit (PACU) or day surgery unit.
- Provide the essential postoperative care information (situation, background, assessment, recommendation [SBAR]) to the nurses continuing the patient care.
- Reinforce the verbal and/or written information to the patient about the care of the blocked extremity.
- Ensure adequate instructions for postoperative analgesia after the block resolution.

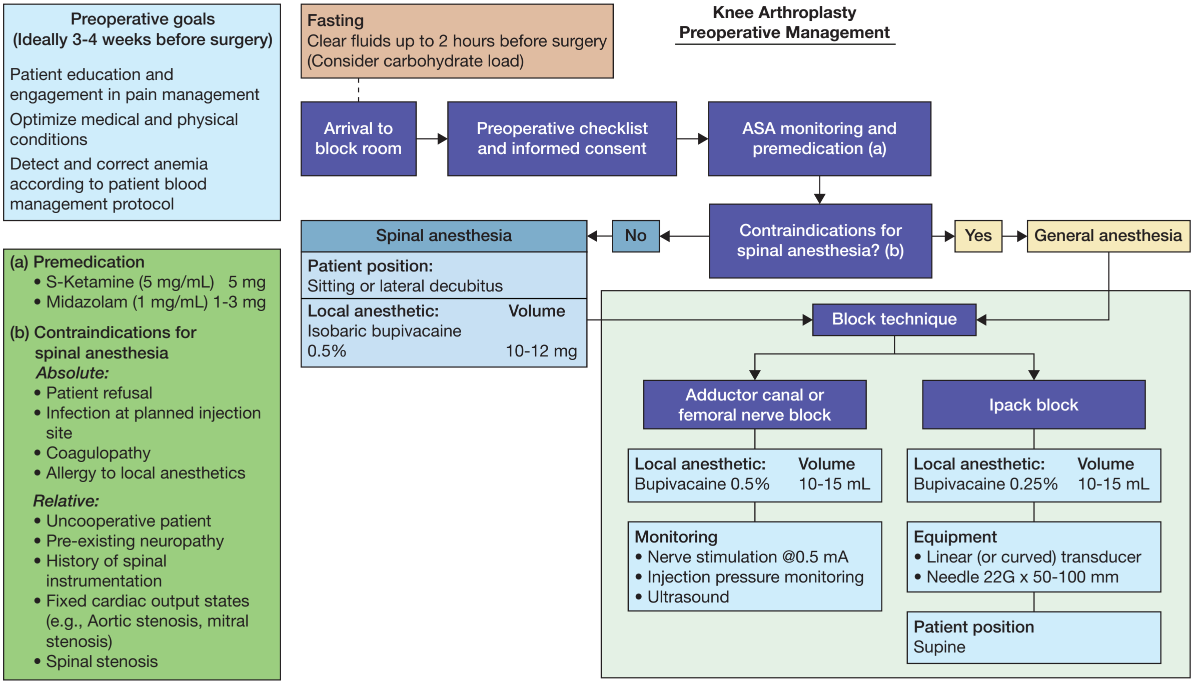

FIGURE 11-5. Example of a standardized perioperative protocol for a common surgical procedure (e.g., knee arthroplasty).

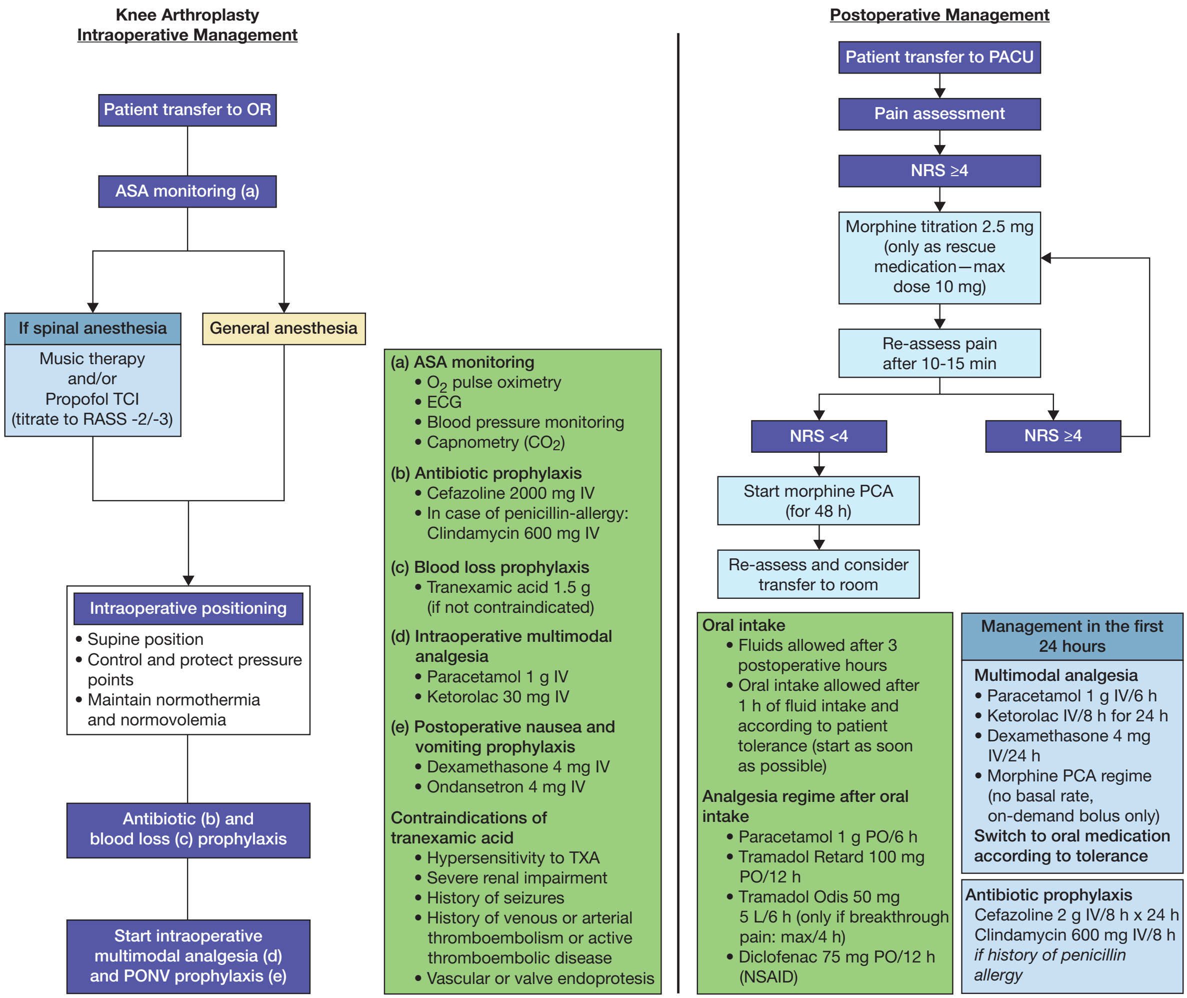

FIGURE 11-5. *(Continued)*

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SECTION 2

Head and Neck Blocks

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12 Cervical Plexus Block

BLOCK AT A GLANCE

Block of the branches of the cervical plexus (C2-C4).

- **Indications**: Anesthesia and/or analgesia for carotid surgery, thyroid and superficial neck surgery, treatment of cervical muscle spasm, and analgesia for clavicle fracture
- **Goal**: Local anesthetic (LA) spread around the branches of the cervical plexus
- **Local anesthetic volume**: 5 to 8 mL

General Considerations

The cervical plexus block is a well-established technique that traditionally has been performed using external anatomical landmarks before the introduction of ultrasound (US).

Although the terminology and description of the cervical fasciae can be inconsistent, there are three common approaches to block the cervical plexus (Figure 12-1).

1. Deep injection technique: LA can be deposited at the C2-C4 paravertebral space, deep to the prevertebral fascia, to block the entire plexus. *Note:* This technique is more

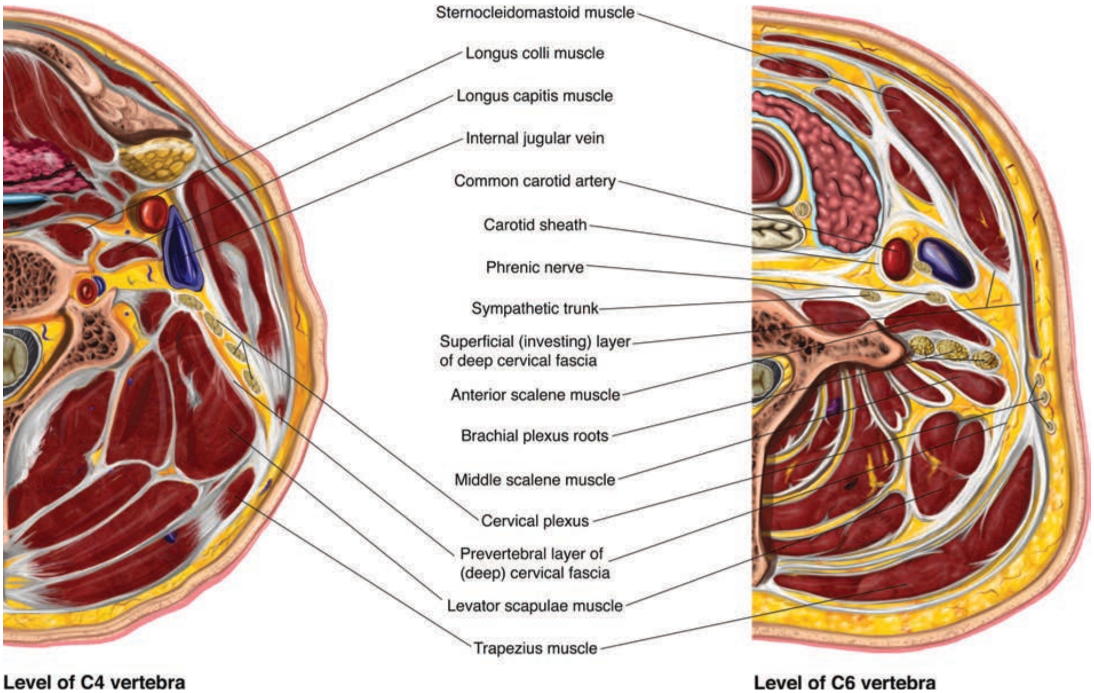


FIGURE 12-1. Cross-sectional anatomy of the cervical plexus at the level of C4 and at the level of C6.

accurately termed a paravertebral block of spinal nerves C2-C4, rather than “deep cervical plexus.”

2. Intermediate technique: LA is injected at the level of the C4 transverse process, between the prevertebral fascia and the investing layer of the deep cervical fascia, to block the superficial branches of the plexus.
3. Superficial technique: At the level of C6, the LA is injected subcutaneously and superficially to the deep cervical fascia to block all or specific cutaneous branches.

A deep injection technique carries a higher risk of injection into the spinal canal or vertebral artery, or blocking the cranial nerves. Therefore, in this chapter, we describe the intermediate and superficial techniques, which are safer and equally effective for most indications. There are few, if any, indications for a cervical plexus block deep to the prevertebral fascia. Moreover, bilateral deep injection techniques are not recommended because of potential respiratory failure and airway obstruction due to a bilateral block of the vagus, hypoglossal, and phrenic nerves.

Specific Risks

The risks include paroxysmal cough, recurrent or phrenic nerve block, dysphagia, dysphonia, Horner syndrome, and stellate ganglion block.

Anatomy

The cervical plexus originates from the anterior rami of C1-C4. The anterior ramus of C1 (the suboccipital nerve) is a motor nerve that is not blocked as part of any described cervical plexus block technique. Thus, a *cervical plexus block* is best defined as a block of the anterior rami of C2 through C4. The anterior branches of C1-C4 of the cervical plexus combine into three loops from which the deep and superficial branches arise (**Figure 12-2**). The cervical plexus is connected to the hypoglossal, glossopharyngeal, and vagus nerves, as well as the sympathetic trunk, contributing to the innervation of muscles and structures relevant to airway control, respiratory function, phonation, and swallowing.

The deep muscular branches innervate the muscles of the neck. The phrenic nerve (C3-C5) provides innervation to the diaphragm. The superficial sensory branches are the lesser occipital, greater auricular, transverse cervical, and supraclavicular nerves, which innervate the skin and superficial structures of the head, neck, and shoulder (**Figure 12-3**).

The superficial branches of the plexus emerge from the prevertebral fascia in between the longus capitis and middle scalene muscle and run along the posterior aspect of the sternocleidomastoid muscle (SCM). Subsequently, branches emerge from behind the posterior border of the SCM, approximately at the intersection with the external jugular vein (Erb’s point), located at the midpoint of the insertions to the mastoid and clavicle (**Figure 12-4**).

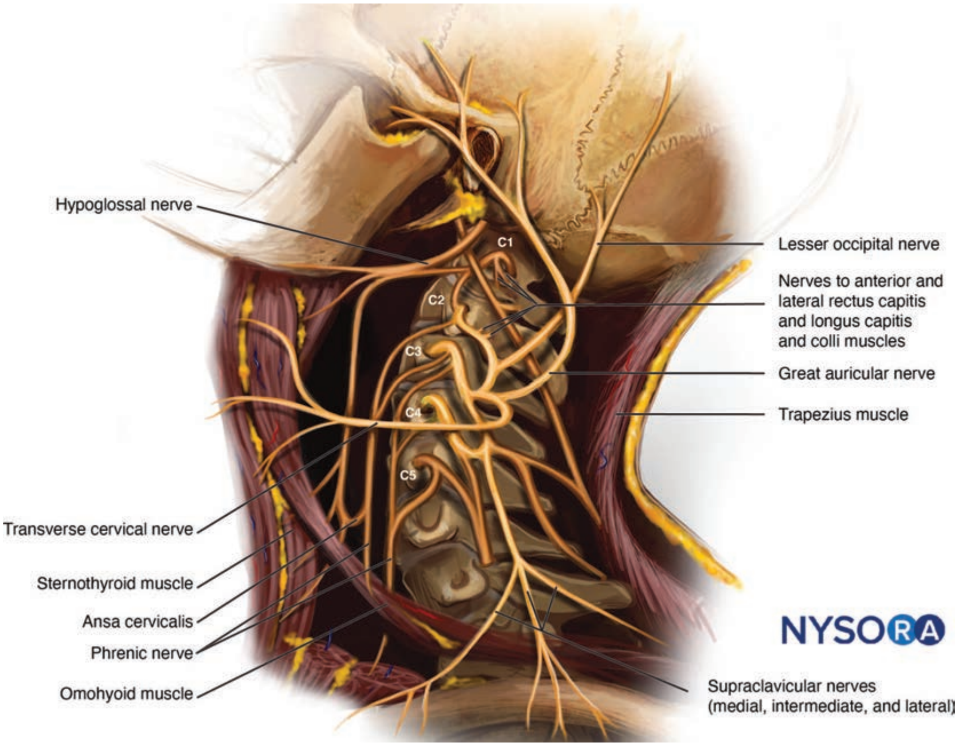


FIGURE 12-2. Anatomy of the cervical plexus.

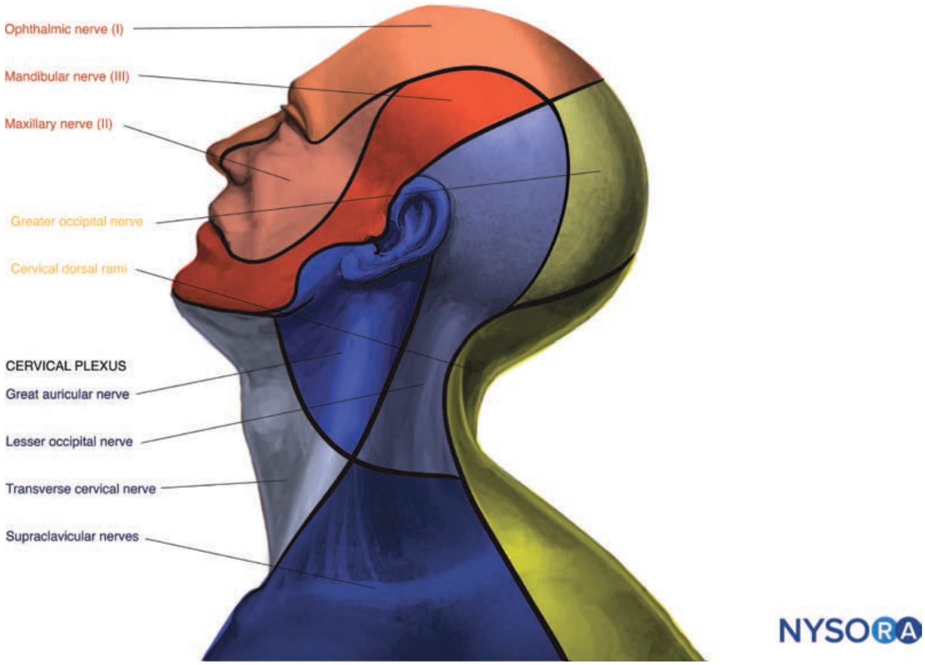


FIGURE 12-3. Dermatome distribution of the cervical plexus.

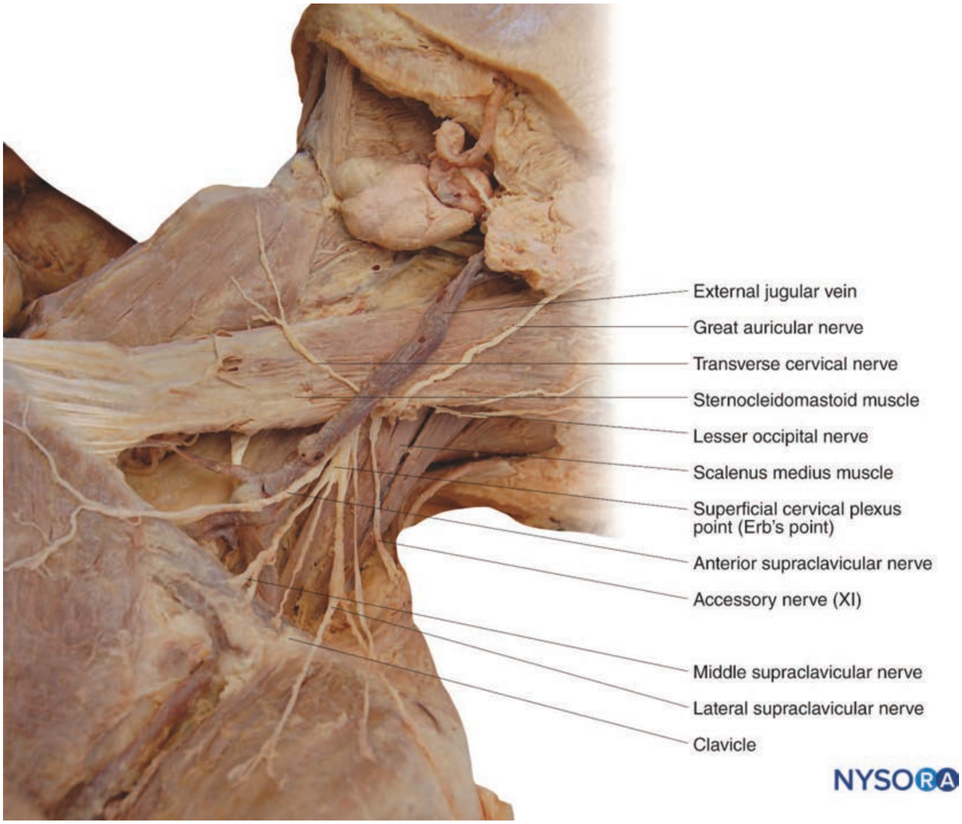


FIGURE 12-4. Dissection of the superficial branches of the cervical plexus exiting at the Erb's point.

Cross-Sectional Anatomy and Ultrasound View

Cranially to the C4 transverse process, the cervical plexus is located within the prevertebral layer of the deep cervical fascia in a groove between the longus capitis and middle scalene muscle. At the level of C4-C5, the plexus is located superficial to the prevertebral fascia overlying the interscalene groove, immediately deep to the SCM (Figure 12-1).

The sensory branches can often be visualized as a collection of small, oval, hypoechoic nodules with US. Occasionally, the greater auricular nerve is imaged on the superficial surface of the SCM as a round, hypoechoic structure (Figure 12-5). At the level of C6-C7, elements of the cervical plexus can be imaged superficially around the posterior border of the SCM or subcutaneously (e.g., supraclavicular branches) (Figure 12-6).

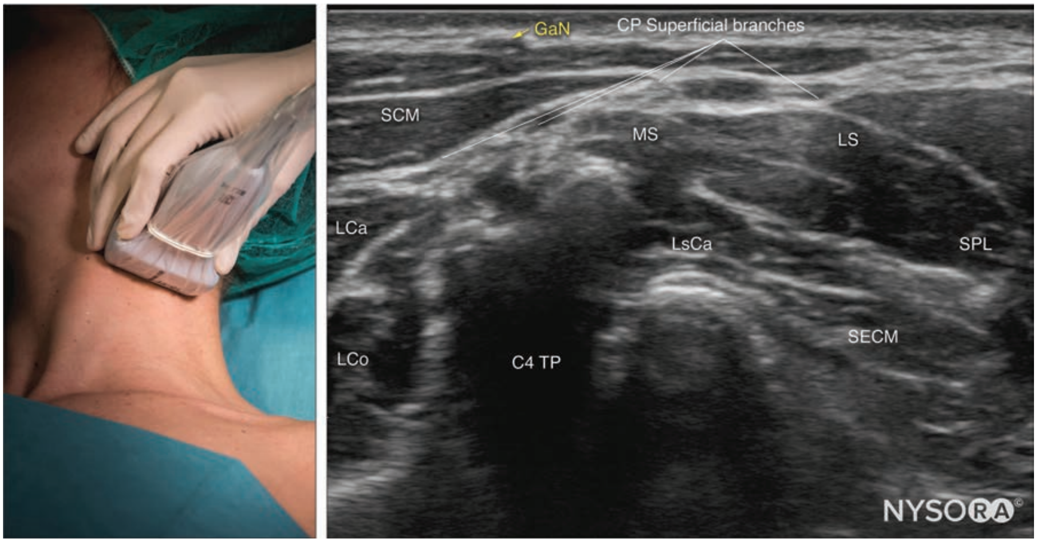


FIGURE 12-5. Transducer position and sonoanatomy of the cervical plexus at the level of the C4 transverse process. GaN, greater auricular nerve; SCM, sternocleidomastoid muscle; LCa, longus capitis muscle; LCo, longus Colli muscle; MS, middle scalene muscle; LsCa, longissimus capitis muscle; LS, levator scapulae muscle; SPL, splenius capitis muscle; SECM, semispinalis capitis muscle.

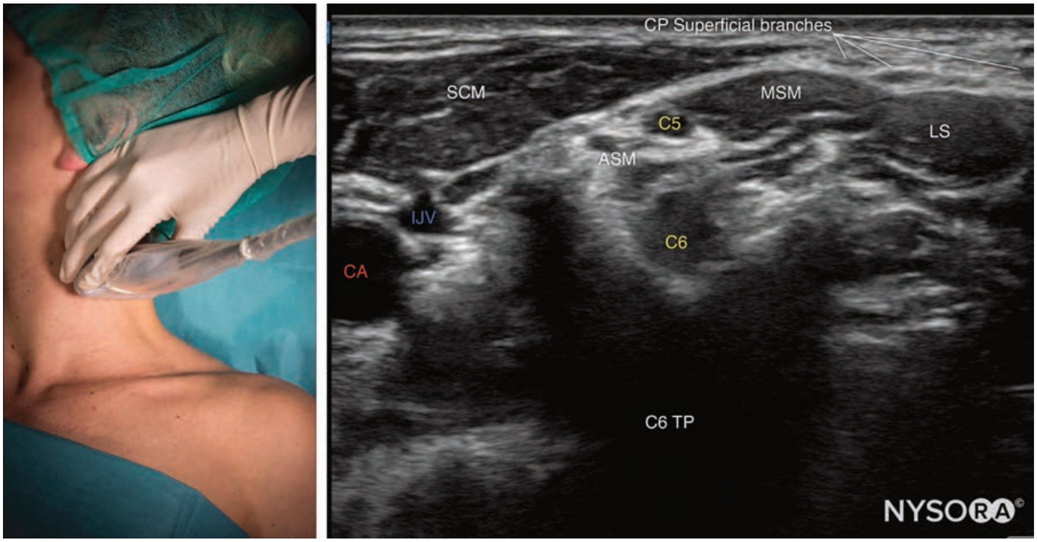


FIGURE 12-6. Transducer position and sonoanatomy of the cervical plexus at the level of the C6 transverse process. CA, carotid artery; IJV, internal jugular vein; SCM, sternocleidomastoid muscle; ASM, anterior scalene muscle; MSM, middle scalene muscle; LS, levator scapulae muscle; CP, cervical plexus superficial branches.

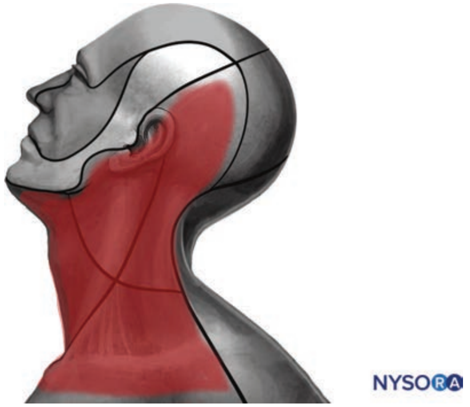


FIGURE 12-7. Distribution of anesthesia after a cervical plexus block.

Distribution of Anesthesia and Analgesia

The superficial block of the cervical plexus results in anesthesia of the skin of the anterolateral neck, the ante-auricular, and retro-auricular areas, as well as the skin overlying and immediately inferior to the clavicle on the chest wall (Figure 12-7). The intermediate block also anesthetizes the branches to the SCM and the phrenic nerve.

Block Preparation

Equipment

- Transducer: High-frequency linear transducer
- Needle: 50-mm, 25-gauge, short-bevel, stimulating needle

Local Anesthetic

Because the superficial branches of the cervical plexus are sensory nerves, low concentrations of the LA are adequate (e.g., ropivacaine 0.25–0.5%, bupivacaine 0.25%, or lidocaine 1%).

Patient Positioning

The patient is placed in a semi-sitting, supine, or semi-lateral position with the head extended and rotated to the contralateral side, to expose the posterior triangle of the neck. If the posterior border of the SCM is difficult to locate, especially in obese patients, asking the patient to lift the head off the bed facilitates the identification of its posterior border (Figure 12-8).

Technique

Initial Transducer Position

Place the transducer in a transverse orientation on the lateral aspect of neck, at the midpoint of the posterior border of the SCM, approximately at the cross-section of the external jugular vein, or at the level of the thyroid cartilage.

Scanning Technique

Identify the SCM and slide the transducer posteriorly until the tapering posterior edge is positioned in the middle of the screen.

Sliding the transducer craneo-caudally will help to identify the superficial branches of the cervical plexus as a small collection of hypoechoic nodules between the scalene muscles and SCM as they travel posteriorly and superficially (Figure 12-5).

A B

FIGURE 12-8. (A) Patient position for a cervical plexus block. (B) Patient with head lifted to facilitate identification of the sternocleidomastoid muscle.

Needle Insertion

Both in-plane and out-of-plane approaches may be used. **For the intermediate approach,** advance the needle through the skin, platysma, and investing layer of the deep cervical fascia. Place the needle tip adjacent to the branches of the cervical plexus between the scalene muscles and SCM (Figures 12-9). **For the superficial approach**, inject the LA subcutaneously at the midpoint of the posterior border of the SCM (Figure 12-10).

Local Anesthetic Distribution

Following negative aspiration, inject 1 to 2 mL of LA to confirm the proper needle tip location and complete the block with 5 to 8 mL, limiting medial spread to the carotid sheath. If the injection of LA does not appear to result in a linear spread superficial to the scalene muscles, additional injections may be necessary.

An alternative **longitudinal approach** may be used for the intermediate approach; place the transducer in the coronal plane over the SCM without the need to visualize the plexus (Figure 12-11). With this technique, the needle tip is placed in the space between the posterior border of the SCM and prevertebral fascia. The LA should layer out along this space.

Problem-Solving Tips

- Carotid surgery also requires blockade of the glossopharyngeal nerve branches. This can be accomplished intraoperatively by injecting LA inside the sheath of the carotid artery.

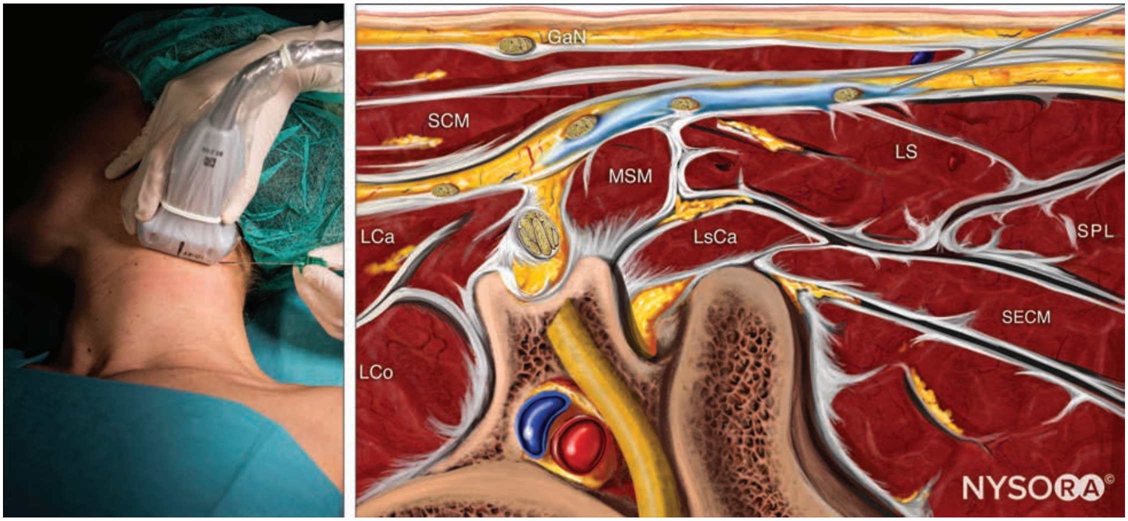


FIGURE 12-9. Cervical plexus block (intermediate approach). Reverse ultrasound anatomy with needle insertion in-plane. GaN, greater auricular nerve; SCM, sternocleidomastoid muscle; LCa, longus capitis muscle; LCo, longus colli muscle; MSM, middle scalene muscle; LsCa, longissimus capitis muscle; LS, levator scapulae muscle; SPL, splenius capitis muscle; SECM, semispinalis capitis muscle.

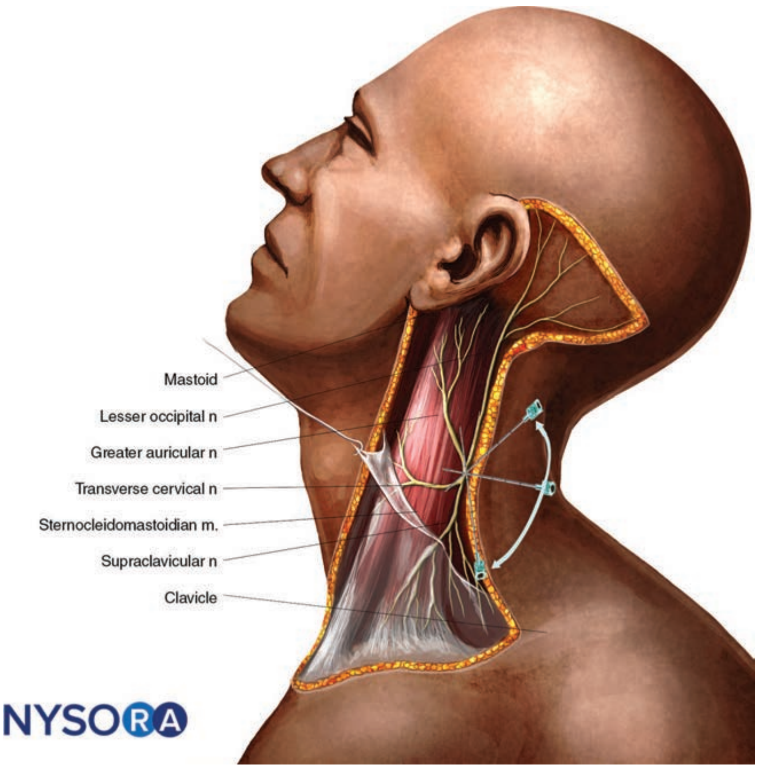
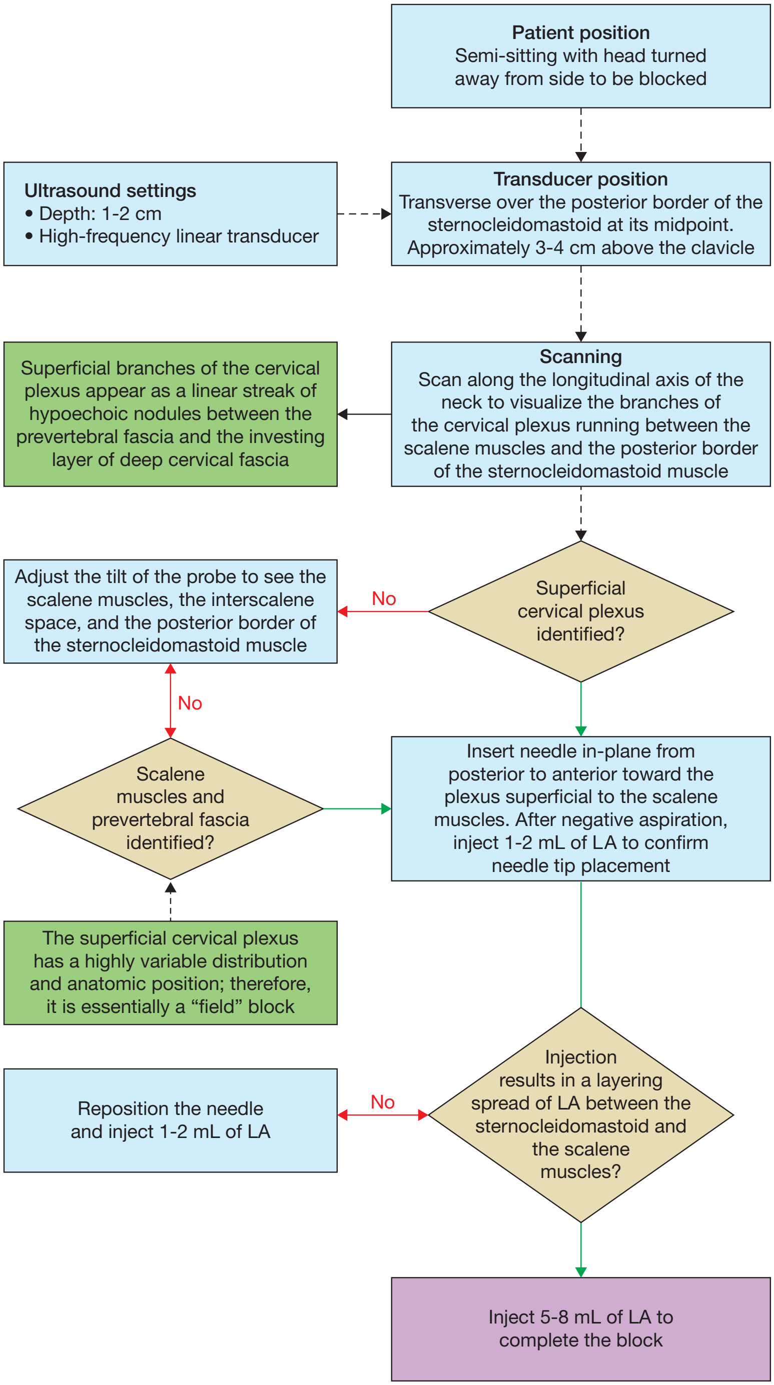


FIGURE 12-10. Schematic subcutaneous infiltration to block the superficial branches of the cervical plexus at Erb's point.

FIGURE 12-11. Transducer position in a longitudinal approach to block the superficial branches of the cervical plexus.

Flowchart

Cervical Plexus Block Technique Algorithm



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SECTION 3

Upper Extremity Blocks

13 Interscalene Brachial Plexus Block

BLOCK AT A GLANCE

Blockade of the brachial plexus at the level of the interscalene space.

- **Indications:** Anesthesia and analgesia for shoulder, upper arm, and clavicle surgery
- **Goal:** Local anesthetic (LA) spread around the superior and middle trunks of the brachial plexus, between the anterior and middle scalene muscles
- **Local anesthetic**: 5 to 15 mL

General Considerations

The interscalene brachial plexus block is a common regional anesthesia technique for anesthesia and analgesia of the shoulder and upper arm surgery, as it provides complete blockade of the nerves involved in the innervation of the shoulder (Figure 13-1). Ultrasound (US) guidance has improved the block's success and popularity and reduced the volume of LA required. Ipsilateral phrenic nerve block with consequent hemi-diaphragmatic palsy remains the most common adverse effect of the interscalene block despite several modifications of the technique to decrease its occurrence. Using lower volumes (<10 mL), diluted LAs, more distal injection sites, selective superior trunk block, or a combination of these interventions does decrease the incidence, but does not consistently avoid block of the phrenic nerve. Therefore, this block should be used with caution in patients with respiratory insufficiency; more distal interventional techniques are recommended instead. (See Chapter 18.)

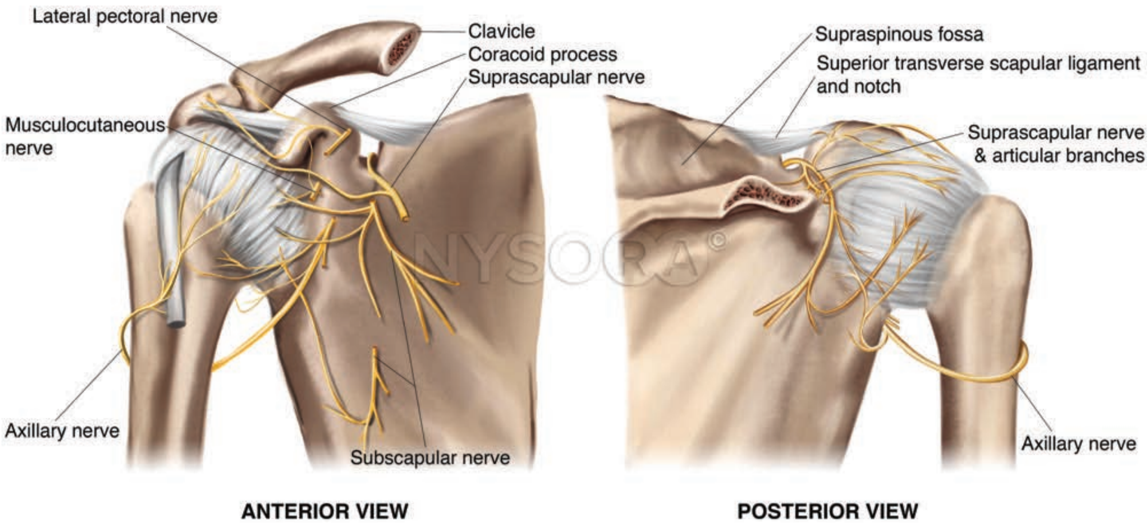


FIGURE 13-1. Innervation of the shoulder joint; all neural elements come from the brachial plexus at the interscalene level.

Specific Risks

Procedural injuries of the interscalene brachial plexus have been reported, including nerve injury of the median, radial, phrenic, dorsal scapular, and long thoracic nerves. The recurrent laryngeal nerve may also be blocked with interscalene block, resulting in airway obstruction in patients with existing vocal cord palsy. Epidural or spinal injection, Horner syndrome, diaphragmatic paralysis, and myotoxicity have all been reported.

Anatomy

The brachial plexus is a nerve network comprised of the anterior rami from the spinal nerves from C5 to T1 (Figure 13-2). The spinal nerves continue to form roots, trunks, divisions, cords, and branches. At the posterior triangle of the neck, the plexus is seen as three trunks (superior, middle, and inferior) posterior to the carotid artery and internal jugular vein between the anterior and middle scalene muscles. The phrenic nerve courses anterior to the brachial plexus over the surface of the anterior scalene muscle (Figure 13-3). The dorsal scapular nerve runs down and posterior through the middle scalene muscle, often close to the long thoracic nerve. Anatomical variations in brachial plexus anatomy are common. As an example, the C5 root often (35%) takes a course over or through the anterior scalene muscle rather than the interscalene space. The branches of the thyrocervical trunk (suprascapular artery and transverse cervical artery) cross the brachial plexus at variable levels as they travel posteriorly.

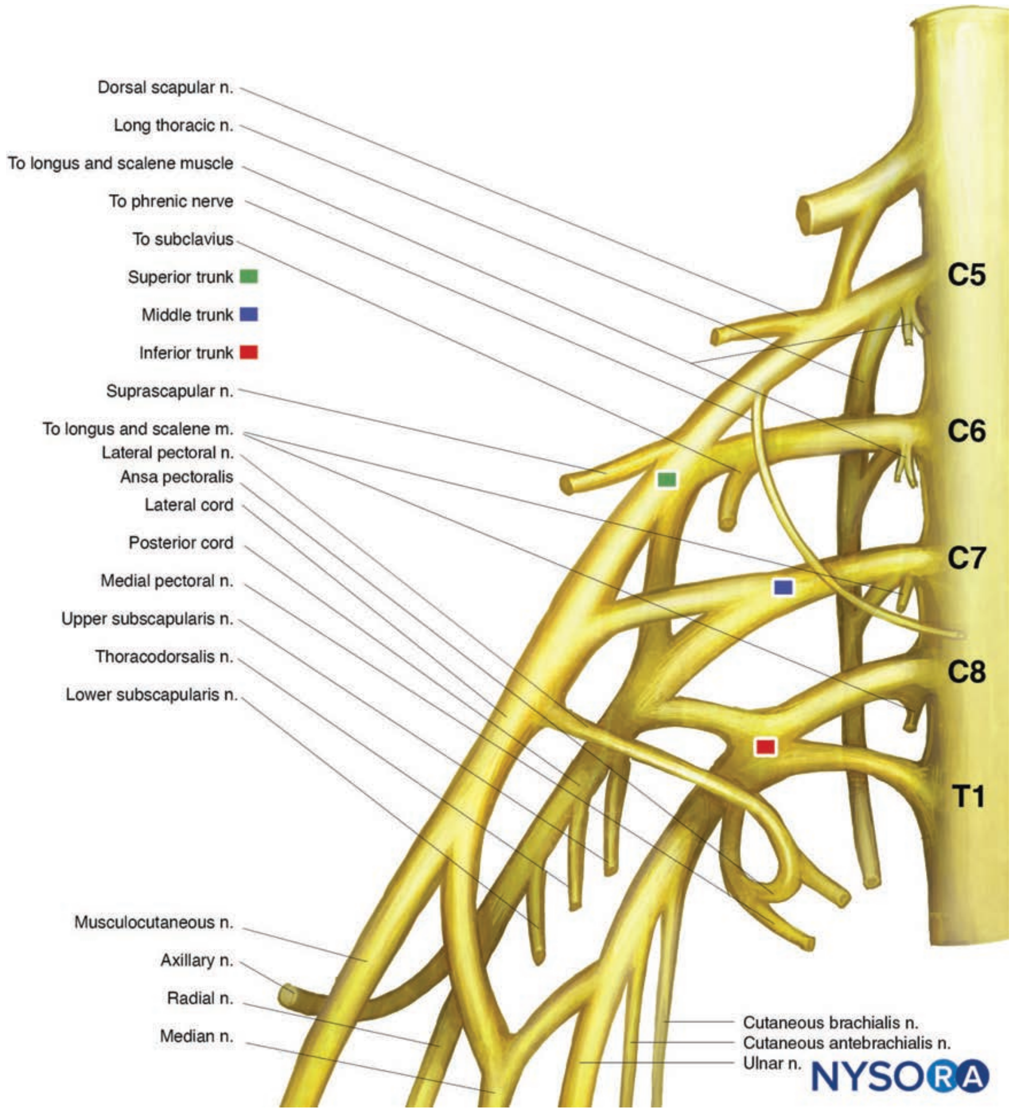


FIGURE 13-2. Organization of the brachial plexus from roots to terminal nerves.

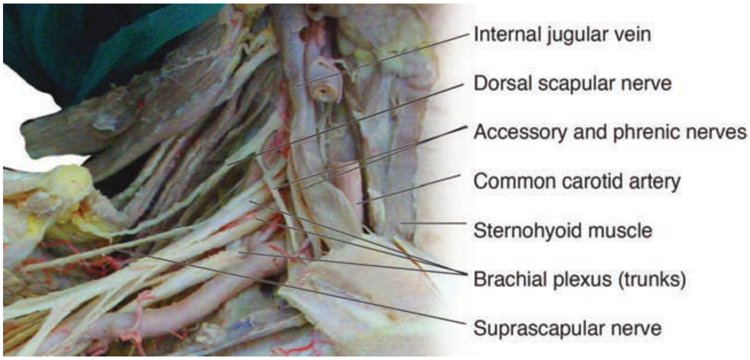


FIGURE 13-3. Dissection of the brachial plexus.

Cross-Sectional Anatomy and Ultrasound View

The brachial plexus is located between the anterior and middle scalene muscles, deep to the sternocleidomastoid muscle (SCM) and the deep cervical (prevertebral) fascia (Figure 13-4). On US, the brachial plexus is typically visualized at a depth of 1 to 3 cm as hypoechoic round structures that exit the transverse process and rapidly change their appearance and organization from roots to trunks within few centimeters. The fascicles can be seen separating and rearranging along their course appearing as two to four round structures. The C6 nerve root often splits into two hypoechoic bundles and can thus be mistaken for two separate roots. The shape and depth of the transverse processes of the cervical vertebrae allow recognizing each individual root. Due to the pyramidal shape of the anterior scalene muscle, it is easier to identify the interscalene groove at the base of the neck.

Distribution of Anesthesia and Analgesia

The interscalene approach to brachial plexus blockade results in reliable anesthesia of the shoulder, upper arm, and lateral two-thirds of the clavicle (Figure 13-5). The supraclavicular

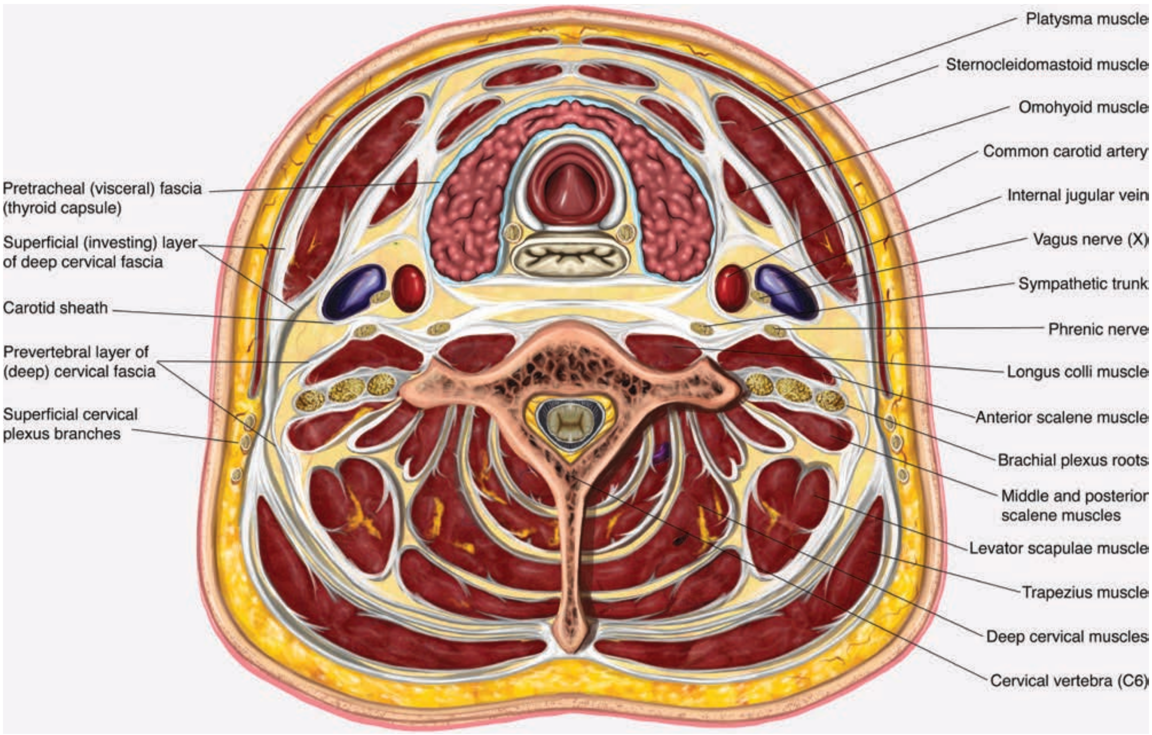


FIGURE 13-4. Cross-section anatomy illustration of the brachial plexus at the level of the C6 vertebra.

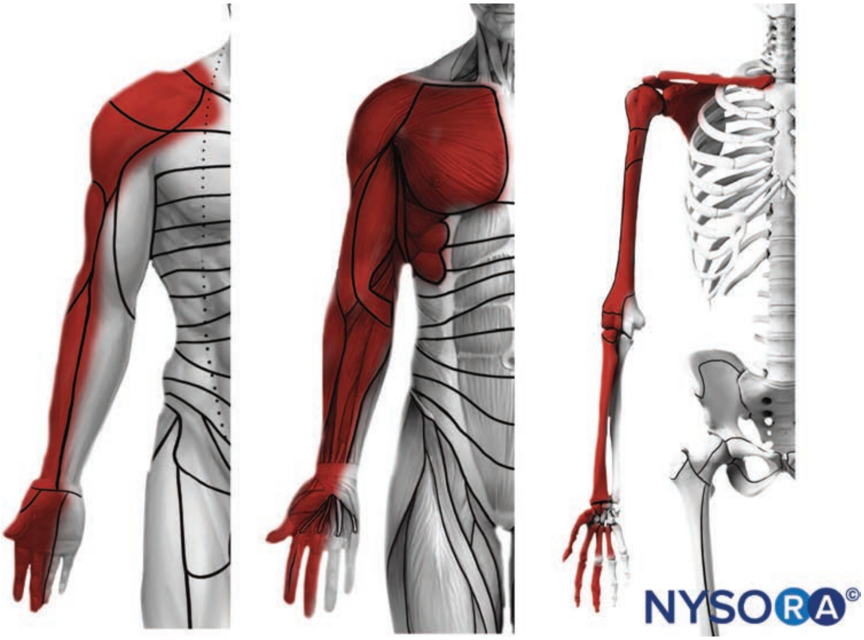


FIGURE 13-5. Expected sensory distribution of the interscalene brachial plexus block (red). The ulnar nerve distribution area (C8-T1) is usually not covered.

branches of the cervical plexus, supplying the skin over the acromion and clavicle, are often blocked due to the proximal and superficial spread of LA. The volume of LA can also spread anteriorly and affect the sympathetic trunk, resulting in Horner syndrome. The inferior trunk (C8-T1) is usually spared, unless the injection occurs at the supraclavicular level.

Block Preparation

Equipment

- Transducer: High-frequency linear transducer
- Needle: 50-mm, 22-gauge, short-bevel, insulated stimulating needle

Local Anesthetic

To provide prolonged analgesia after painful shoulder surgery, long-lasting LAs and high concentrations are usually used for single-shot interscalene block (bupivacaine 0.5%, ropivacaine 0.5-0.75%). For analgesia beyond 24 hours, liposome bupivacaine can be added to bupivacaine, resulting in analgesia for 72 hours or more without significant motor block. Typically, 10 mL of liposome bupivacaine 1.33% is mixed with 5 mL of 0.5% bupivacaine. For continuous blocks, more diluted concentrations are used of the same drugs, followed by the infusion or automated bolus. Of note, the use of continuous interscalene catheters requires substantial expertise, effort, and service to manage. Catheters tend to dislodge from their therapeutic position and may require replacement.

Patient Positioning

The block is typically performed with the patient in a supine, semi-sitting, or semi-lateral decubitus position, with the head facing toward the contralateral side to expose the posterior triangle of the neck. The position of the head and shoulder should be adjusted to maximize the space to scan and to allow the insertion of the needle from the posterolateral aspect of the neck (Figure 13-6).

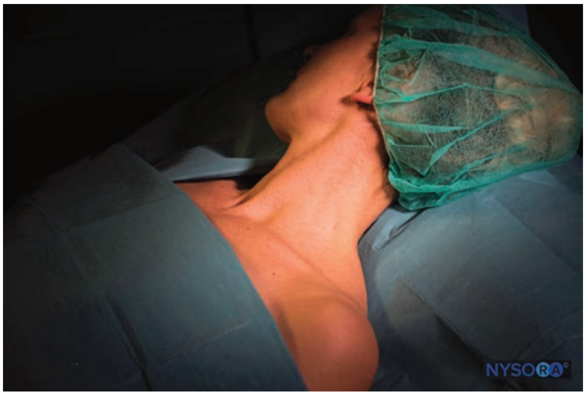


FIGURE 13-6. Ideal patient position for an ultrasound-guided interscalene brachial plexus block.

Technique

Initial Probe Position

Place the transducer in a sagittal orientation at the supraclavicular fossa to identify the subclavian artery. The brachial plexus is seen posterior and superficial to the subclavian artery (Figure 13-7), and from there it can be traced cranially to the desired level.

An alternative is to place the tranducer in a transverse orientation on the lateral aspect of the neck just below the level of the cricoid cartilage to identify the carotid artery deep to the SCM.

Scanning Technique

The transducer is moved slightly posteriorly across the neck to identify the anterior and middle scalene muscles. Tilting the transducer caudally helps identify the round shapes of the brachial plexus emerging in between the scalene muscles (Figure 13-8). It is recommended to systematically apply color Doppler to identify arteries and veins in the vicinity of the plexus before deciding the site of the block.

Needle Insertion

The needle is inserted usually in-plane in a posterior-to-anterior direction, toward the brachial plexus. The needle tip should be directed in between the elements of the brachial plexus in order to minimize the risk of accidental nerve injury as the needle enters the interscalene space.

Local Anesthetic Distribution

After careful aspiration to rule out intravascular needle placement, 1 to 2 mL of LA is injected to verify proper needle placement (Figure 13-9). Injection of LA should displace the brachial plexus away from the needle and result in its spread within the scalene space. When injection of the LA does not displace the plexus or does not result in adequate spread around the trunks, additional needle repositioning and injections are necessary.

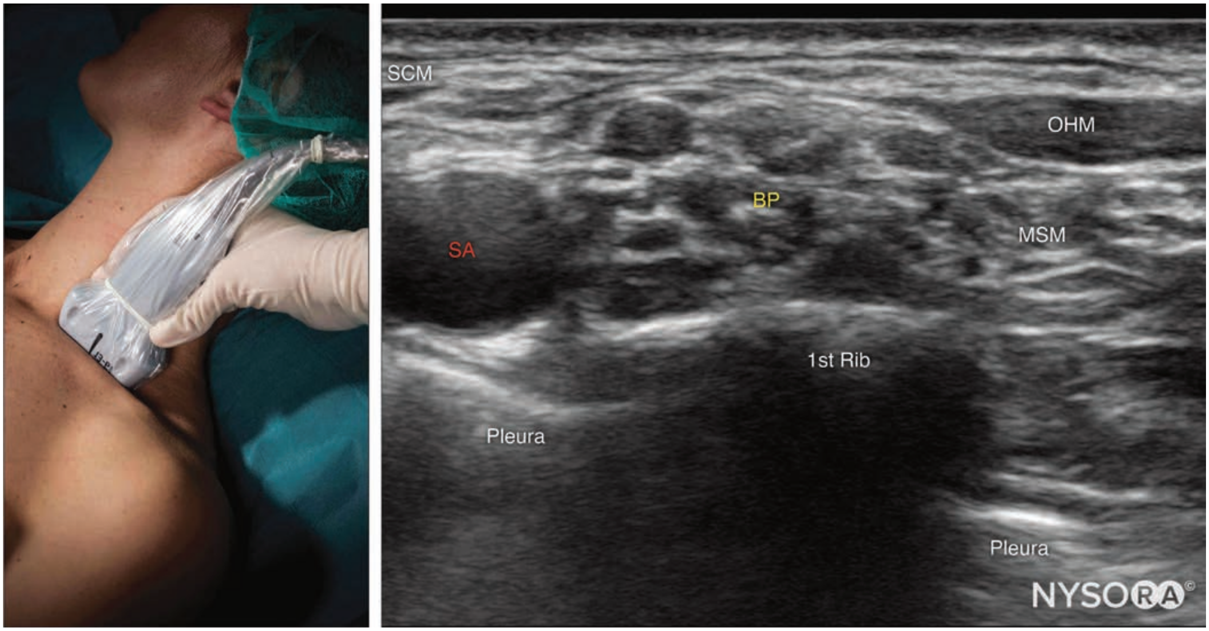


FIGURE 13-7. Transducer position at the supraclavicular fossa and ultrasound image obtained at this level. SCM, sternocleidomastoid muscle; SA, subclavian artery; BP, brachial plexus; OHM, omohyoid muscle; MSM, middle scalene muscle.

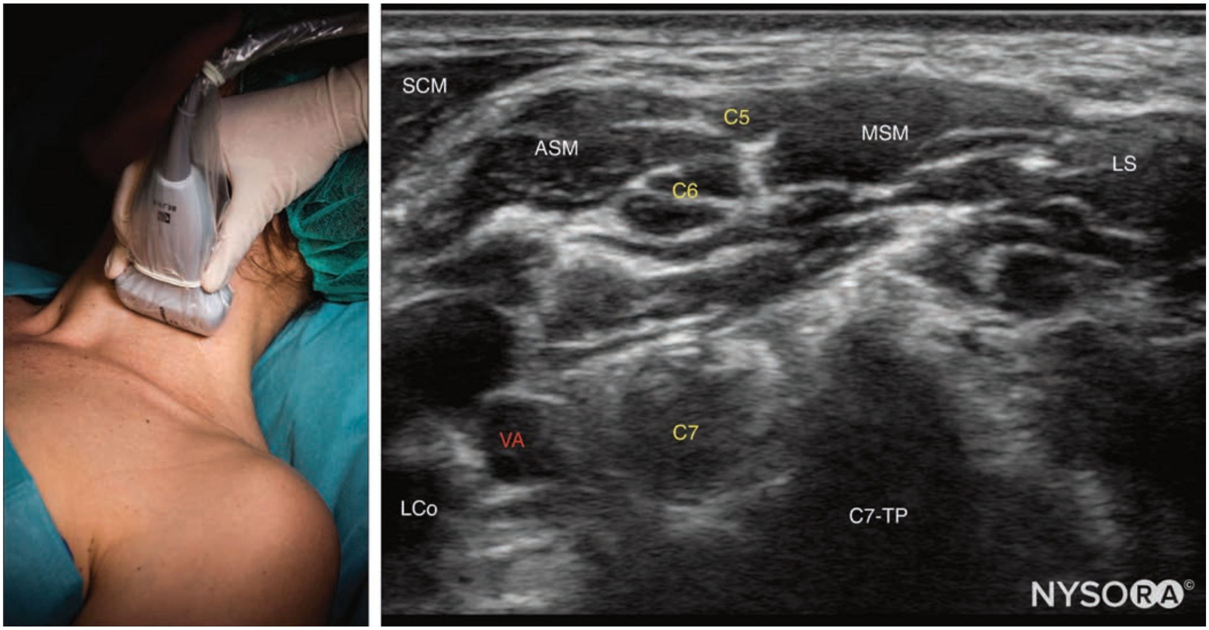


FIGURE 13-8. Transducer position to obtain initial ultrasound view of the brachial plexus at the interscalene groove. SCM, sternocleidomastoid muscle; ASM, anterior scalene muscle; MSM, middle scalene muscle; LS, levator scapulae muscle; LCo, longus colli muscle; C7-TP, transverse process of C7.

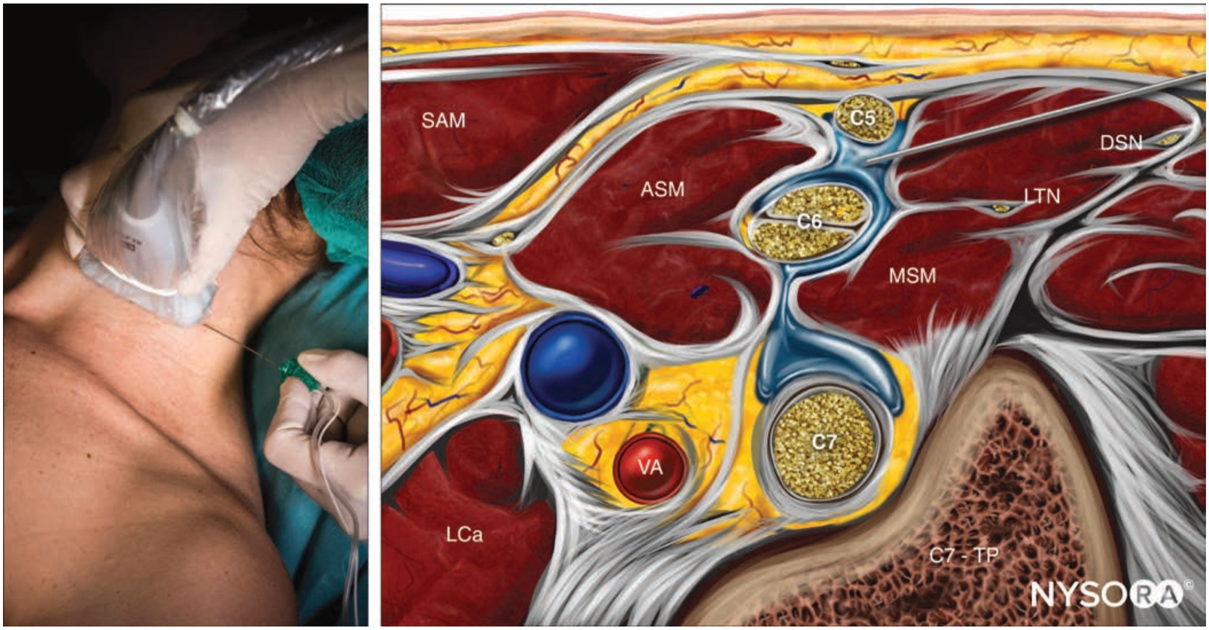


FIGURE 13-9. Reverse ultrasound anatomy with needle insertion in-plane for an interscalene brachial plexus block. Ideal local anesthetic spread (blue). ASM, anterior scalene muscle; MSM, middle scalene muscle and roots of the brachial plexus; SCM, sternocleidomastoid muscle; LCa, longus capitis muscle; VA, vertebral artery; LTN, long thoracic nerve; DSN, dorsal scapular nerve; C7-TP, transverse process of C7.

Problem-Solving Tips

- The neck is a highly vascular area, and care must be exercised to avoid needle placement or injection into the vascular structures (vertebral artery, thyrocervical trunk, inferior thyroid artery, suprascapular artery, and transverse cervical artery). Use color Doppler imaging before inserting the needle to rule out any blood vessels that might be in the path of the needle.
- Never inject against high resistance because high opening injection pressure (>15 psi) may indicate needle-nerve contact or an intrafascicular injection. In addition to the mechanical needle and injection injury to the nerve roots, intraneural needle placement may result in injection spread into the spinal canal.
- To confirm LA spread into the proper compartment, one can stop the injection after a few mL and trace the disposition of the injectate proximal-distal alongside the plexus. The transducer is then moved back to visualize the needle in order to complete the injection or to re-adjust the position of the needle.
- The lateral-to-medial insertion is often chosen to prevent injury to the phrenic nerve, which is typically located anteriorly to the anterior scalene, although one should be aware that the dorsal scapular nerve and the long thoracic nerve usually course through the middle scalene and could potentially be injured as well (Figure 13-10).
- C6 and C7 commonly split at this level; avoid injecting between the nerves coming from a single root as this has a risk of an intraneural injection. It is safer to inject between C5 and C6 or between the upper and middle trunk.
- When the root of C5 is showing in the anterior scalene, trace the root distally until it enters the interscalene space for the injection.
- Multiple injections should be avoided as they are unnecessary for brachial plexus block and may be associated with a higher risk of complications.

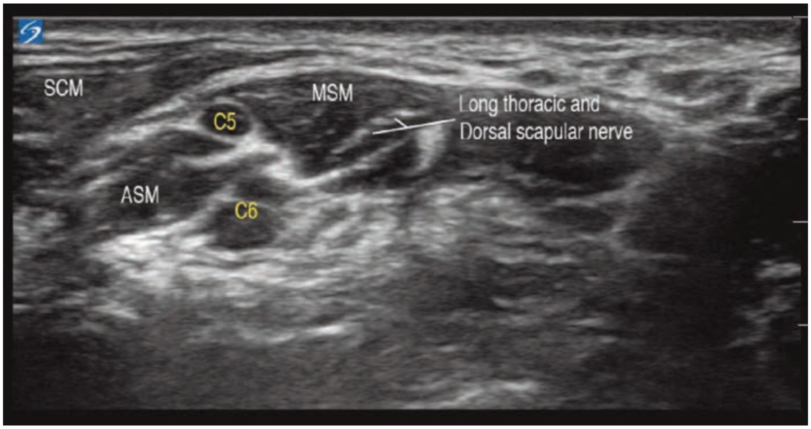
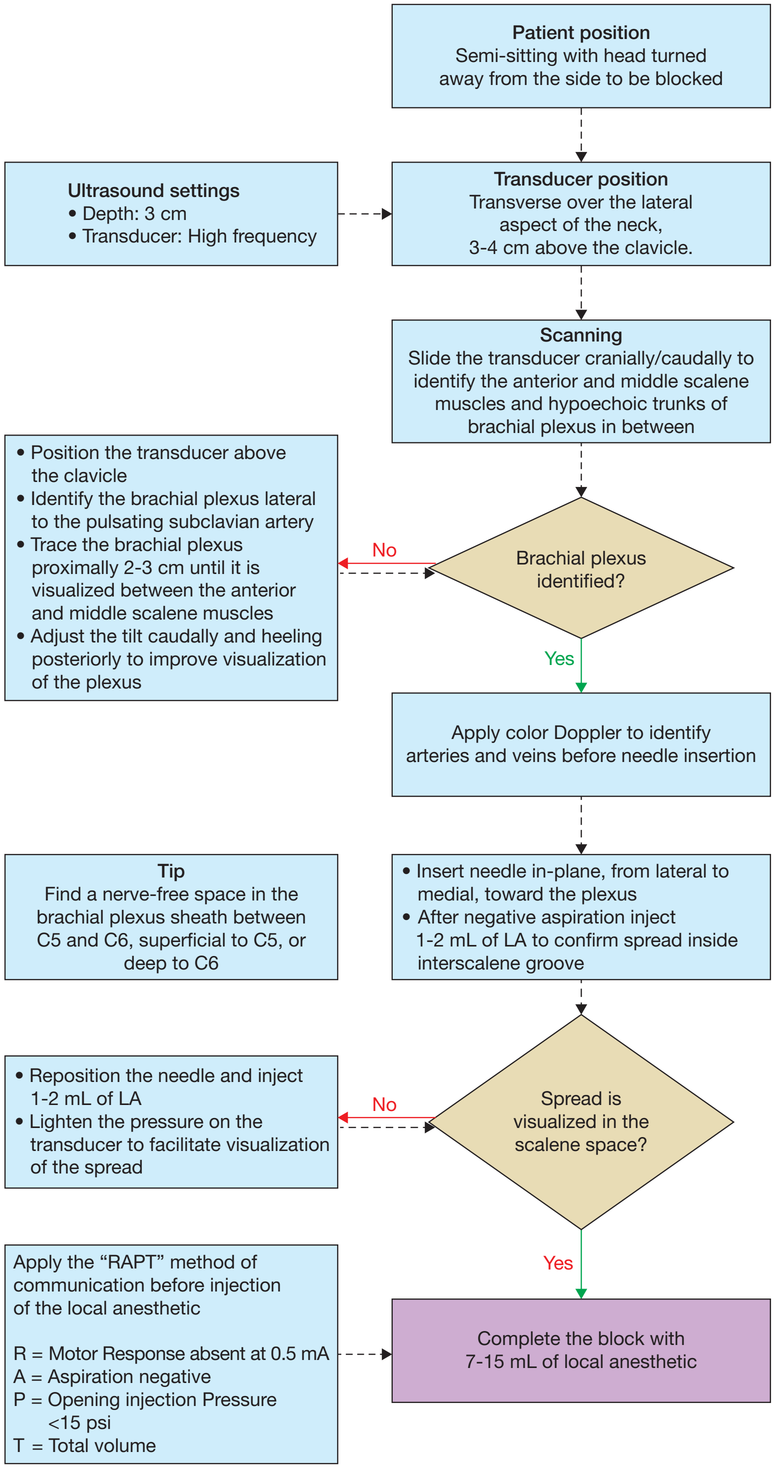


FIGURE 13-10. Ultrasound image showing the long thoracic and dorsal scapular nerves crossing the middle scalene muscle. SCM, sternocleidomastoid muscle; ASM, anterior scalene muscle; MSM, middle scalene muscle.

Flowchart

Interscalene Brachial Plexus Block Technique Algorithm



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14 Supraclavicular Brachial Plexus Block

BLOCK AT A GLANCE

Block of the brachial plexus at the level of the supraclavicular fossa.

- **Indications:** Anesthesia and analgesia for procedures on the shoulder, arm, elbow, forearm, and hand surgery
- **Goal:** Injection of the local anesthetic (LA) around the trunks and divisions of the brachial plexus via two separate injections—one for the lower trunk (10 mL) and one between upper and middle trunk (10 mL)
- **Local anesthetic volume:** 20 mL

General Considerations

The supraclavicular block is a commonly used technique for surgery of the upper extremity at or distal to the shoulder. As the trunks and divisions of the brachial plexus travel between the clavicle and the first rib, they are closely related to each other, therefore, affording supraclavicular block the fast, consistent, and complete block of the arm, forearm, and hand. Ultrasound (US) guidance has renewed the interest in the supraclavicular block due to its ability to visualize the plexus and avoid the vascular structures and the pleura. More precise needle placement using US allows better monitoring of the spread of LA and decreases the risk of complications caused by unintended pleural or vascular puncture. Different authors debate about the ideal position of the needle tip and the number of injections required. For instance, the so-called injection inside the "cluster" of neural structures has been reported to result in a faster onset than one injection deep to the brachial plexus ("corner pocket"). Some authors advise two separate injections (aiming at deep and superficial structures). However, considering that most studies show a similar success rate and that intracluster injection may carry a higher risk of intraneural injection, "intracluster" injection is not recommended.

A selective block of the upper (superior) trunk with low volume of LA (5 mL) is an alternative to the interscalene block for shoulder surgery. Also, because the suprascapular nerve departs posteriorly from the upper trunk, a selective block of this nerve for analgesia of the shoulder without phrenic nerve involvement is possible (see Chapter 18).

Limitations

The risk of phrenic nerve block is lower than with the interscalene block, but cannot be reliably avoided. Therefore, in patients who cannot tolerate a 20-30% decrease in respiratory function as it occurs with a phrenic block, an infraclavicular approach to brachial plexus block is a better choice for upper extremity surgery or analgesia.

Specific Risks

Pneumothorax is an uncommon but potentially life-threatening complication because it is typically delayed and may occur in an unmonitored setting after discharge home. It is paramount to monitor the needle advancement at all times. Nerve injury to the plexus due to intraneural needle placement, or suprascapular and long thoracic nerve injuries have also been described. Routine use of US, nerve stimulation, and injection pressure monitoring is recommended.

Anatomy

From a sagittal orientation in the interscalene space, the brachial plexus changes to a transverse orientation as the plexus approaches the costoclavicular outlet and the scalene muscles

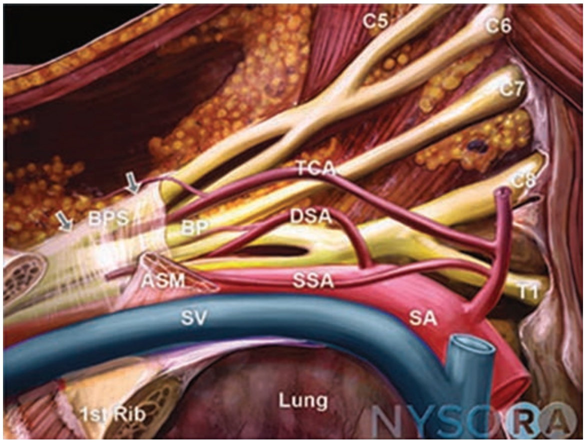


FIGURE 14-1. Anatomy of the brachial plexus at the supraclavicular level. BP, brachial plexus; BPS, brachial plexus sheath; ASM, anterior scalene muscle; SV, subclavian vein; SSA, suprascapular artery; SA, subclavian artery; DSA, dorsal scapular artery; TCA, transverse cervical artery.

diverge to insert on the first rib. In this short path, the three trunks give rise to anterior and posterior divisions, appearing as a compact group of multiple neural structures (Figure 14-1). The subclavian artery accompanies the brachial plexus crossing anteromedially and above the first rib to enter the infraclavicular fossa. The suprascapular and transverse cervical arteries (tyrocervical trunk) often course between the elements of plexus.

Cross-Sectional Anatomy and Ultrasound View

The brachial plexus and the subclavian artery cross over the first rib between the insertions of the anterior and middle scalene muscles, underneath the midpoint of the clavicle. Brachial plexus elements form an inverted triangular shape in between the artery (anterior), the rib and middle scalene muscle (inferior-posterior), and the omohyoid muscle (superficial). The dome of the pleura is located caudal to the artery and the rib. On US, the subclavian artery is readily apparent as an anechoic round structure, with the brachial plexus posterior and superficial to it as a group of hypoechoic round structures surrounded by thin layers of fascial sheaths. The pleura and the first rib can be seen as linear hyperechoic structures deep to the subclavian artery (Figure 14-2). The rib is more superficial and casts an acoustic shadow (anechoic image), while the pleura is seen on both sides of the rib, "sliding" with respiration. Crossing blood vessels can be seen in a transverse view, as hypoechoic nodules, similar to the neural structures, or in a longitudinal view crossing in between the plexus; therefore, color Doppler is recommended to detect them before the procedure.

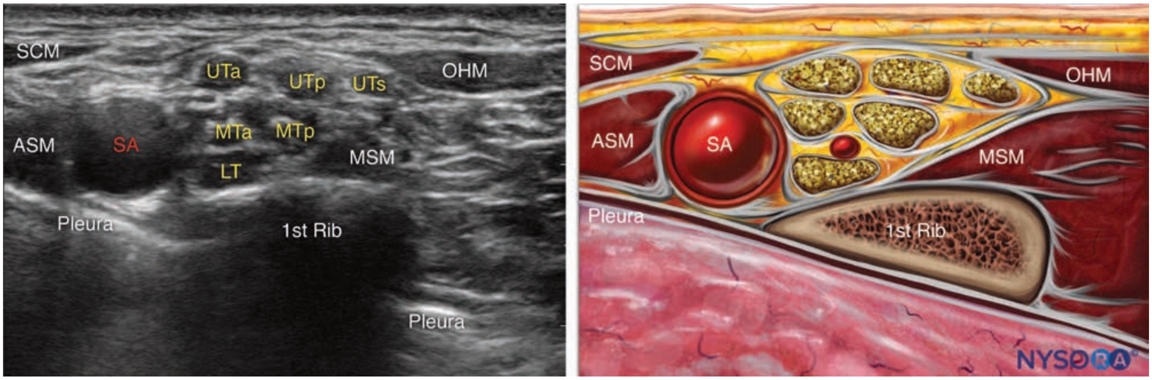


FIGURE 14-2. Ultrasound view and reverse anatomy illustration of the brachial plexus at the supraclavicular level. SA, subclavian artery; SCM, sternocleidomastoid muscle; ASM, anterior scalene muscle; UTa, UTp, and UTs, anterior, posterior, and suprascapular divisions of the upper trunk; MTa and MTp, anterior and posterior divisions of the middle trunk; LT, lower trunk; OHM, omohyoid muscle; MSM, middle scalene muscle.

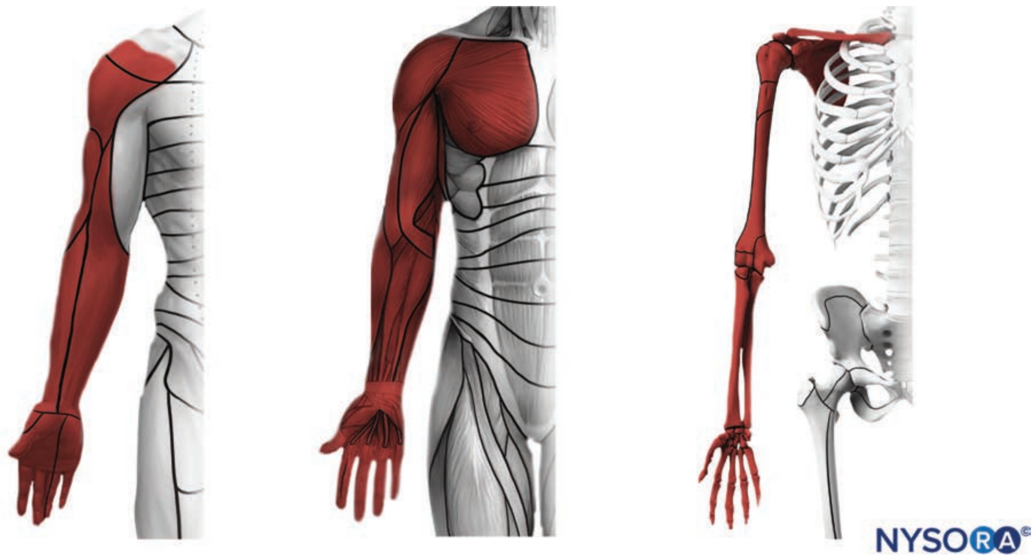


FIGURE 14-3. Expected sensory distribution of the supraclavicular brachial plexus block.

Distribution of Anesthesia and Analgesia

The supraclavicular brachial plexus block results in anesthesia of the entire upper extremity, including the shoulder, provided the suprascapular nerve is enclosed in the LA spread. However, the skin of the proximal part of the medial side of the arm (intercostobrachial nerve, T2) is not anesthetized (Figure 14-3). When cutaneous incision is needed in this area (e.g., vascular implants), the cutaneous fibers of the intercostobrachial nerve can be blocked by an additional subcutaneous injection at the axilla (see Chapter 17).

Block Preparation

Equipment

- Transducer: High-frequency linear transducer
- Needle: 5-cm, 22-gauge, short-bevel, insulated stimulating needle

Local Anesthetic

A short-acting (lidocaine 2%) or long-acting (bupivacaine 0.5% or ropivacaine 0.5%) according to the desired duration of the analgesia.

Patient Positioning

The block can be performed with the patient in the supine, semi-sitting, or semi-lateral position. A slight elevation of the head of the bed is often more comfortable for the patient and facilitates drainage of the neck veins. The patient's head must be turned away from the side to be blocked, the shoulder relaxed, and the arm positioned alongside the trunk to depress the clavicle slightly and allow better access to the posterior triangle of the neck (Figure 14-4).

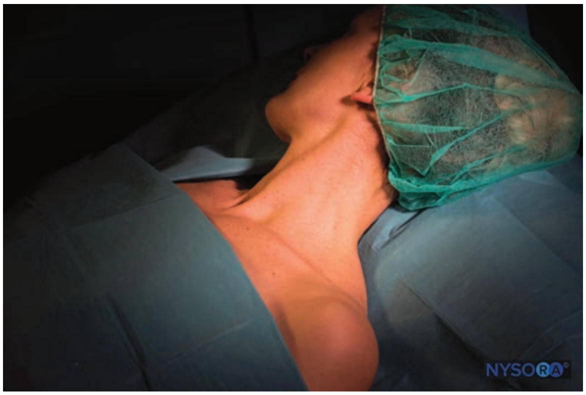


FIGURE 14-4. Patient position to perform a supraclavicular brachial plexus block.

Technique

Landmarks and Initial Transducer Position

Identify the base of the posterior triangle of the neck (between the mid-clavicle, the lateral border of SCM, and the anterior border of the trapezius muscle).

The transducer is positioned in a sagittal oblique plane immediately proximal and parallel to the clavicle (Figure 14-5).

Scanning Technique

The first goal is to obtain a clear cross-sectional view of the subclavian artery, the first rib, and the pleura underneath; this can be achieved by sliding and adjusting the tilt of the transducer. The elements of the brachial plexus are located posterior and superficial to the artery, contained within the brachial plexus sheath, typically at 1 to 2 cm depth. To enhance the view of the limits of this space, clockwise transducer rotation and alternating the pressure on the anterior or posterior edge of the transducer (heel-toeing) are recommended.

Although recognizing the individual elements is not necessary to perform a successful supraclavicular block, the individual trunks and divisions can be identified following the plexus craneo-caudally and tilting the transducer (Figure 14-5). The upper trunk is the most superficial structure, arising from C5-C6 and dividing into three components, the anterior division, posterior division, and suprascapular nerve, which can be selectively blocked at this level for analgesia of the shoulder (see Chapter 18). The middle trunk is the continuation of C7, whereas the lower trunk (C8-T1) is in close relationship with the artery and the first rib. Color Doppler should be routinely used prior to needle insertion to rule out the passage of large branches of the thyrocervical trunk.

Needle Insertion

The needle is advanced in-plane, typically from posterior to anterior, through the omohyoid muscle toward the brachial plexus. The first injection (10 mL) is deposited between the first rib and the lower trunk to ensure the block of the median and ulnar nerves. Insertion of the needle into the sheath is often associated with a perceptible loss of resistance. The needle is then withdrawn and carefully redirected toward the superficial elements of the brachial plexus to complete the injection between the divisions of the upper and middle trunks with an additional 10 mL of LA. Once the needle enters the fascial plane and after negative aspiration, the spread of LA is assessed and the position of the needle tip adjusted as needed, avoiding unnecessary advancement (Figure 14-6).

Local Anesthetic Distribution

For procedures at or below the arm, it is necessary that the spread of LA includes all elements of the brachial plexus at this level. For procedures on the shoulder, the spread of LA should target the upper and middle trunks.

Problem-Solving Tips

- Visualization: If the subclavian artery is not clearly seen, adjust the tilt of the transducer from sagittal to oblique. Once the artery is defined, the brachial plexus can be defined sliding the transducer craneo-caudally. Finally, scan as lateral as possible to image the first rib deep to the artery and plexus; the rib functions as a safety "net."
- Avoid needle placement into the vessels: the neck is a highly vascular area, and care must be exercised to avoid them. Use color Doppler before needle placement and aspirate every 5 mL before injection. The suprascapular artery is particularly commonly seen crossing the brachial plexus at this level. Other vessels can be found within the vicinity of the brachial plexus, such as the transverse cervical artery.
- Beware of the suprascapular and long thoracic nerves that can be in the needle path when advancing in-plane from posterior to anterior. Use nerve stimulator to detect muscular responses of the supraspinatus or serratus anterior muscles.
- Enter the needle at a shallow angle to assure its visualization and only then adjust the angle as needed, keeping the needle in view as it advances to avoid entering the pleura.

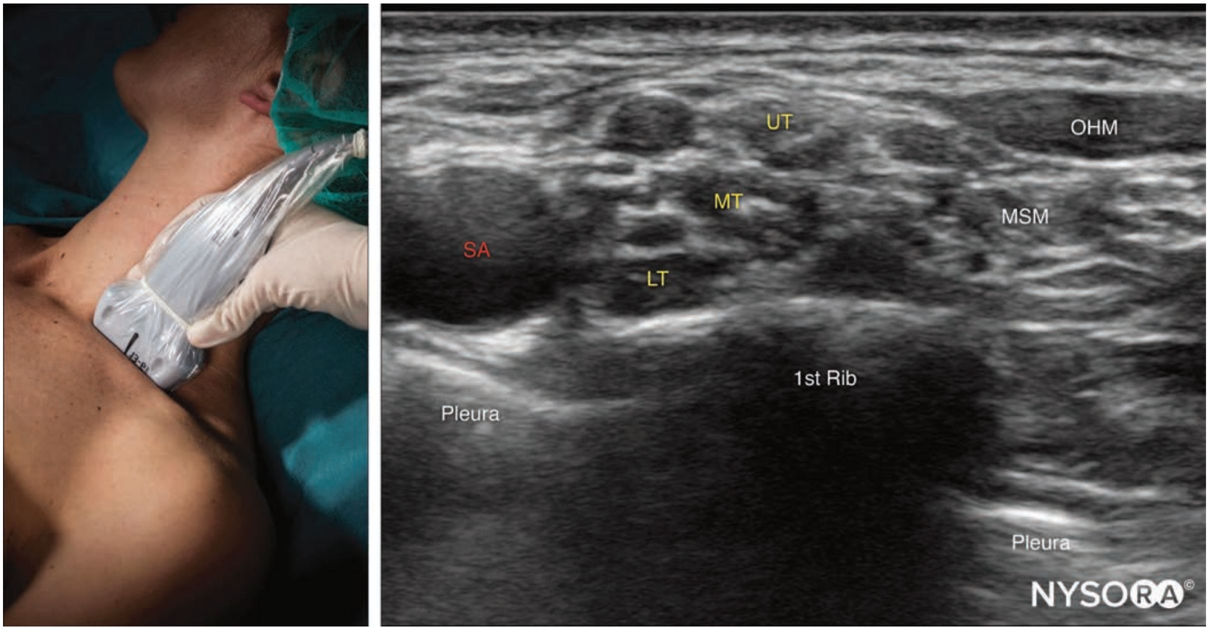


FIGURE 14-5. Transducer position and ultrasound image to perform a supraclavicular block. SA, subclavian artery; LT, lower trunk; MT, middle trunk; UT, upper trunk; MSM, middle scalene muscle; OHM, omohyoid muscle.

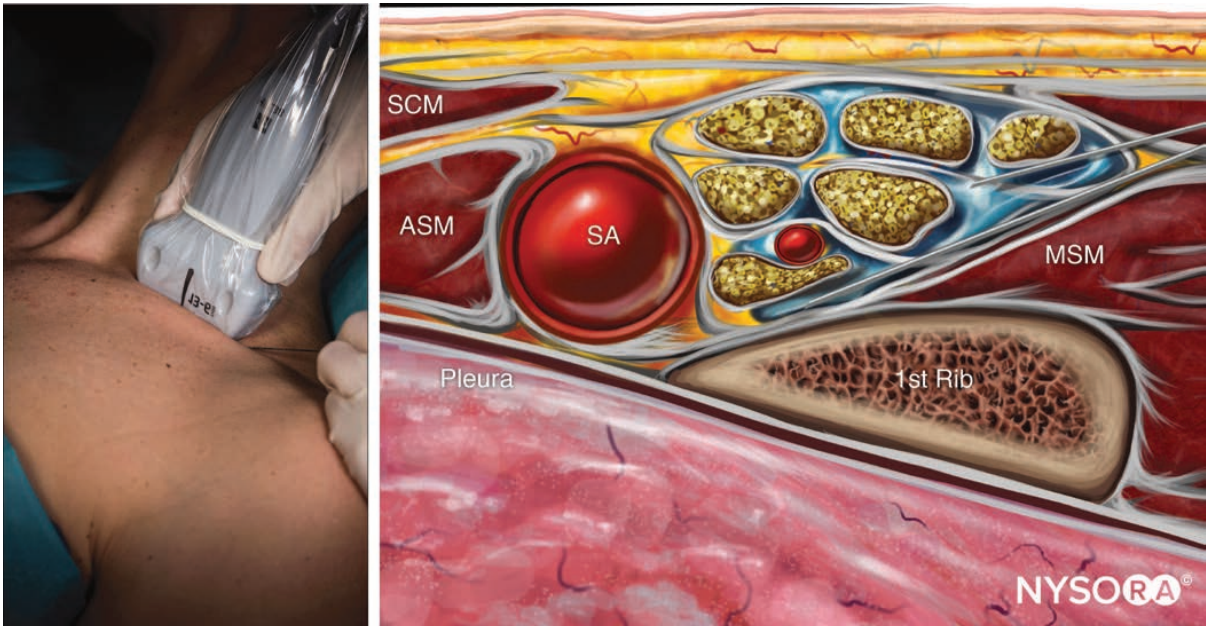
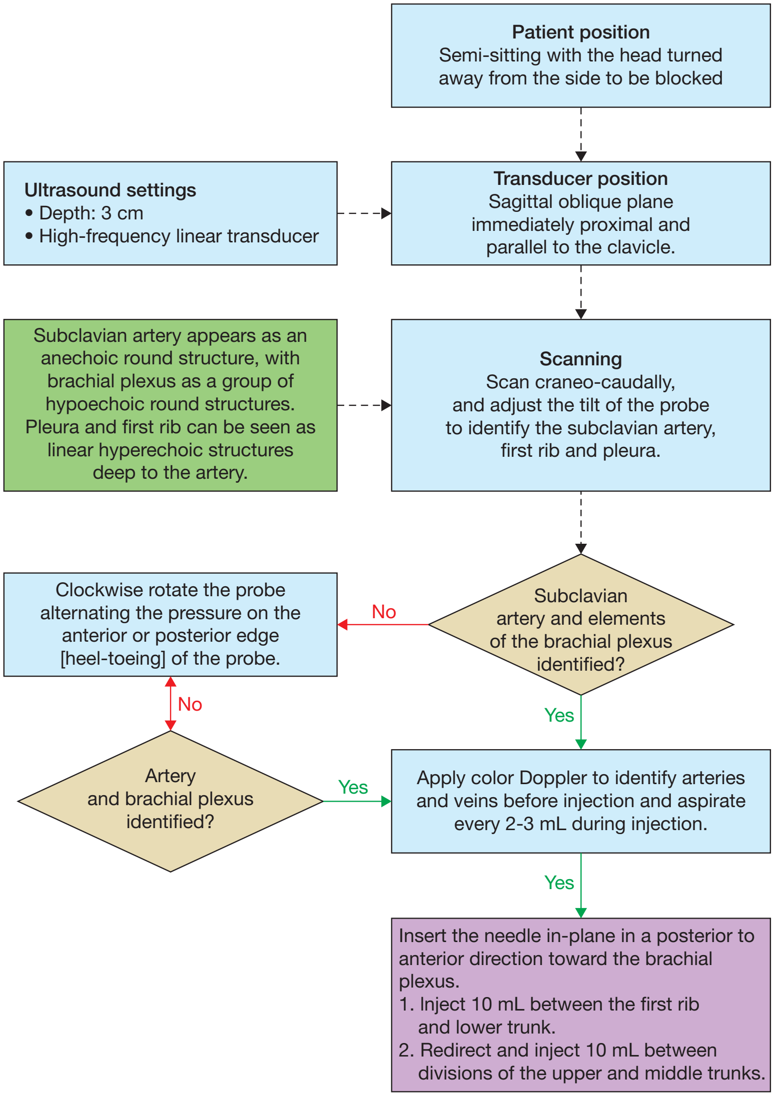


FIGURE 14-6. Reverse ultrasound anatomy with needle insertion in-plane for a supraclavicular brachial plexus block. Ideal LA spread around divisions of the brachial plexus (in blue). The first injection (1) placed in between the first rib and the lower trunk, and the second (2) between the divisions of the upper and middle trunks. SCM, sternocleidomastoid muscle; ASM, anterior scalene muscle; MSM, middle scalene muscle; SA, subclavian artery.

Flowchart

Supraclavicular Brachial Plexus Block Technique Algorithm



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15 Infraclavicular Brachial Plexus Block

BLOCK AT A GLANCE

Block of the brachial plexus at the level of the lateral infraclavicular fossa, deep to the pectoral muscles.

- **Indications:** Surgery on the arm, elbow, forearm, and hand
- **Goal:** Local anesthetic (LA) spread around the axillary artery next to the medial, posterior, and lateral cords of the brachial plexus
- **Local anesthetic volume:** 20 to 30 mL

General Considerations

The infraclavicular brachial plexus block is a well-established regional anesthesia technique for procedures below the shoulder. The infraclavicular block is devoid of respiratory symptoms that can occur with phrenic nerve palsy with supraclavicular and interscalene blocks. Compared to the axillary block, abduction of the arm is not absolutely necessary; therefore, an infraclavicular block may be more suitable in patients with painful fractures or requiring arm immobilization. An infraclavicular block is also suitable for catheter placement because the musculature of the chest wall may help to stabilize the catheter, preventing its dislodgement compared with the more superficial location of the interscalene or supraclavicular approaches.

Ultrasound (US) guidance facilitates the technique and provides more consistent practice by monitoring of the LA distribution. Although it is not always possible to reliably identify all three cords of the plexus at this position, a successful block can be accomplished simply by depositing the LA around the infraclavicular portion of the axillary artery around its lateral, posterior, and medial aspects. Anatomical studies suggest that several factors may negatively affect the success rate of the brachial plexus block at this level due to the anatomical variability among the cords and their location in the infraclavicular fossa. The infraclavicular periarterial space may also have septae and fascial layers within the neurovascular bundle that can prevent the spread of LA to all cords of the brachial plexus unless additional needle tip adjustments and injections are done. Recently, several other approaches to the infraclavicular plexus have been proposed to circumvent limitations of the classic lateral sagittal approach. In particular, the retroclavicular approach provides a better visualization of the needle, and the costoclavicular approach targets the plexus more proximally (see Chapter 16).

Limitations

The neurovascular bundle at the lateral infraclavicular fossa in patients with a large amount of adipose tissue or large pectoral muscles (e.g., obesity or bodybuilders) is positioned much deeper, making adequate imaging difficult. In these patients, a more proximal (e.g., supraclavicular) or more distal (e.g., axillary) approach to brachial plexus block may be more suitable.

Specific Risks

Although uncommon, the proximity of the pleural cavity theoretically poses the risk of pneumothorax. Injury to and dissection of the axillary artery has also been described.

Anatomy

The boundaries of the infraclavicular space are the pectoralis minor and major muscles anteriorly, serratus anterior and ribs medially, clavicle and the coracoid process superiorly, and the humerus laterally. On its descent, the brachial plexus organization changes as it progresses into the axilla as terminal nerves. The three cords (lateral, medial, posterior) enter the axillary fossa clustered lateral to the artery through the costoclavicular space, and then they twist to adopt a circumferential disposition around the axillary artery on their course deep to the pectoralis major and minor muscles (Figure 15-1). At this level, the organization of the brachial

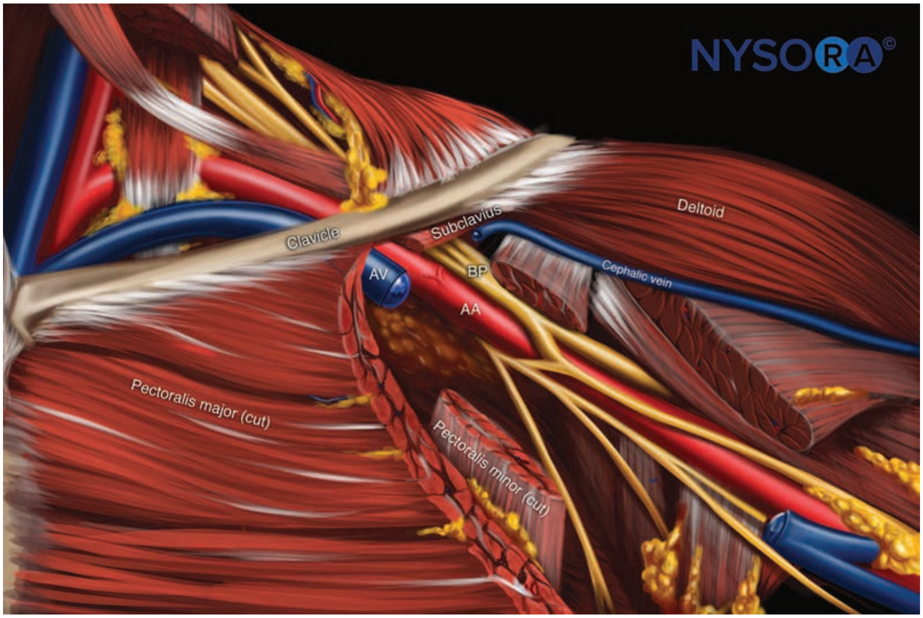


FIGURE 15-1. Anatomy of the brachial plexus at the infraclavicular fossa. AV, axillary vein; AA, axillary artery; BP, brachial plexus.

plexus is quite complex due to rearrangement of fascicles and departure of the terminal nerves. The axillary and musculocutaneous nerves may leave the brachial plexus at or cranially to the coracoid process in 50% of patients, possibly affecting the extent of the sensory blockade.

Cross-Sectional Anatomy and Ultrasound View

In a sagittal plane of the infraclavicular area just medial to the coracoid process, the axillary artery, vein, and the brachial plexus are positioned deep to the pectoralis minor muscle, anterior to the subclavius muscle, and lateral to the serratus anterior muscle. The dispositions of the cords at this level are located on the lateral, posterior, and medial side of the artery, according to their respective names, although there is a great deal of anatomic variation (Figure 15-2). The ribs and the pleura are deeper and medial to the neurovascular bundle. By placing the US transducer in the sagittal orientation and adjusting the tilt, it is possible to obtain clear views of both pectoralis muscles and their respective fasciae. The pulsation of the axillary artery appears in a cross-section underneath the fascia of the pectoralis minor muscle, whereas the axillary vein is seen as a compressible hypoechoic structure medial to it. The cords can often be seen as rounded hyperechoic structures lateral, posterior, and medial to the artery (Figure 15-3), while the chest wall and pleura can be identified medially and slightly deeper. Multiple other, smaller blood vessels are often present as well in the vicinity of the plexus.

Distribution of Anesthesia and Analgesia

The infraclavicular approach to brachial plexus block results in anesthesia of the arm below the shoulder (Figure 15-4). Although the axillary nerve is also anesthetized with an infraclavicular block, anesthesia and analgesia of the shoulder are not complete. However, selective blockade of the lateral and posterior cords in combination with a suprascapular nerve block has been proposed as a phrenic nerve-sparing technique for shoulder surgery (see Chapter 18). Similar to all other techniques of the brachial plexus, the infraclavicular block will not anesthetize the medial aspect of the skin of the proximal arm (intercostobrachial nerve, T2). However, in the infraclavicular area, the intercostobrachial nerve can be selectively blocked

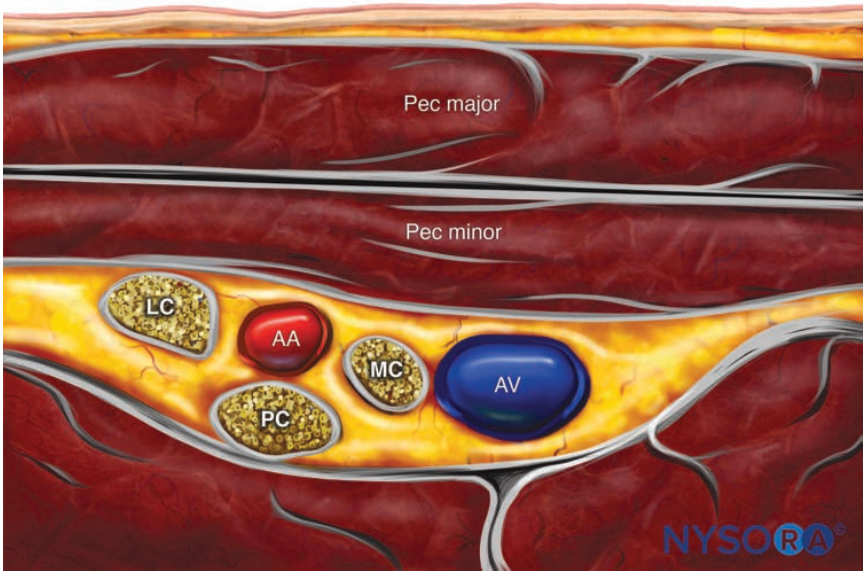


FIGURE 15-2. Cross-sectional anatomy of the lateral, posterior, and medial cords. AA, axillary artery; AV, axillary vein; MC, medial cord; LC, lateral cord; PC, posterior cord.

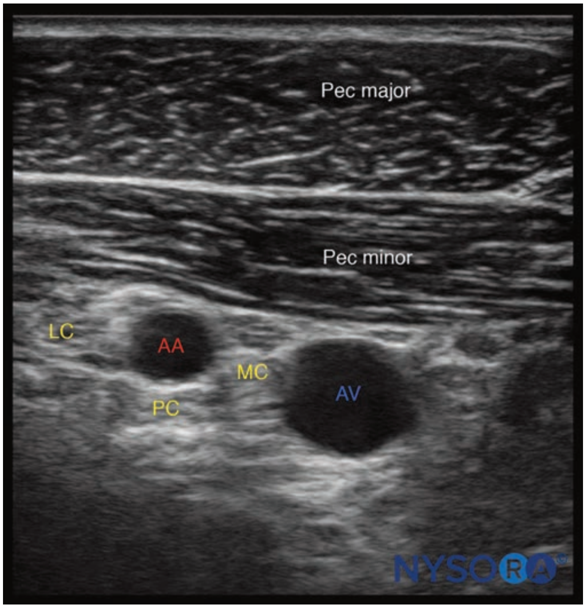


FIGURE 15-3. Infraclavicular block, ultrasound image. AA, axillary artery; AV, axillary vein; MC, medial cord; LC, lateral cord; PC, posterior cord.

by infiltrating LA between the pectoralis minor and serratus anterior at the level of the third rib.

Block Preparation

Equipment

- Transducer: High-frequency linear transducer
- Needle: 50-100 mm, 22-gauge, short-bevel, stimulating needle

Local Anesthetic

The sagittal paracorachoid approach requires higher volume (25-30 mL) of LA. Choices are short-acting (lidocaine 2%) or long-acting (bupivacaine 0.5%, levobupivacaine 0.5%, or ropivacaine 0.5%) according to the desired duration of the analgesia.

Patient Positioning

The patient is placed in the supine position with the head turned away from the side to be blocked. Abduction of the arm to 90° stretches the pectoral muscles, accentuates the pectoralis muscles' fasciae, and brings the neurovascular bundle more superficially, which facilitates visualization of the axillary artery and brachial plexus (Figure 15-5).

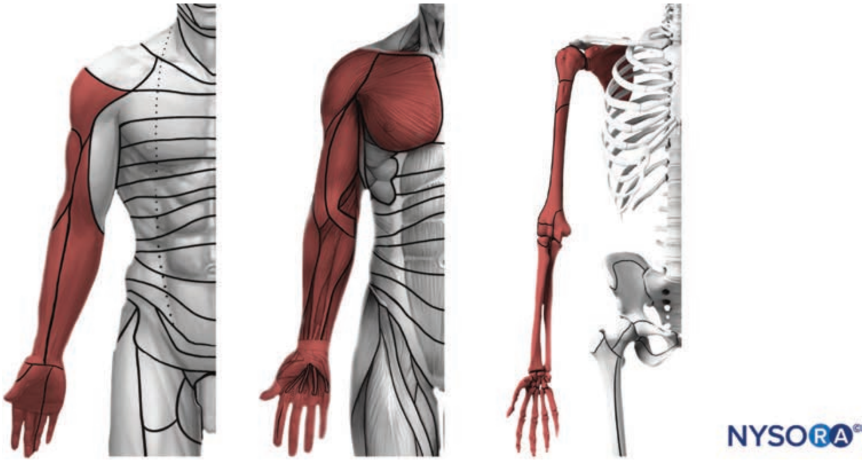


FIGURE 15-4. Distribution of anesthesia.

Technique

Landmarks and Initial Transducer Position

The coracoid process and the clavicle are the relevant surface landmarks that can be easily identified by palpating the bony prominences just medial to the shoulder. For the sagittal paracorachoid approach, the transducer is placed over the lateral infraclavicular fossa in a sagittal orientation medial to the coracoid process and caudal to the clavicle (Figure 15-6).

Scanning Technique

Scanning starts by identifying the pectoralis major, the pectoralis minor, and their fasciae by sliding the transducer in a cranial and caudal orientation. Visualization of the axillary artery and vein in a cross-section on the sonographic image is the primary goal in establishing the landmarks for the block. This may require adjustment of the depth, keeping in mind that the axillary artery is typically at a depth of 3 to 5 cm, depending on the thickness of the patient's chest wall musculature. To identify the hyperechoic cords of the brachial plexus on their corresponding positions relative to the artery, it is often necessary to apply some pressure and tilt the transducer, although not all cords are always visualized (Figure 15-6). The chest wall may be seen in the medial inferior aspect of the image, with the lung and pleura sliding in synchrony with respiratory movement.

FIGURE 15-5. Patient position.

Needle Approach and Trajectory

The needle is inserted in-plane from a cephalad-to-caudal direction, just inferior to the clavicle to pass through the pectoralis major and minor muscles, aiming toward the posterior aspect of the axillary artery (Figure 15-7). When the needle pierces the fasciae, a loss of resistance is often felt. If a motor response is elicited with the nerve stimulator, it is usually from the lateral cord (elbow flexion or finger flexion), because it can be on the path of the needle. If the needle is further advanced beneath the artery, a posterior cord motor response may appear (finger and wrist extension). After careful aspiration and avoiding high opening injection pressure, inject 1 to 2 mL of a LA to confirm proper needle tip placement and initial spread.

Local Anesthetic Distribution

The desirable spread of LA is around the axillary artery, medially and laterally, reaching all three cords (Figure 15-7). When a single injection does not appear to result in an adequate spread, reposition of the needle tip and further injections (up to 30 mL) under US visualization may be needed to accomplish a successful block.

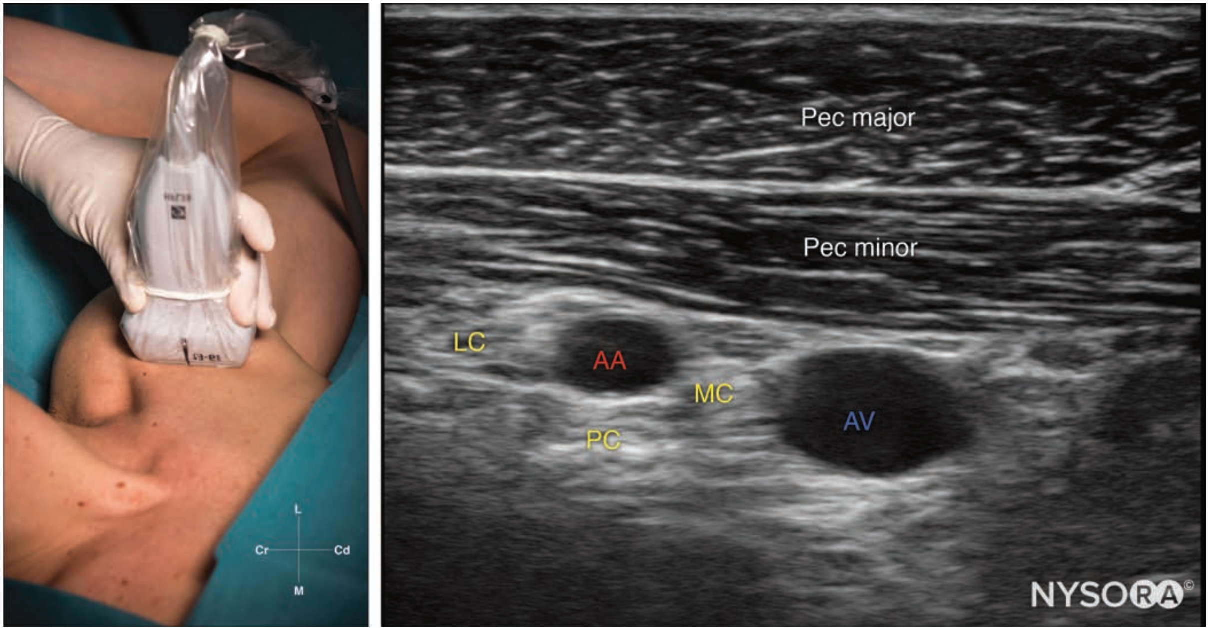


FIGURE 15-6. Desired transducer position and ultrasound image. AA, axillary artery; AV, axillary vein; MC, medial cord; LC, lateral cord; PC, posterior cord.

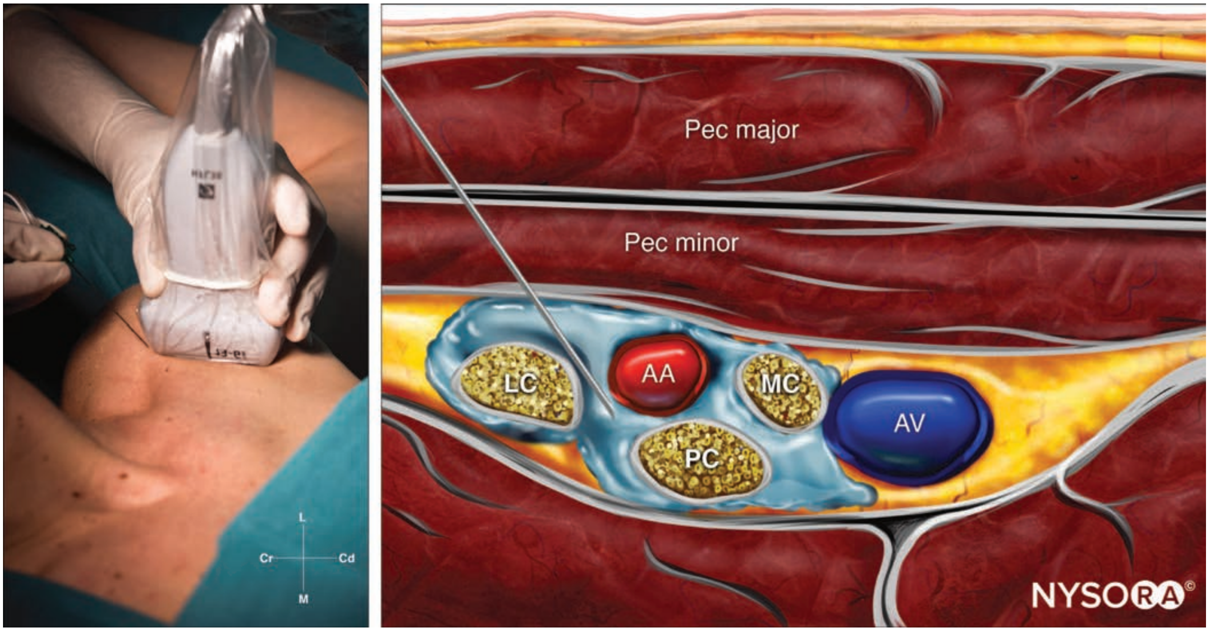


FIGURE 15-7. Reverse ultrasound anatomy with needle insertion (in-plane) in a cephalad-to-caudal direction to place needle tip post the axillary artery (AA). AV, axillary vein; MC, medial cord; LC, lateral cord; PC, posterior cord.

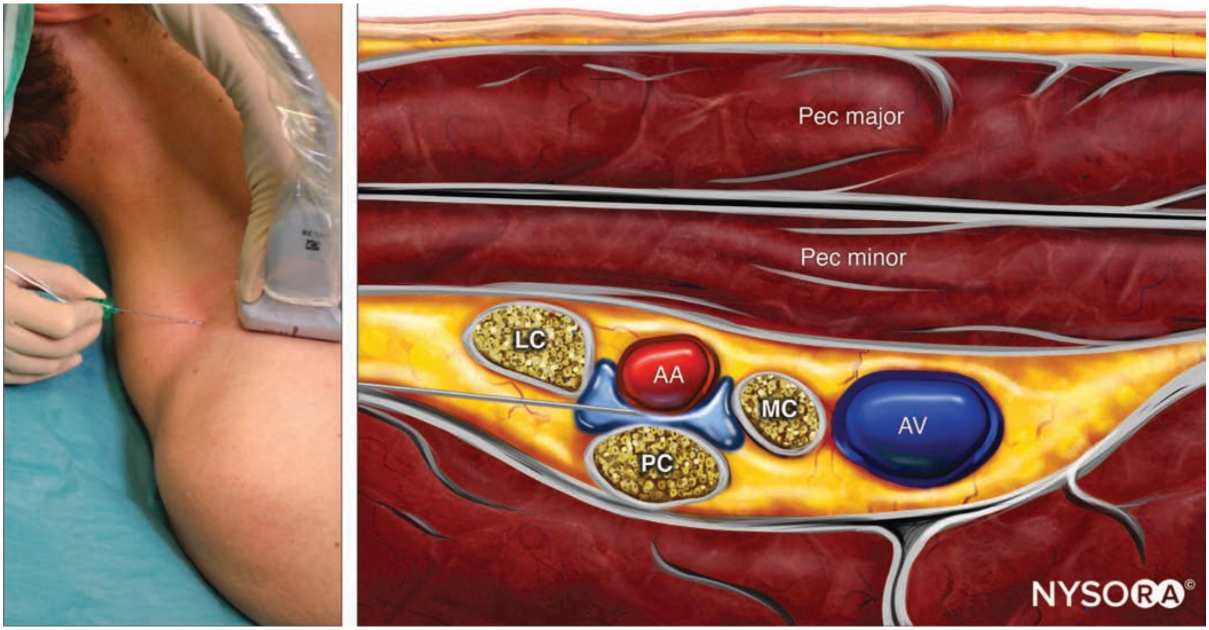


FIGURE 15-8. Reverse ultrasound anatomy with needle insertion in-plane from the supraclavicular fossa underneath the clavicle (retroclavicular approach). AA, axillary artery; AV, axillary vein; MC, medial cord; LC, lateral cord; PC, posterior cord.

Alternative Techniques

Over the last 10 years, alternative approaches for US infraclavicular blocks have been proposed to overcome the difficulties in the visualization of the plexus and the needle advancement due to the deep location of the structures.

Retroclavicular Approach

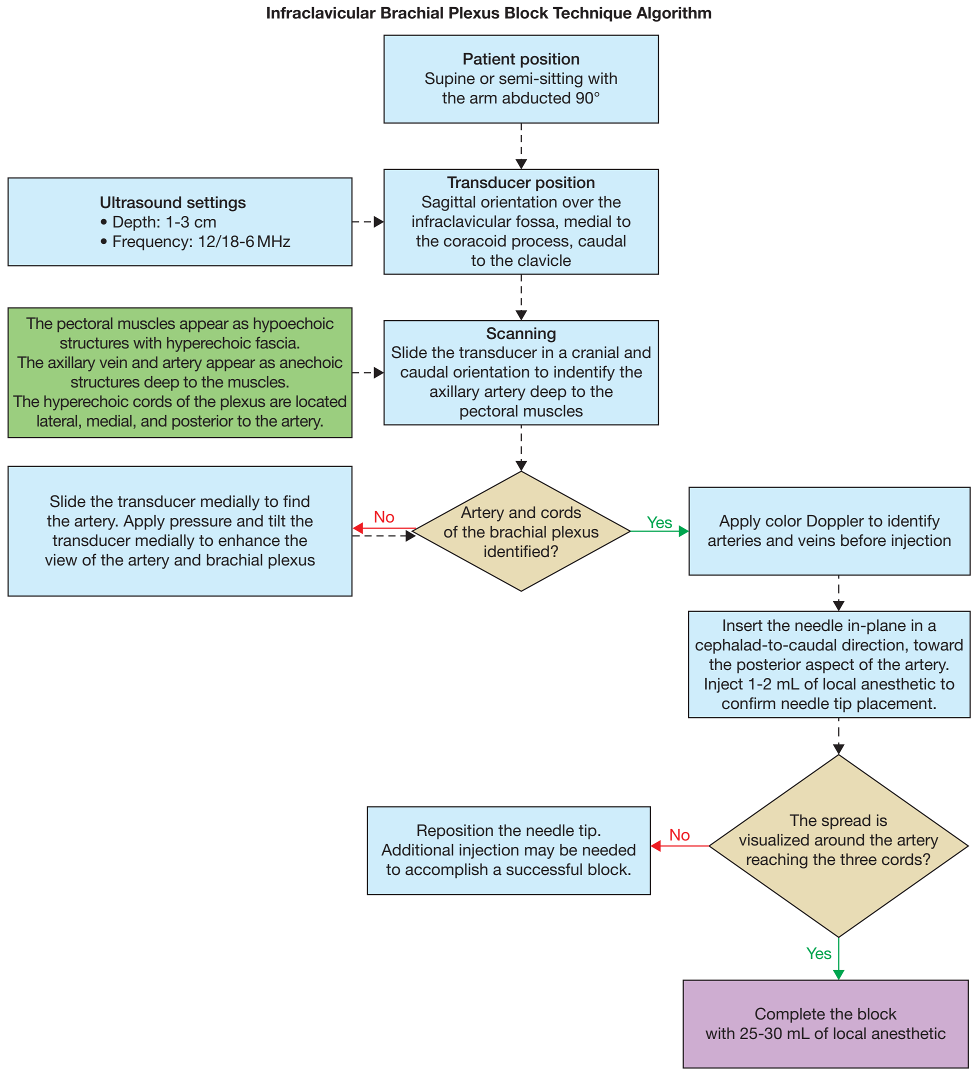
With the transducer in a sagittal position, the needle is advanced from the supraclavicular fossa, underneath the clavicle (Figure 15-8). A possible advantage of this approach is that the needle insertion is almost parallel to the transducer, resulting in greater visibility of the needle tip as it approaches the posterior aspect of the artery. Some anatomical structures that lie in the path of the traditional infraclavicular block (e.g., cephalic vein, and the acromial branch of the thoracoacromial artery) can be avoided, while others such as the suprascapular nerve and vein may be in the needle's way. Additionally, because the needle trajectory is more posterior, the risk of pneumothorax could be higher. Due to the acoustic shadow of the clavicle, needle advancement cannot be monitored for the first 3 to 4 cm after needle insertion. More safety data is required before suggesting this approach as a standard.

The costoclavicular approach is described in Chapter 16.

Problem-Solving Tips

- Rotating the probe to an oblique orientation (slightly moving the caudal end of the transducer medially) helps to image the neurovascular bundle in a more perpendicular plane, obtaining a cross-sectional image of the artery and cords.
- Applying color Doppler before needle insertion helps to detect vessels in the vicinity of the plexus and the needle path.
- Choose a needle of the appropriate length according to the depth of the posterior aspect of the artery. Echogenic needles are best suited when a steeper angle of insertion is presumed as in the infraclavicular approach.
- When the clavicle obstructs the needle entry or advancement, a heel-toeing maneuver (lifting the pressure of the cephalad end of the transducer in a sagittal plane and pressing the tissue on the caudal end) facilitates needle insertion.
- Aspirate every 3 to 5 mL to decrease the risk of intravascular injection.
- Make sure that the LA spreads medially around the artery to ensure the block of the medial cord.

Flowchart



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16 Costoclavicular Brachial Plexus Block

BLOCK AT A GLANCE

Block of the brachial plexus at the medial aspect of the infraclavicular fossa, close to the midpoint of the clavicle.

- **Indications:** Same as with traditional infraclavicular block—anesthesia and analgesia for the upper extremity, elbow, forearm, and hand surgeries. Analgesia for shoulder procedures.
- **Goal:** Local anesthetic (LA) spread between the three cords of the brachial plexus
- **Local anesthetic volume:** 15 to 20 mL

General Considerations

The ultrasound (US)-guided brachial plexus block at the costoclavicular space has been recently described as an alternative approach to the traditional infraclavicular block (sagittal paracoracoid approach deep to the pectoral muscles). Of note, the site of injection is similar to the landmark-based "vertical infraclavicular brachial plexus block" (VIB) described by Kilka et al. The compact organization of the brachial plexus at this level, clustered lateral to the artery and more superficial than in the traditional approach, may be more favorable to block with a single needle pass. The more cephalad spread of LA toward the supraclavicular fossa also may reach the trunks of the brachial plexus and, therefore, provide shoulder analgesia.

Few recent studies suggest that the onset of sensory and motor block may be somewhat faster compared to the paracoracoid approach and that lower volumes of LA may be efficacious.

Limitations and Specific Risks

The cephalic vein and the thoracoacromial artery may be on the needle's path. Care must be taken to avoid these vessels during needle advancement. Otherwise, risks are similar as for infraclavicular block and mostly related to the proximity of the axillary artery, vein, and the pleura.

Anatomy

The transition from trunks to cords of the brachial plexus occurs at the costoclavicular space, where all the neural elements travel flattened, arranged laterally to the axillary artery. It is at this level that the lateral and medial pectoral nerves leave the corresponding cords, whereas the subscapular and thoracodorsal nerves leave the posterior cord. More distally, the cords separate from each other and surround the axillary artery as they travel deep to the pectoral muscles (Figure 16-1).

Cross-Sectional Anatomy and Ultrasound View

The cords of brachial plexus at this location lie between the subclavius and the anterior serratus muscle, lateral to the artery, in a consistent relationship to each other. The lateral cord is in the most superficial, the posterior and medial cords lie lateral and medial respectively sharing a common sheath. The second rib can be imaged deep to the serratus muscle. The axillary vein is located medially to the artery and deep to the pectoralis major muscle (Figure 16-2).

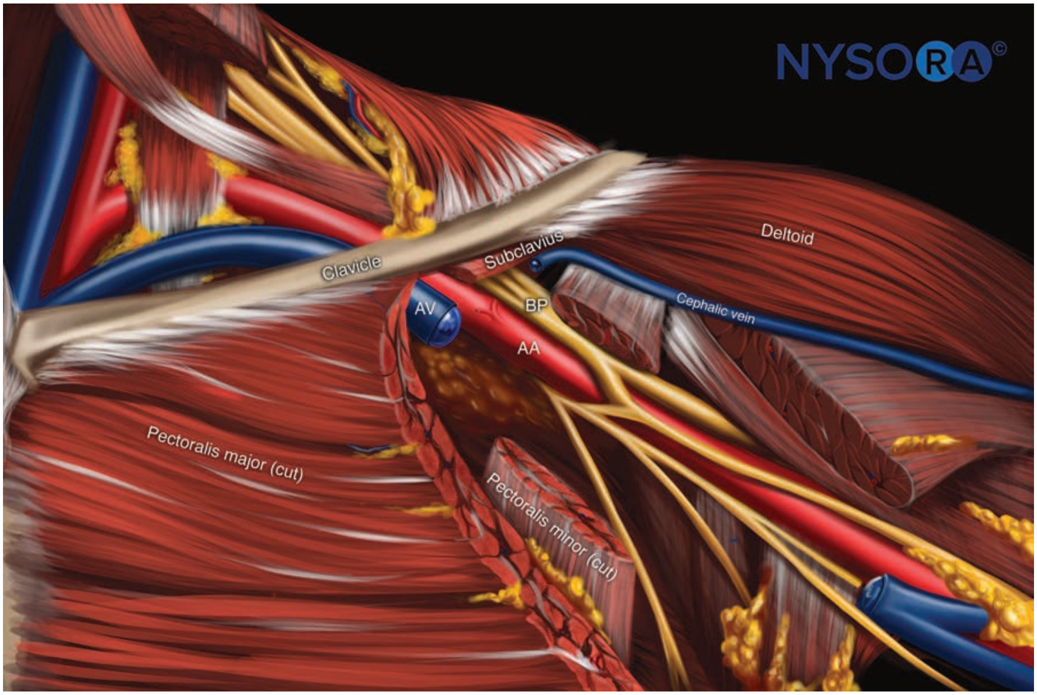


FIGURE 16-1. Functional anatomy of the brachial plexus for the costoclavicular approach. Note the relationship of the brachial plexus cords to the proximal axillary artery. BP, brachial plexus; AV, axillary vein; AA, axillary artery.

Distribution of Anesthesia and Analgesia

The costoclavicular approach results in sensory and motor block of the upper extremity and anterior shoulder (Figure 16-3). The cephalad spread of larger volumes (20 mL) of the LA may reach to the supraclavicular and the interscalene brachial plexus and result in a complete block of the shoulder. Larger volumes (35 mL) may even reach the phrenic nerve. The combination of low-volume costoclavicular block with a suprascapular nerve block is an effective alternative for shoulder surgery (see Chapter 18). Like with

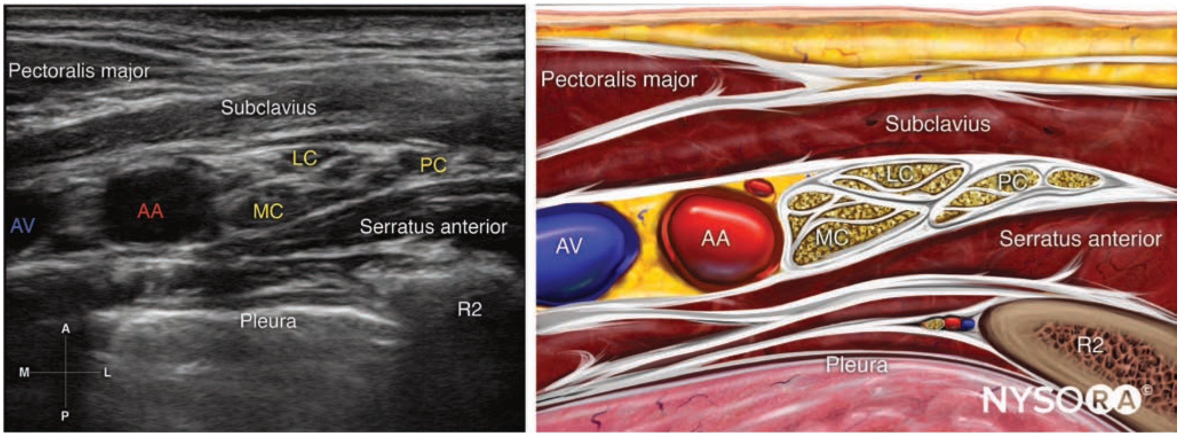


FIGURE 16-2. Sonoanatomy and reverse anatomy of the brachial plexus at the costoclavicular level. AA, axillary artery; AV, axillary vein; MC, medial cord; LC, lateral cord; PC, posterior cord; R2, second rib.

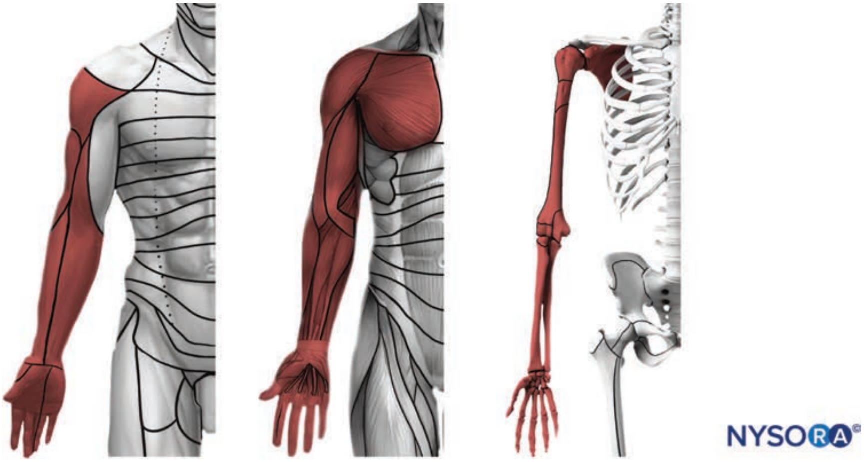


FIGURE 16-3. Distribution of anesthesia with the costoclavicular brachial plexus block.

any other brachial plexus block, the skin of the medial side of the upper arm is not anesthetized (that is innervated by the intercostobrachialis [T2]). When required, the skin of the medial aspect of the upper arm can be anesthetized by an additional subcutaneous injection on the medial aspect of the arm just distal to the axilla.

Block Preparation

Equipment

- Transducer: High-frequency linear transducer
- Needle: 50-mm, 22-23 gauge, insulated needle

Patient Positioning

The block can be performed with the patient in the supine or semi-sitting position, and a slight elevation of the head of the bed may improve the patient's comfort and exposure of the anatomy. The patient's head is turned away from the side to be blocked, and if possible, the arm is abducted 90° to facilitate the view of the plexus as it positions the plexus more superficially (Figure 16-4).

Technique

Scanning Technique

Position the transducer in the medial infraclavicular fossa parallel and next to the clavicle to identify the axillary artery. The transducer is then tilted cephalad to image the brachial plexus and the artery in a perpendicular orientation between the subclavius muscle and the serratus anterior. The three cords are visualized in a single transverse US scan superficial and lateral to the artery as a triangular shaped hyperechoic structure (Figure 16-5). Releasing the pressure on the transducer and applying color Doppler is useful to determine the location of the cephalic vein and thoracoacromial artery.

Needle Approach and Trajectory

The needle is advanced in-plane in a lateral-to-medial direction, adjusting the angle to reach the space in between the three cords (ideally through the gap between the lateral and posterior cord). After negative aspiration, 1-2 mL of LA is injected to confirm the spread in between the three elements (Figure 16-6). An alternative approach is to advance the

FIGURE 16-4. Recommended patient position for a costoclavicular brachial plexus block.

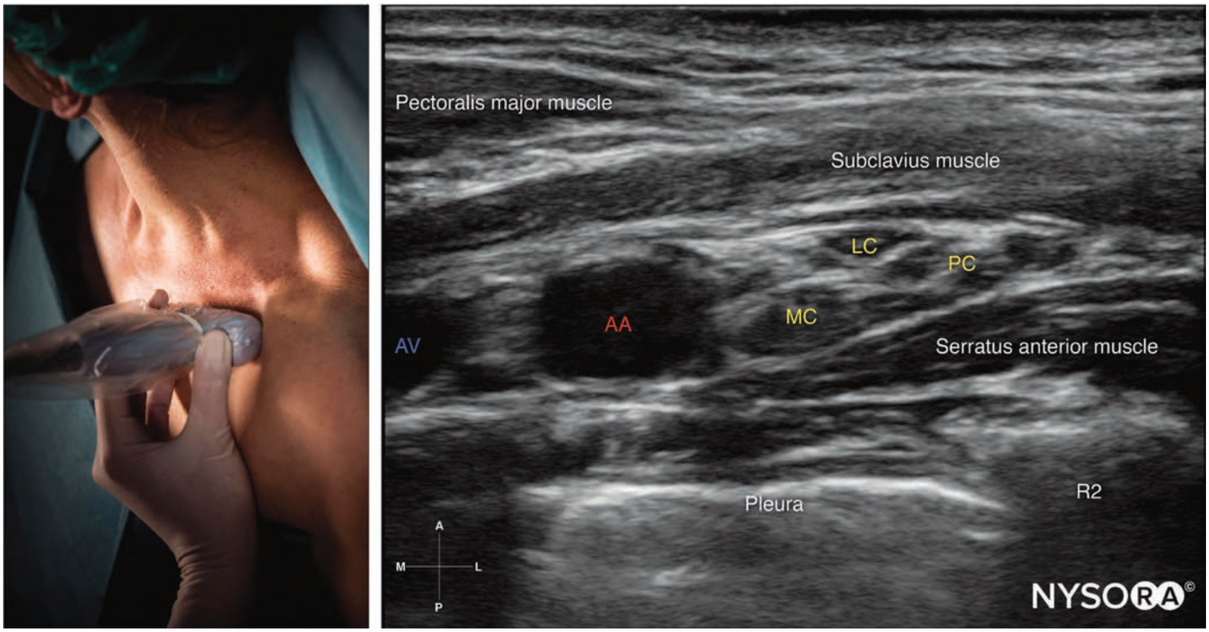


FIGURE 16-5. Transducer position and ultrasound image required for a costoclavicular block. AA, axillary artery; AV, axillary vein; MC, medial cord; LC, lateral cord; PC, posterior cord; R2, second rib.

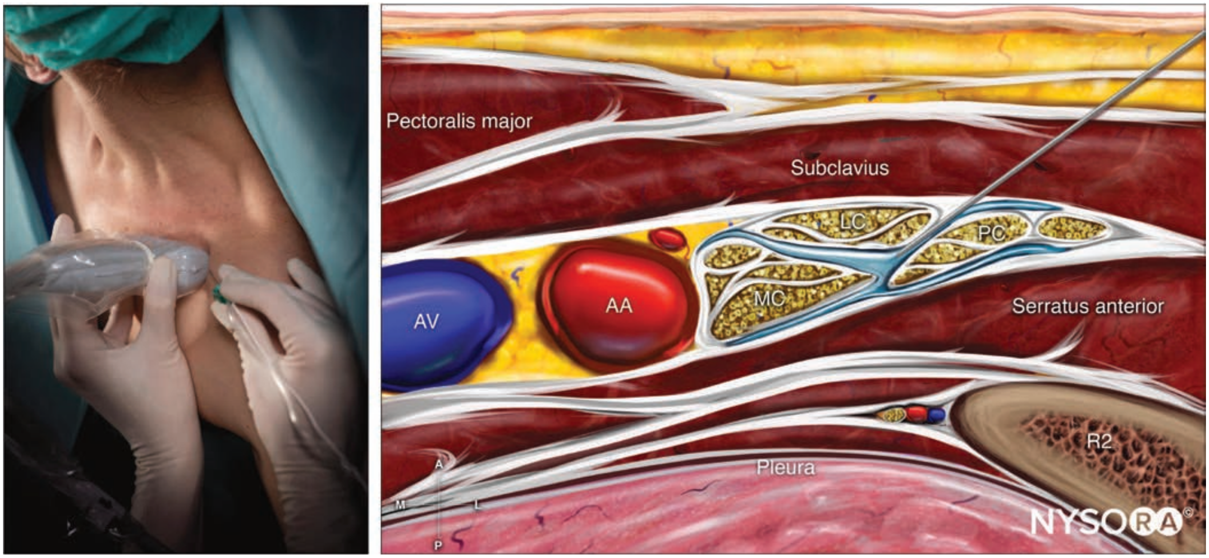


FIGURE 16-6. Reverse ultrasound anatomy with needle insertion (in-plane) from lateral to medial and desired spread between the cords. AA, axillary artery; AV, axillary vein; MC, medial cord; LC, lateral cord; PC, posterior cord; R2, second rib.

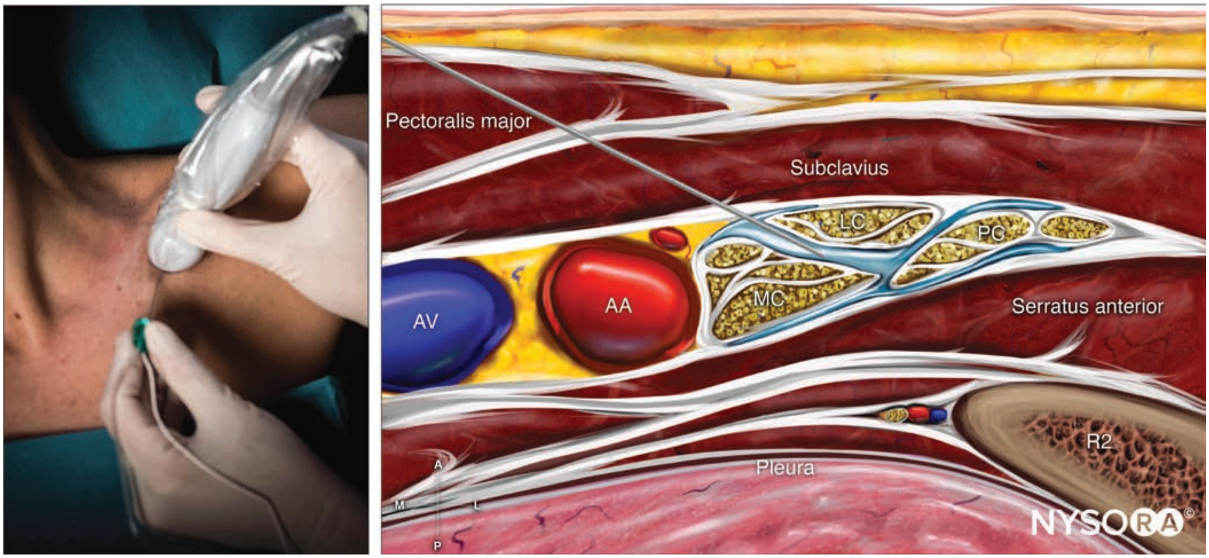


FIGURE 16-7. Reverse ultrasound anatomy with an alternative needle insertion (in-plane), from medial to lateral. AA, axillary artery; AV, axillary vein; MC, medial cord; LC, lateral cord; PC, posterior cord; R2, second rib.

needle in-plane from medial to lateral aiming for the space between the artery and the lateral cord (Figure 16-7).

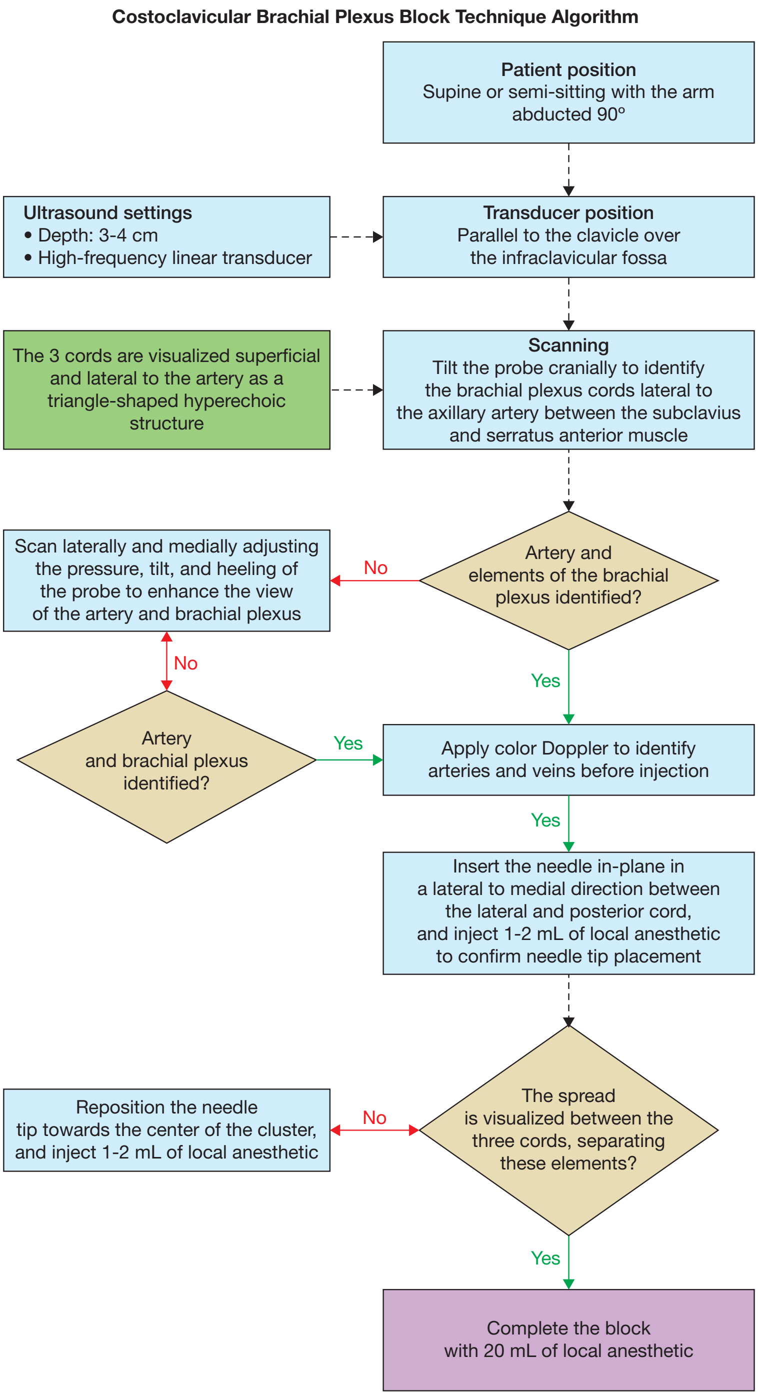
Local Anesthetic Distribution

The ideal spread will result in separation of the three cords by the LA with a single injection. When necessary, the needle tip is advanced further in between the medial and posterior cords through the sheath that bounds the two elements, to complete the injection. Studies to date suggest that a volume between 15 and 20 mL suffices to achieve a consistent spread and fast onset of the blockade.

Problem-Solving Tips

- During scanning, apply pressure and tilt the transducer cephalad to optimize the US image and identify all three cords of the brachial plexus lateral to the axillary artery.
- 20 mL of LA are adequate for a satisfactory block. Future research is needed to determine the optimal dose or volume of LA required to produce a block at this level.

Flowchart


Costoclavicular Brachial Plexus Block Technique Algorithm
Patient position
Supine or semi-sitting with the arm abducted 90°
Ultrasound settings
• Depth: 3-4 cm
• High-frequency linear transducer
Transducer position
Parallel to the clavicle over the infraclavicular fossa
The 3 cords are visualized superficial and lateral to the artery as a triangle-shaped hyperechoic structure
Scanning
Tilt the probe cranially to identify the brachial plexus cords lateral to the axillary artery between the subclavius and serratus anterior muscle
Scan laterally and medially adjusting the pressure, tilt, and heeling of the probe to enhance the view of the artery and brachial plexus
No
Artery and elements of the brachial plexus identified?
No
Yes
Artery and brachial plexus identified?
Yes
Apply color Doppler to identify arteries and veins before injection
Yes
Insert the needle in-plane in a lateral to medial direction between the lateral and posterior cord, and inject 1-2 mL of local anesthetic to confirm needle tip placement
Reposition the needle tip towards the center of the cluster, and inject 1-2 mL of local anesthetic
No
The spread is visualized between the three cords, separating these elements?
Yes
Complete the block with 20 mL of local anesthetic

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17 Axillary Brachial Plexus Block

BLOCK AT A GLANCE

Block of the terminal nerves of the brachial plexus at the level of the axilla.

- **Indications:** Elbow, forearm, and hand surgery
- **Goal:** Local anesthetic (LA) spread around the axillary artery next to the median, ulnar, radial, and medial antebrachial cutaneous nerves. Separate injection often required for the musculocutaneous nerve (between the biceps and coracobrachialis muscle).
- **Local anesthetic volume:** 15 to 20 mL

General Considerations

The axillary brachial plexus block is a well-established, widely used regional anesthesia technique for procedures of the upper extremity at and below the elbow. The superficial location of the terminal nerves at this level, in the same sheath as the axillary artery, simplifies the technique and reduces the risk of complications compared with more proximal brachial plexus blocks. Ultrasound (US) monitoring of the LA spread has improved the success rate of the axillary block, including the musculocutaneous nerve. This is because the musculocutaneous nerve separates from the neurovascular bundle proximal to the level of injection and presents numerous anatomical variations. A perivascular technique, consisting of two injections anterior and posterior to the artery, results in a similar success rate and shorter procedural time than the perineural approach, which relies on identification and injections next to each individual nerve. However, the latter may result in faster block onset. The quality of US view and the relative disposition of the vascular and neural structures will dictate the best option in each case.

Anatomy

The terminal nerves of the brachial plexus emerge from the cords proximally in the axillary fossa and travel distally toward the upper extremity surrounding the axillary artery, passing superficial tand anterior o the insertion of the conjoint tendon on the humerus (Figure 17-1). The radial nerve originates from the posterior cord, runs posterior to the artery in close contact with the conjoint tendon, and turns deep posterior to enter the spiral groove of the humerus. The median nerve is formed by fascicles of the medial and lateral cords and it is located typically anterior and lateral to the artery. The ulnar nerve is the continuation of the medial cord and travels along the medial side of the artery. The musculocutaneous nerve

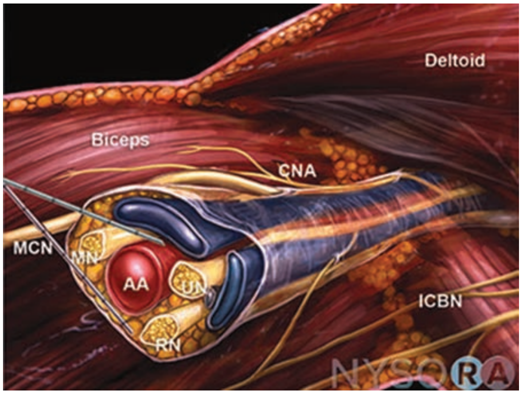


FIGURE 17-1. Terminal nerves of the brachial plexus. AA, axillary artery; McN, musculocutaneous nerve; MN, median nerve; UN, ulnar nerve; RN, radial nerve; CNA, cutaneous nerve of arm; ICBN, intercostobrachial nerve.

arises proximally from the lateral cord and it is located at a variable distance from the artery in the fascial plane between the coracobrachialis and the biceps muscles or the body of the coracobrachialis.

Cross-Sectional Anatomy and Ultrasound View

The neurovascular bundle is located superficially at the junction of the arm and the axilla, contained in a triangular space limited by the conjoint tendon (posterior), the biceps muscle (lateral), and the brachial fascia and subcutaneous tissue (anteromedial). The axillary artery is located approximately within a centimeter of the skin surface and can be palpated on the medial aspect of the proximal arm. Accompanying the artery there are one or more axillary veins, usually located medially. The ulnar, median, and radial nerves are contained within the neurovascular bundle, surrounding the axillary artery. The medial brachial and antebrachial cutaneous nerves may travel either inside or outside, while the musculocutaneous nerve is frequently located outside. However, different anatomical variations are usually found (Figure 17-2).

On US, the artery and veins are identified in the triangular musculofascial space mentioned above. The three nerves appear as groups of round hyper- or hypoechoic structures moving around the artery. The musculocutaneous nerve is seen as a hypoechoic oval structure surrounded by a bright hyperechoic rim made by the confluence of the fasciae of the biceps and coracobrachialis.

Distribution of Anesthesia and Analgesia

The axillary brachial plexus block results in anesthesia of the upper extremity from the mid-arm down to the hand. Importantly, the axillary block does not anesthetize the axillary nerve (it departs more proximally from the posterior cord). Therefore, the shoulder or skin over the deltoid muscle is not anesthetized (Figure 17-3). Similar to all other techniques of the brachial plexus, the infraclavicular block will not anesthetize the medial aspect of the skin of the proximal arm (intercostobrachial nerve, T2).

Block Preparation

Equipment

- Transducer: High-frequency linear transducer
- Needle: 5-cm, 22-23 gauge, short-bevel, stimulating needle

Local Anesthetic

Ropivacaine 0.5%, bupivacaine 0.5%, or lidocaine 2% are commonly used in axillary block. The minimum volume of LA for a successful block has been reduced with US guidance, compared to the traditional technique. Typically, 15 to 20 mL in total, 3 to 5 mL per nerve, is adequate. Effective axillary brachial plexus blocks have been described even with lower volumes (<2 mL per nerve).

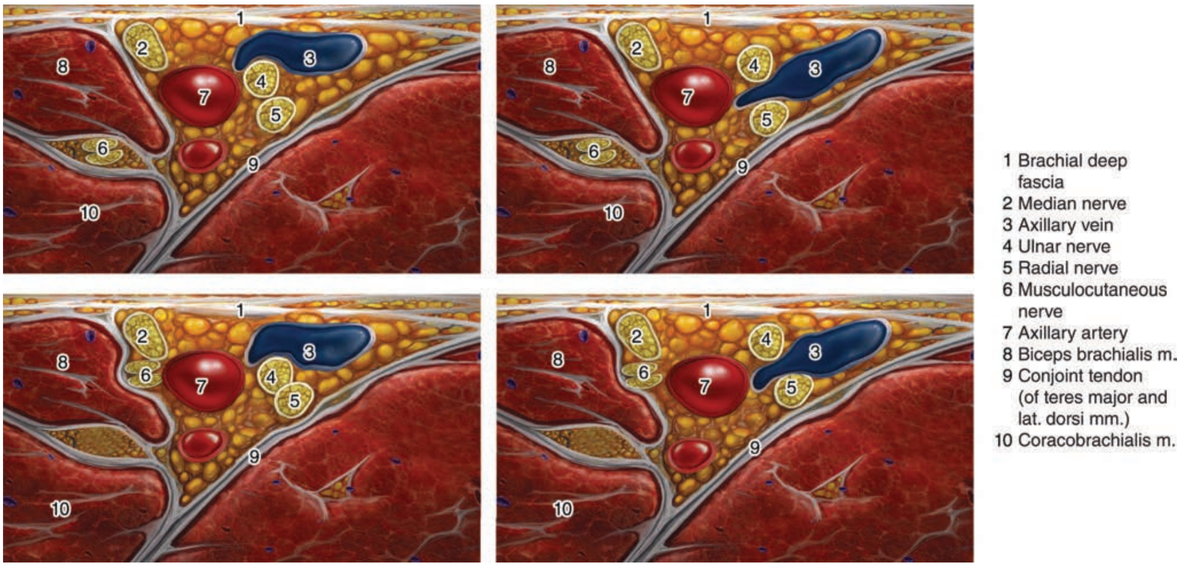


FIGURE 17-2. Common anatomical variations of the axillary brachial plexus.

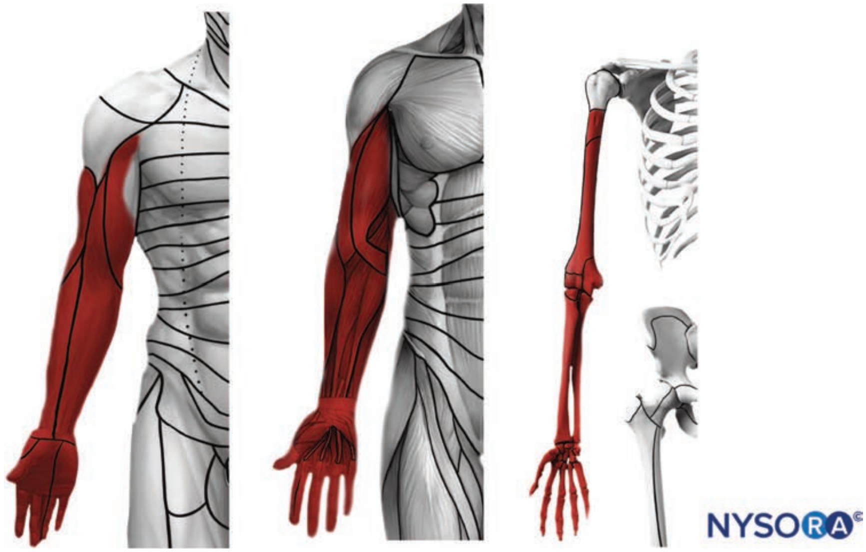


FIGURE 17-3. Distribution of anesthesia with axillary brachial plexus block.

Patient Positioning

The patient is placed in the supine or mild upright position with the arm abducted 90° and elbow flexed 90° (Figure 17-4). A semi-upright position will provide more patient comfort during block placement without compromising anatomy or needle approach. Likewise, abduction of the shoulder 90° and extension of the elbow (0°) may be better tolerated by patients with reduced upper extremity mobility. Avoid over-abduction as it may cause traction on the brachial plexus, rendering it more vulnerable to injury, as well as patient discomfort. The position of the shoulder and elbow has been reported to influence the relative position and distance between the nerves in the axilla, although this may be clinically irrelevant for the success of the block.

FIGURE 17-4. Patient position.

Technique

Landmarks and Initial Transducer Position

The transducer is placed perpendicular to the axis of the arm on the intersection between the anterior axillary fold and the biceps (Figure 17-5).

Scanning Technique

The axillary artery and veins are easily identified in the axilla, medially to the biceps and coracobrachialis muscles. The veins may be obliterated by applying pressure on the transducer when required. If the conjoint tendon is not clearly visible (a bright fascial plane deep to the vessels), slide the transducer a few centimeters proximally. By scanning proximally and distally along the upper arm, and adjusting the tilt, the median, ulnar, radial, and musculocutaneous nerves can be identified around the artery and the musculocutaneous nerve in between the muscles. The acoustic enhancement artifact deep to the artery is often misinterpreted as the radial nerve (Figure 17-5).

Needle Approach and Trajectory

The needle is inserted, in-plane, from anterolateral-to-posterior direction, and advanced according to the disposition of the nerves. When the nerves are visualized around the artery, or not clearly seen, the first injection is made posterior to the artery. This often lifts up the brachial plexus and facilitates the visualization of the structures. Thereafter, the needle is withdrawn and redirected superficially to the artery to block the median and ulnar nerves. When the three nerves are seen aligned on the anteromedial side of the artery, a single needle pass is sufficient to complete the injection (Figure 17-6).

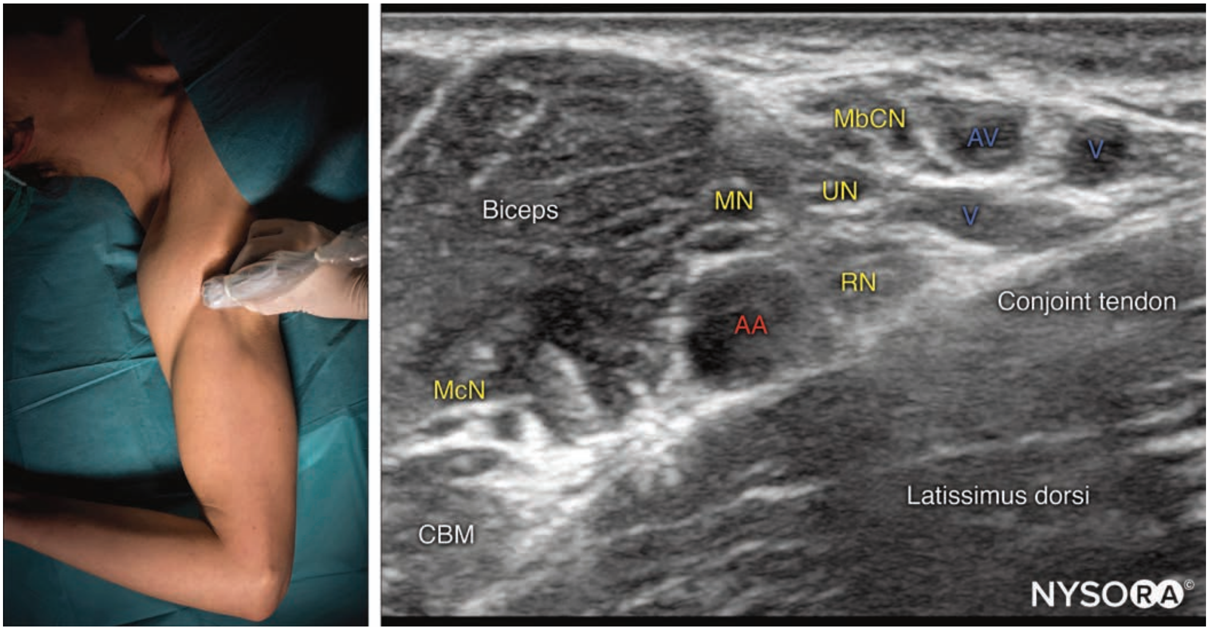
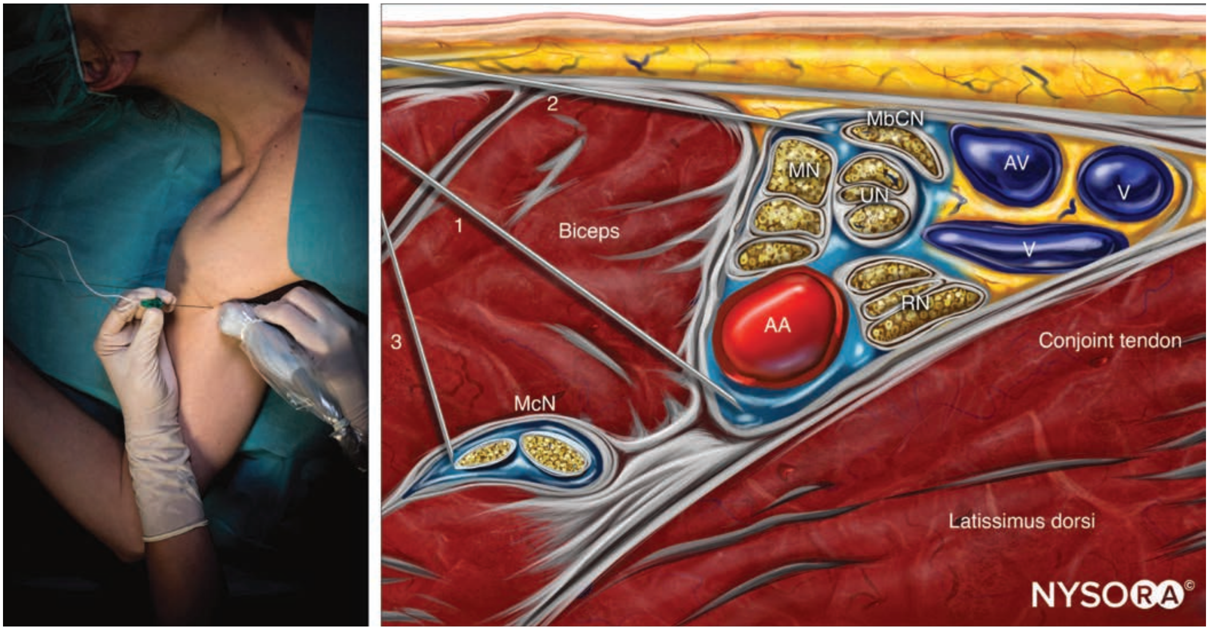
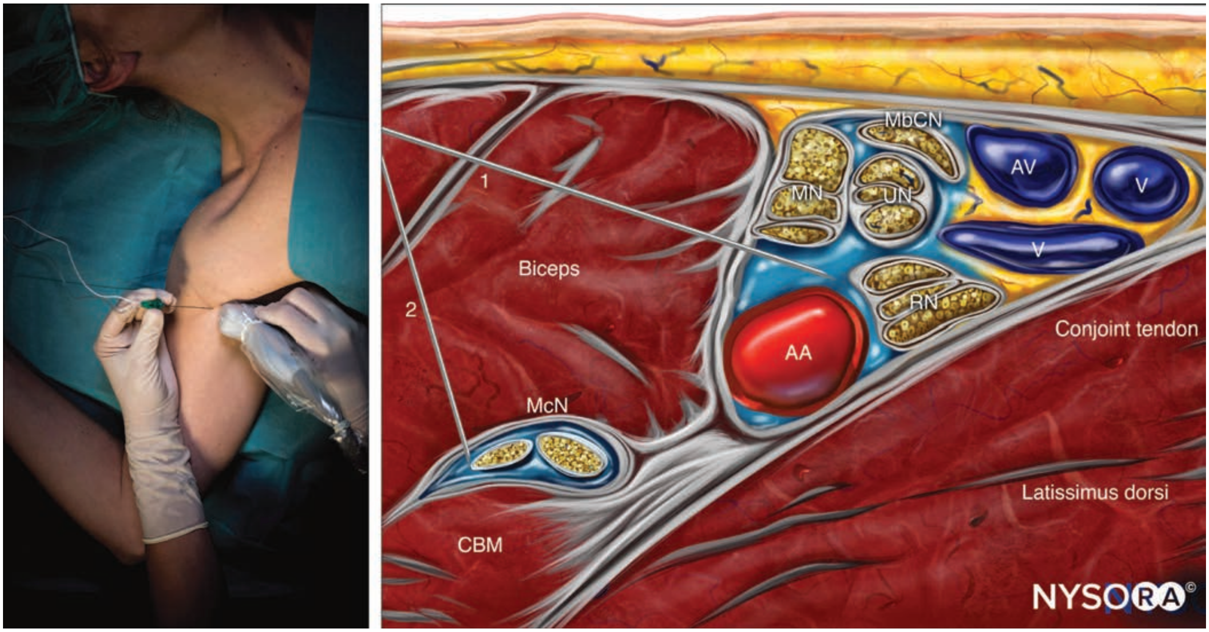


FIGURE 17-5. Transducer position and sonoanatomy for an axillary block. AA, axillary artery; AV, axillary vein; McN, musculocutaneous nerve; MN, median nerve; UN, ulnar nerve; RN, radial nerve; MbCN, medial brachial cutaneous nerve; CBM, coracobrachialis muscle.



A

FIGURE 17-6. Reverse ultrasound anatomy and needle insertions (in-plane) for axillary brachial plexus block. Axillary block can be accomplished by one to four separate injections, depending on the disposition of the nerves and spread of the local anesthetic. (A) The block with three needle injections. (B) A single needle pass superficially to the artery with one injection for the median (MN) and one between the ulnar (UN) and radial (RN) nerves. The musculocutaneous nerve (MCN) often requires a separate injection.



B

FIGURE 17-6. (Continued)

Finally, the needle is withdrawn and redirected laterally toward the fascial plane where the musculocutaneous nerve travels and an additional 5 mL of LA are injected next to the nerve. Occasionally, the nerve lies in close proximity to the median nerve, inside the brachial plexus sheath, making the additional injection unnecessary.

Local Anesthetic Distribution

Individual nerves can usually be identified and blocked with 3 to 5 mL of LA per nerve, although this is rarely necessary because injection of the LA around the axillary artery is sufficient for an effective block. Keep in mind that the axillary brachial plexus sheath often contains septae that divide the sheath into two or more compartments, requiring separate injections for median-ulnar, and radial nerves. Typically, the total volume of LA (20 mL) is divided into three injections: 7 to 10 mL deep to the artery, 7 to 10 mL superficial to the artery, and 5 mL in the interfascial plane where the musculocutaneous nerve courses distally. If required, the medial skin of the upper arm (intercostobrachial nerve T2) can be anesthetized by an additional subcutaneous injection just distal to the axilla (Figure 17-7).

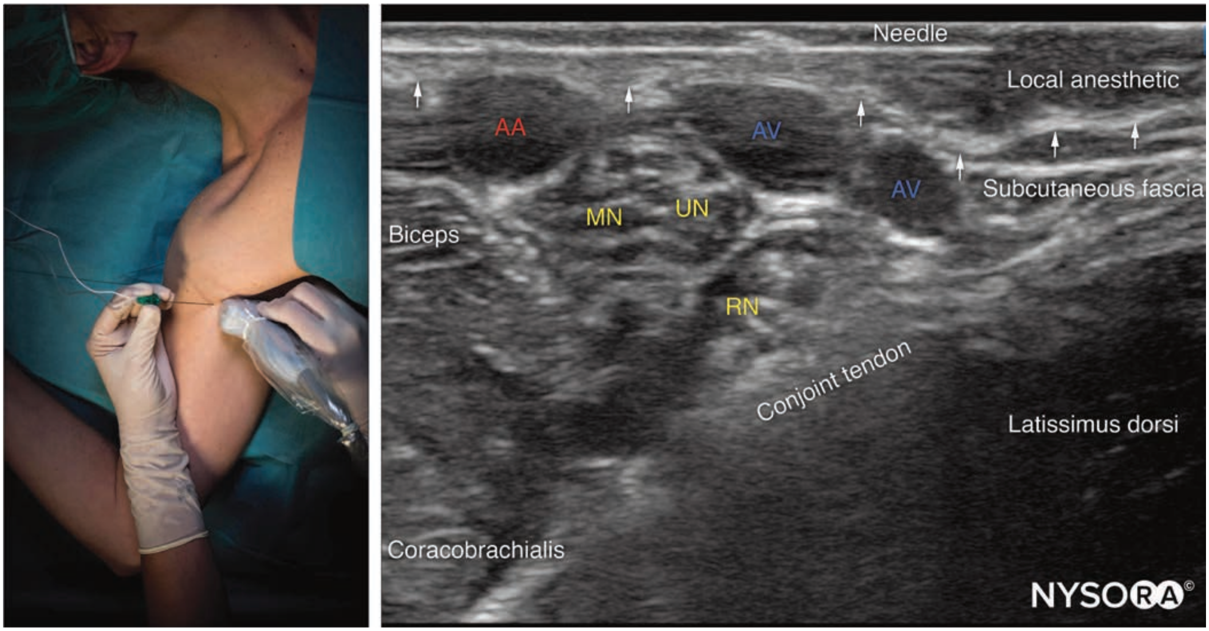


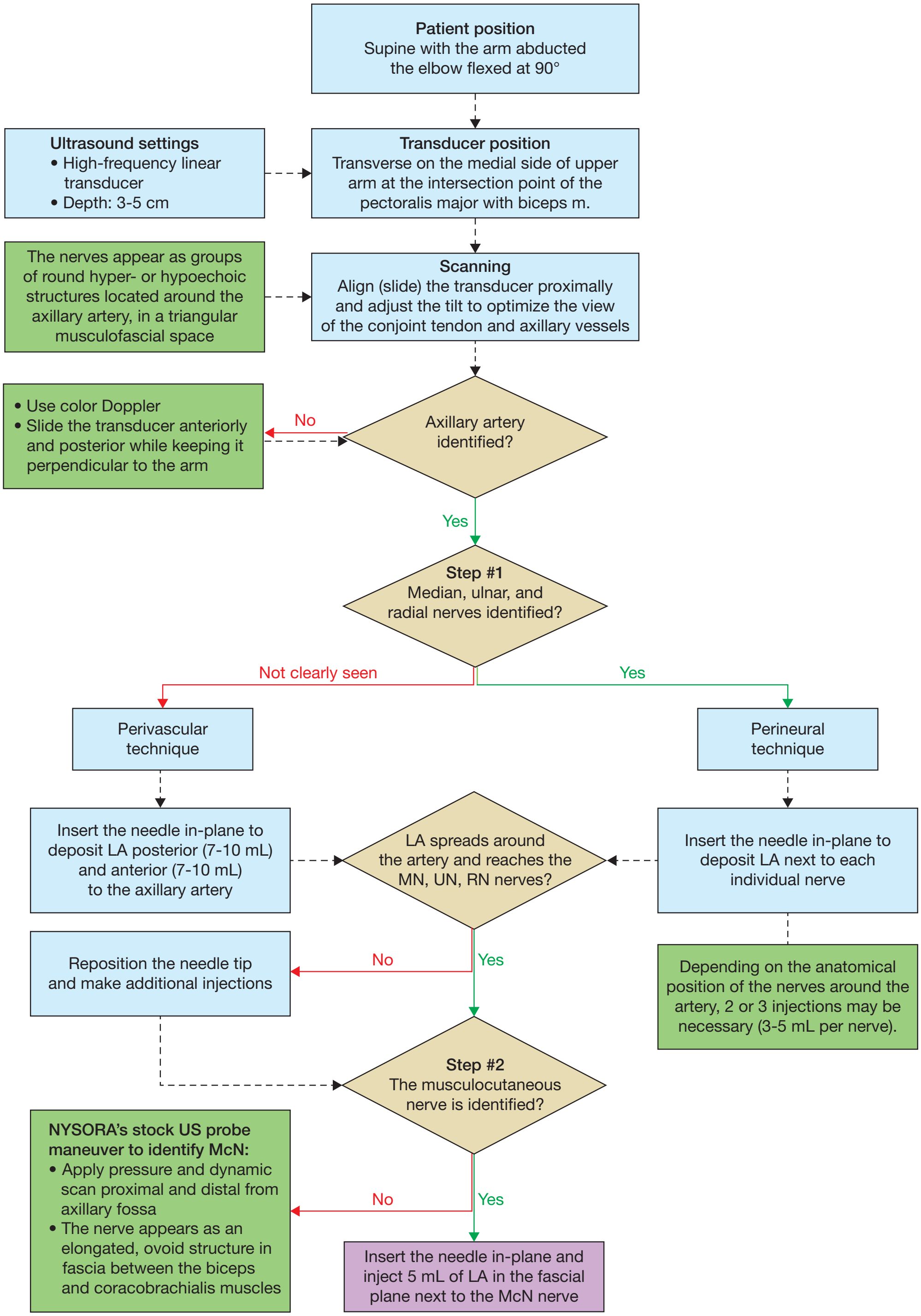
FIGURE 17-7. Skin infiltration distal to the axilla to block the intercostobrachial nerve.

Problem-Solving Tips

Frequent aspiration and slow administration of LAs are critical for decreasing the risk of intravascular injection. Use NYSORA's RAPT method to decrease the risk of complications. (See Chapter 9.) Cases of systemic toxicity have been reported after apparently straightforward US-guided axillary brachial plexus blocks. If no spread is seen on US image during the injection of LA, the needle tip is probably located in one of the axillary veins. When the injection is not visualized on US, the injection should be halted immediately and the needle is withdrawn slightly. Pressure on the transducer should be eased to assess for the presence of vascular structures.

Flowchart

Axillary Brachial Plexus Block Technique Algorithm



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18 Blocks for Analgesia of the Shoulder: Phrenic Nerve Sparing Blocks

BLOCK AT A GLANCE

Shoulder blocks consist of a selective blockade of the suprascapular nerve in combination with the block of the axillary nerve or the infraclavicular brachial plexus block.

- **Indications:** Analgesia of the shoulder in patients with respiratory compromise who cannot withstand >20% reduction in the forced vital capacity (FVC) and/or where an interscalene block is contraindicated
- **Goal:** Local anesthetic (LA) injection for the suprascapular and axillary nerves (or around the lateral and posterior cords of the brachial plexus)
- **Local anesthetic volume:** 5 to 10 mL per injection site, depending on the location

This chapter describes several strategies to accomplish analgesia to the shoulder joint by blocking distal nerves of the brachial plexus that supply innervation to the shoulder joint. Distal blocks preserve the mobility of the arm and hand, and diaphragmatic function by sparing the phrenic nerve. Therefore, distal blocks can also be used in patients with borderline respiratory function.

General Considerations

The selective blockade of the peripheral sensory nerves innervating the shoulder emerged as an alternative analgesic technique to the interscalene or supraclavicular brachial plexus blocks to avoid hemidiaphragmatic paresis. The course of the sensory nerves supplying the shoulder joint enables different injection sites, distant from the trajectory of the phrenic nerve and different combinations of blocks:

- Shoulder block: Selective blocks of the suprascapular and the axillary nerves, which innervate most of the shoulder joint (Figure 18-1). Of note, the shoulder block does not provide surgical anesthesia like an interscalene block; instead, it provides analgesia and decreases opioid consumption after shoulder surgery.
- Block of the suprascapular nerve in combination with an infraclavicular brachial plexus block, selective block of the lateral and posterior cords, or a costoclavicular block. This combination anesthetizes most components of the brachial plexus that supply innervation to the shoulder joint (Figure 18-1), and therfore, it results in a more complete analgesia.

Specific Risks and Limitations

There are no specific contraindications other than the general considerations for regional anesthesia techniques. However, shoulder blocks in obese patients may be challenging because adequate ultrasound (US) images of the suprascapular and axillary nerves may be difficult to obtain. Anatomical variations of the suprascapular notch are common and may render US guidance challenging. Consequently, compared to interscalene blocks, shoulder blocks are less time-efficient and cause a greater degree of patient discomfort because they require two punctures. The limitations and risks of infraclavicular blocks are discussed in Chapter 15.

Anatomy

The shoulder joint innervation is complex and involves multiple branches of the brachial plexus. The **suprascapular** nerve (C5, C6) is a mixed sensory-motor nerve that originates from the *upper trunk* of the brachial plexus and travels posterolaterally through the posterior triangle of the neck deep to the omohyoid and trapezius muscles. The nerve passes through the suprascapular notch underneath the superior transverse scapular ligament, while the accompanying artery and vein pass above the ligament. In the supraspinous fossa, the suprascapular nerve runs posteriorly between the surface of the bone and the supraspinatus muscle giving off the articular branches to the acromioclavicular joint and posterior aspect of the shoulder capsule. The nerve then enters the infraspinous

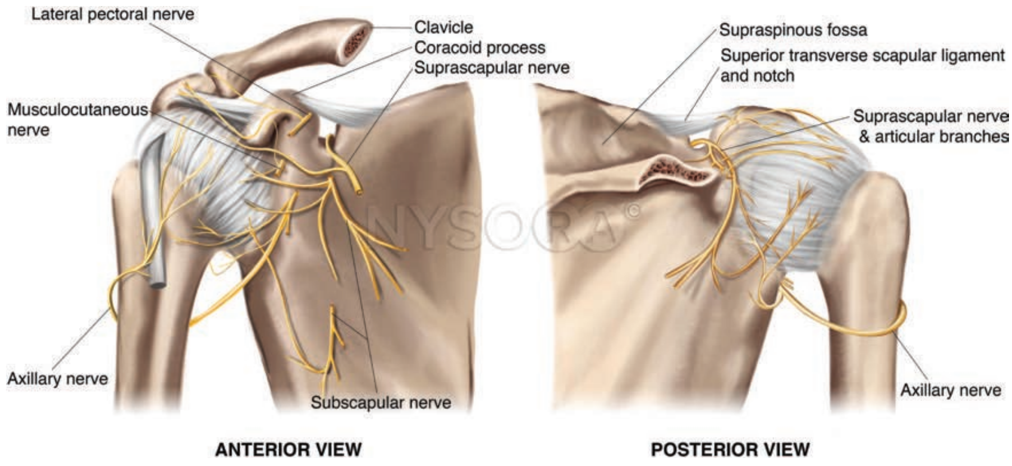

FIGURE 18-1. Innervation of the shoulder joint.

fossa, lateral to the spinoglenoid notch below the lower transverse ligament (Figure 18-2).

The **axillary nerve** originates from the *posterior cord* of the brachial plexus and courses posterior with the posterior circumflex humeral artery (Figure 18-3). The nerve turns around the neck of the humerus and gives innervation to the anterior, inferior, lateral, and posterior aspects of the shoulder. It also innervates the deltoid and teres minor muscles and the skin over the shoulder.

The **subscapular nerve** (from the posterior cord), the **lateral pectoral** nerve, and the **musculocutaneous** nerve (both from the lateral cord) contribute to the innervation of the anterior aspect of the joint (Figure 18-1).

The **phrenic nerve** exits from C4 and leaves the brachial plexus as it descends the anterior scalene muscle. The site of injection and the volume of LAs used in a brachial plexus block can influence the incidence of the phrenic nerve block.

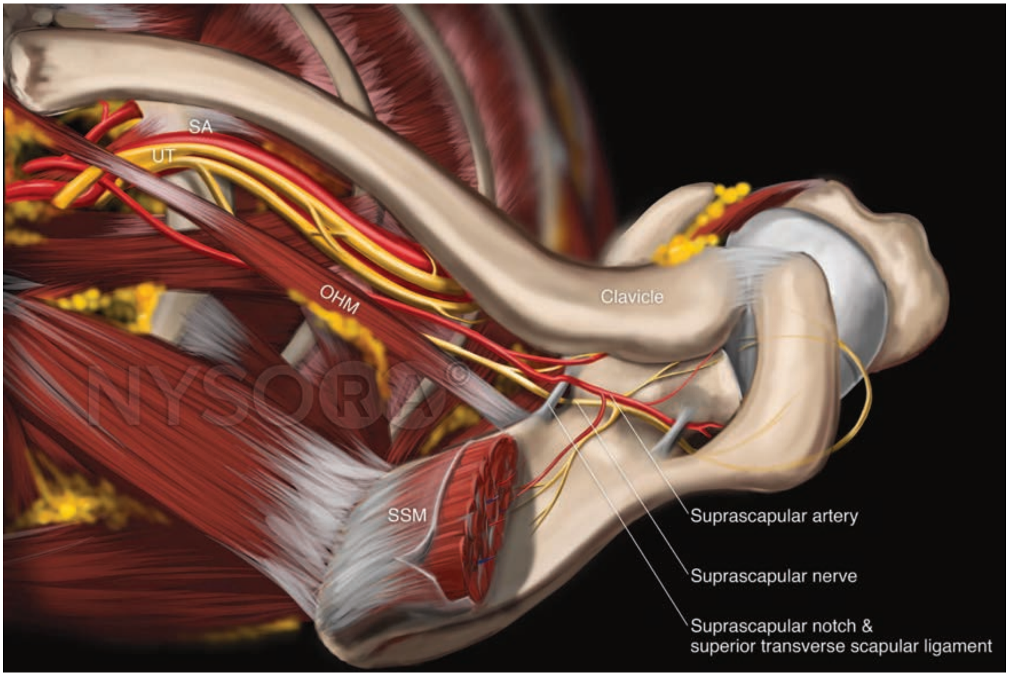

FIGURE 18-2. Superior view of the supraspinatus fossa showing the course of the suprascapular nerve through the suprascapular and spinoglenoid notch. UT, upper trunk; SA, subclavian artery; OHM, omohyoid muscle; SSM, supraspinatus muscle.

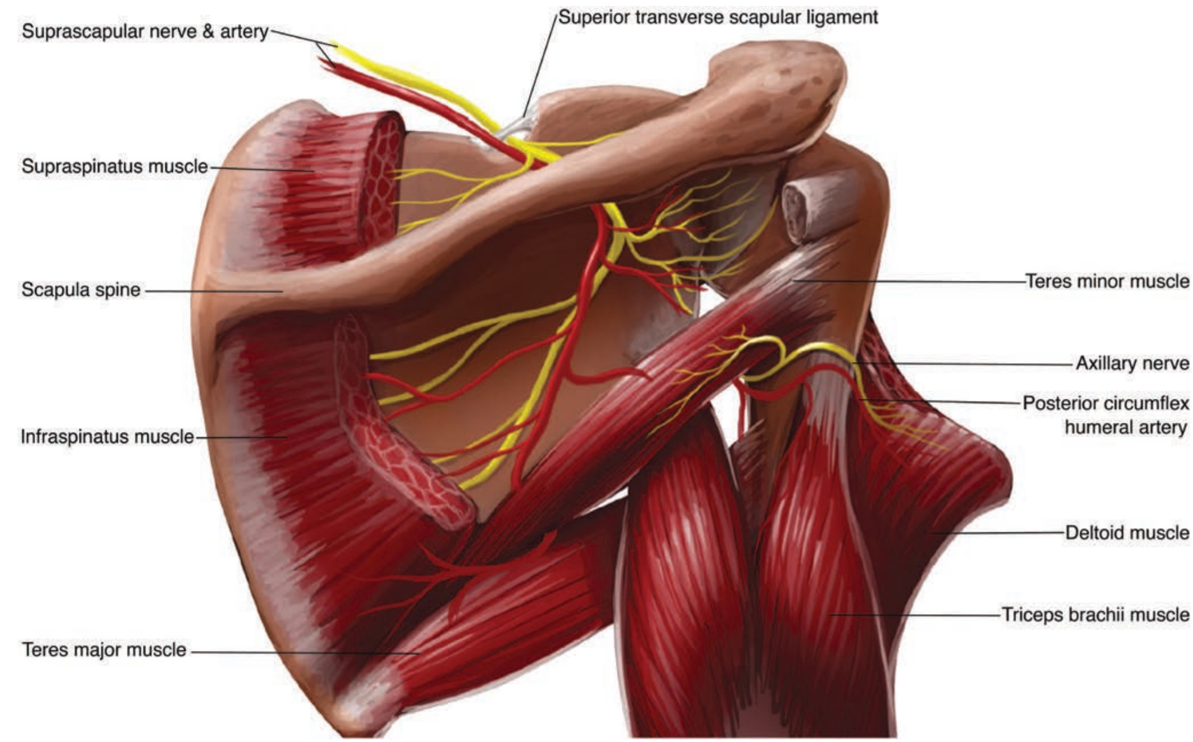

FIGURE 18-3. Posterior view of the suprascapular and axillary nerves showing the distribution of the articular branches to the shoulder joint.

Cross-Sectional Anatomy and Ultrasound View

The **suprascapular nerve** can be imaged at two different locations:

1. Anterior in the supraclavicular fossa: The nerve can be identified in most subjects separating from the upper trunk in a laterodorsal direction, under the omohyoid muscle (Figure 18-4).
2. Posterior in the supraspinous fossa: The nerve can be imaged along its course on the floor of the supraspinous fossa (deep to the supraspinatus muscle), from the entrance through the suprascapular notch to the exit over the spinoglenoid notch (Figure 18-5).

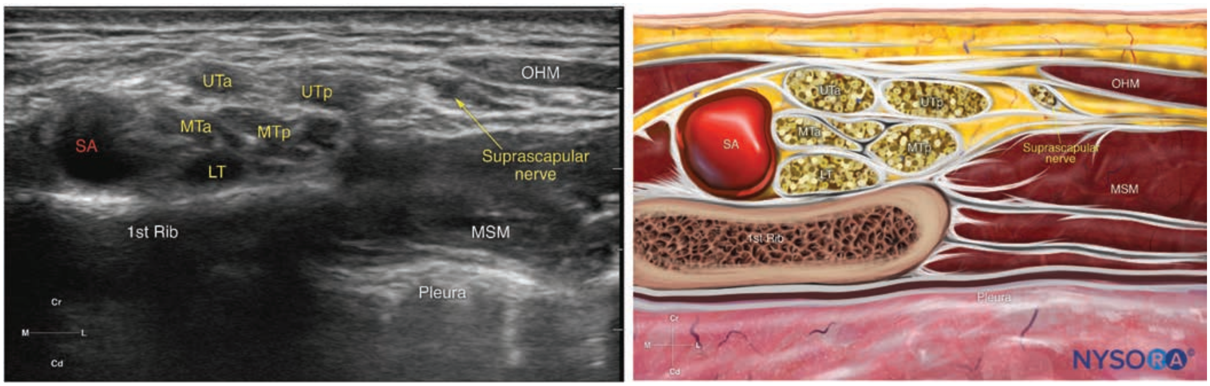

FIGURE 18-4. Reverse anatomy of the suprascapular nerve at the supraclavicular fossa showing the nerve's origin from the upper trunk. SA, subclavian artery; MSM, middle scalene muscle; UTa and UTp, upper trunk anterior and posterior divisions; MTa and MTp, middle trunk anterior and posterior divisions; LT, lower trunk; OHM, omohyoid muscle.

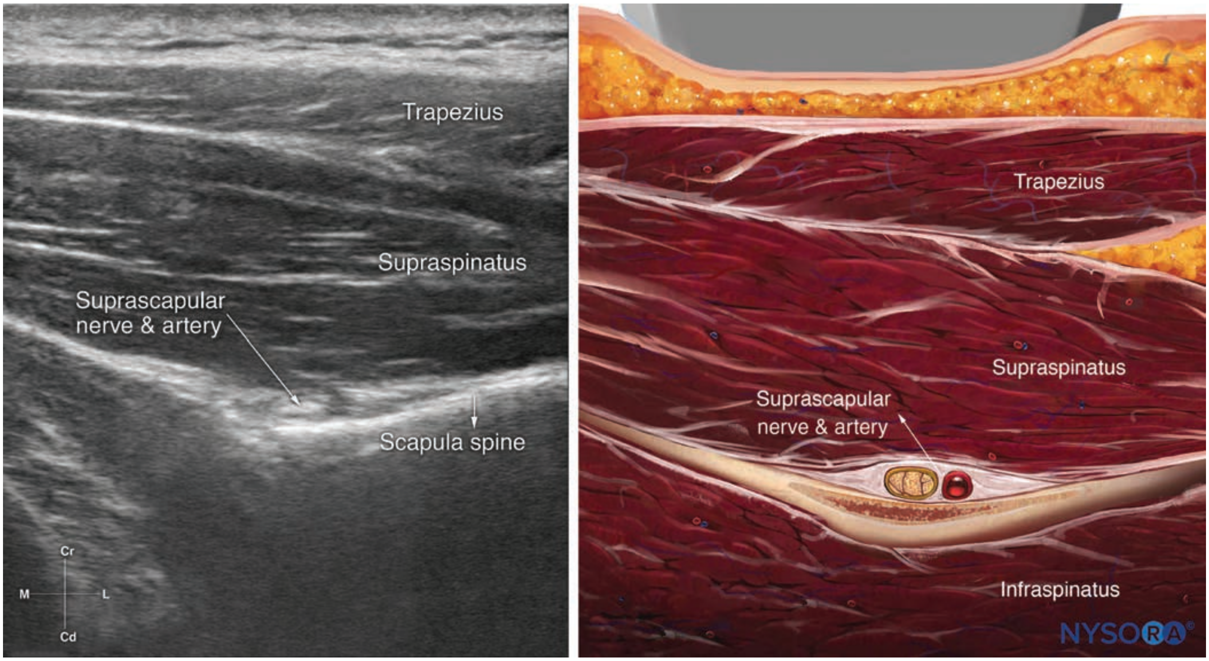

FIGURE 18-5. Reverse anatomy of the suprascapular nerve at the supraspinous fossa.

The **axillary nerve** and posterior circumflex humeral artery pass through the quadrangular space, made by the long head of the triceps medially, the teres minor superiorly, the teres major inferiorly, and the humeral shaft laterally (Figure 18-6).

To review the anatomy of the infraclavicular block, refer to Chapters 15 and 16.

Distribution of Anesthesia and Analgesia

A suprascapular nerve block results in a motor block of the supraspinatus and infraspinatus muscles, and a sensory block of the posterior aspect of the shoulder.

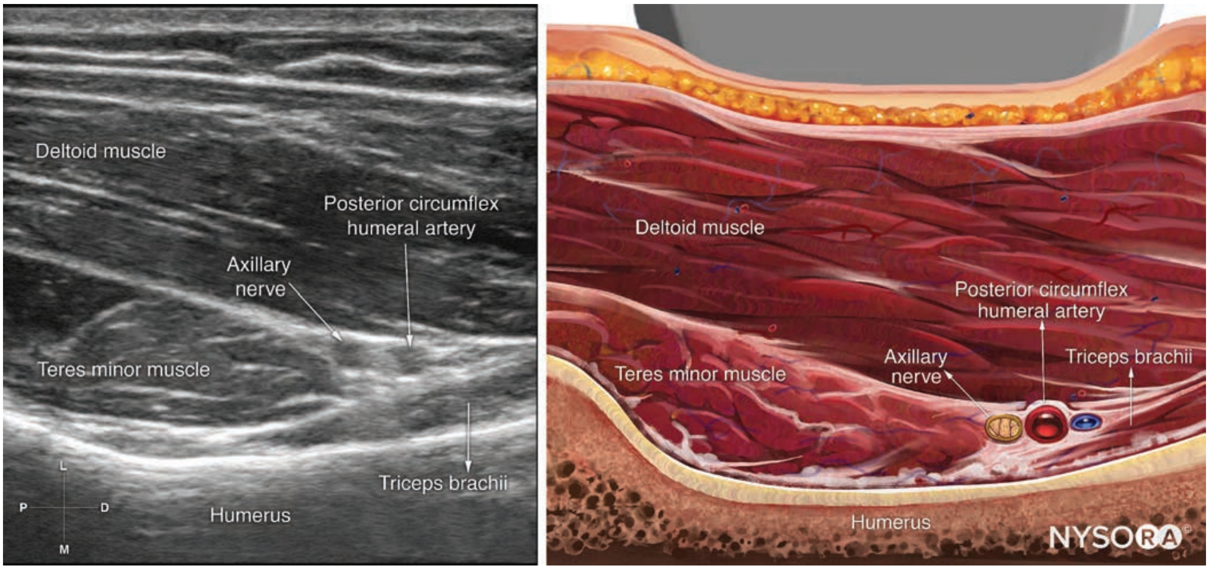

FIGURE 18-6. Reverse anatomy of the axillary nerve at the level of the posterior humerus.

The axillary nerve block results in a motor block of the deltoid muscle (abduction of the shoulder), teres minor, long head of the triceps, and a sensory block of the anterior shoulder joint and the skin over the deltoid muscle.

Block Preparation

Equipment

- Transducer: High frequency linear transducer
- Needle: 5 cm (for supraclavicular approach); 5-8 cm (for suprascapular approach)

Local Anesthetic

For shoulder analgesia, long-acting LA is most commonly used (bupivacaine 0,5%, levobupivacaine 0,5%, ropivacaine 0,5%). Low volumes of 3 to 5 mL/nerve are used to anesthetize the supraclavicular and axillary nerves in these locations.

Patient Positioning

For a shoulder block, the patient should be sitting with the arm adducted and shoulder relaxed (Figure 18-7). To optimize the space for the suprascapular nerve block, ask the patient to place the hand on the contralateral shoulder if possible. Alternatively, the patient can lie in the lateral position with the shoulder to be blocked upwards. For the anterior approach to the suprascapular nerve block, the patient is best positioned in a supine or semi-lateral position with the head turned away to the contralateral side.

TECHNIQUES

Suprascapular Nerve Block

Anterior Approach, in the Supraclavicular Fossa

The transducer is positioned in a sagittal oblique orientation over the supraclavicular fossa, parallel to the clavicle, to image the subclavian artery and the brachial plexus at this level (Figure 18-8). Tracing the plexus craniocaudally, it is often possible to identify the suprascapular nerve as a small hypoechoic round structure separating from the upper trunk posteriorly. The needle is advanced in-plane from posterior to anterior, deep to the omohyoid muscle until the tip is seen in the fascial plane next to the nerve. Injection of 3 to 5 mL of LA is sufficient to block the suprascapular nerve at this location (Figure 18-9). Larger volumes of injectate should be avoided as they may result in spread to the upper trunk and the phrenic nerve.

Posterior Approach, in the Supraspinous Fossa

Place the transducer in a coronal oblique orientation over the shoulder, parallel to the lateral third of the scapular spine. Tilt the probe anteriorly, while applying pressure, until the floor of the supraspinous fossa appears deep to the trapezius and supraspinatus muscles at approximately 3 to 4 cm depth. The surface of the bone has a concave depression from the

FIGURE 18-7. Patient position.

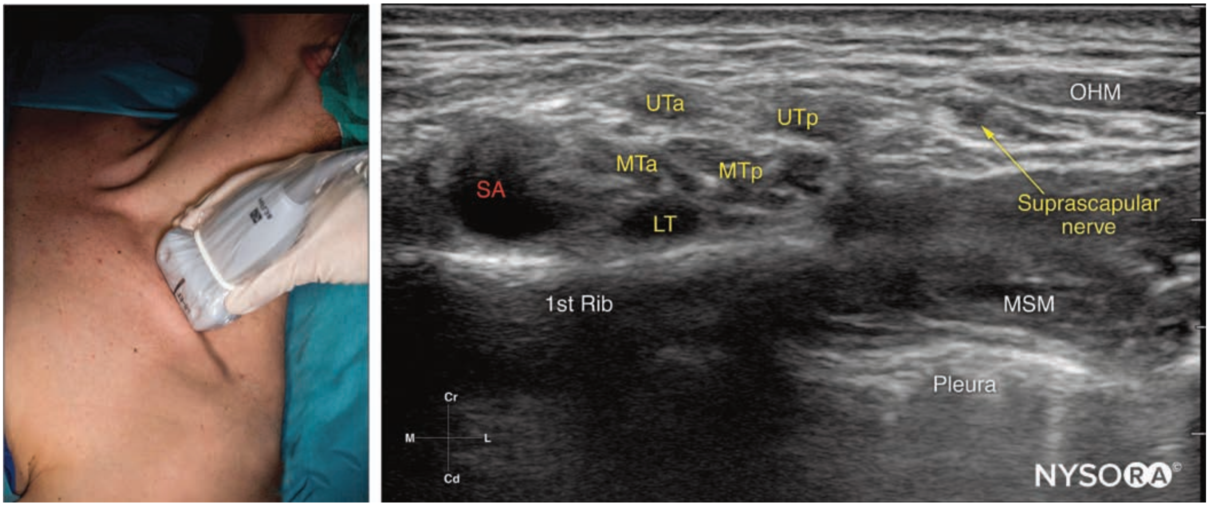

FIGURE 18-8. Transducer position and ideal ultrasound image for a suprascapular nerve block at the supraclavicular fossa. SA, subclavian artery; LT, lower trunk; UTa and UTp, upper trunk anterior and posterior divisions; MTa and MTp, middle trunk anterior and posterior divisions; OHM, omohyoid muscle; MSM, middle scalene muscle.

suprascapular notch (anterior) to the spinoglenoid notch (posterior), which contains the suprascapular nerve, artery, and vein (Figure 18-10). The needle is advanced in-plane in a medial-to-lateral direction until the tip pierces the deep fascia of the supraspinatus muscle and bone contact is felt next to the vessels (or in the bony concavity if the artery is not visible) (Figure 18-11). The LA should be seen spreading deep to the fascia of the supraspinatus muscle.

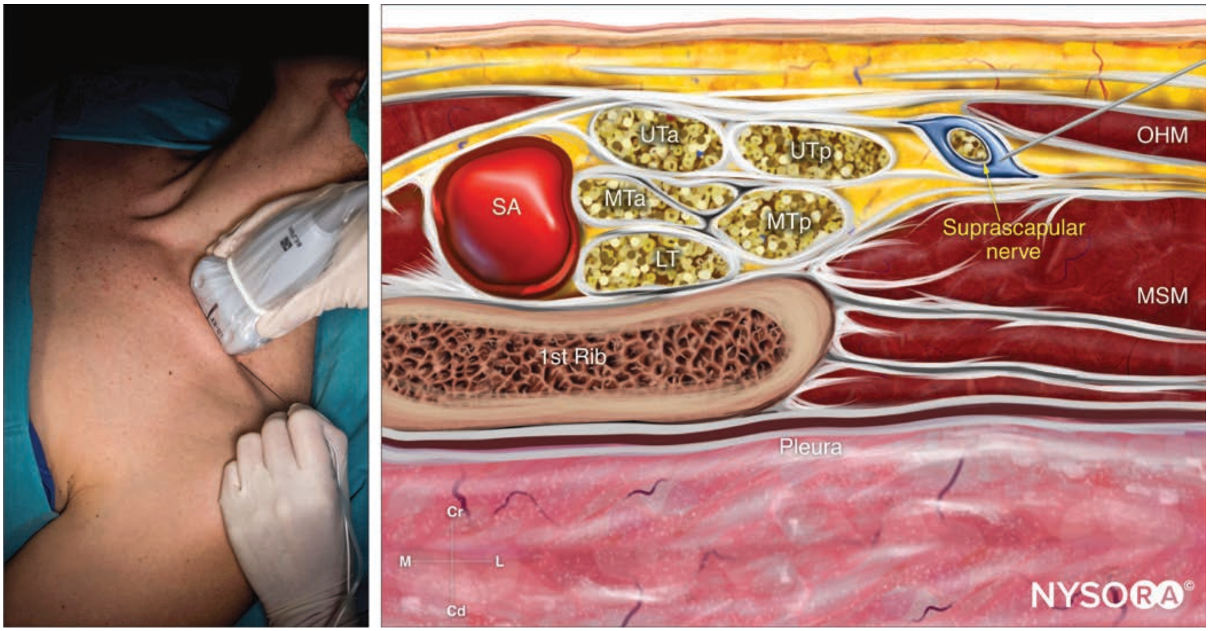

FIGURE 18-9. Reverse ultrasound anatomy with needle insertion in-plane for a suprascapular nerve block at the supraclavicular fossa. SA, subclavian artery; MSM, middle scalene muscle; UTa and UTp, upper trunk anterior and posterior divisions; MTa and MTp, middle trunk anterior and posterior divisions; LT, lower trunk; OHM, omohyoid muscle.

FIGURE 18-10. Transducer position and ideal ultrasound image for a posterior suprascapular nerve block.

Axillary Nerve Block

Position the US in a sagittal orientation over the posterior aspect of the upper arm, midway between the acromion and the axillary fold. Slide the transducer in a lateromedial direction to image the humerus neck in the long axis (Figure 18-12). Adjust the tilt until the posterior circumflex humeral artery is visualized in the short axis between the teres minor, deltoid, and triceps muscle, superficial to the bone. The needle tip is advanced in-plane or out-of-plane until bone contact is felt next to the artery. After negative aspiration, the LA is deposited in this quadrangular space surrounding the artery (Figure 18-13).

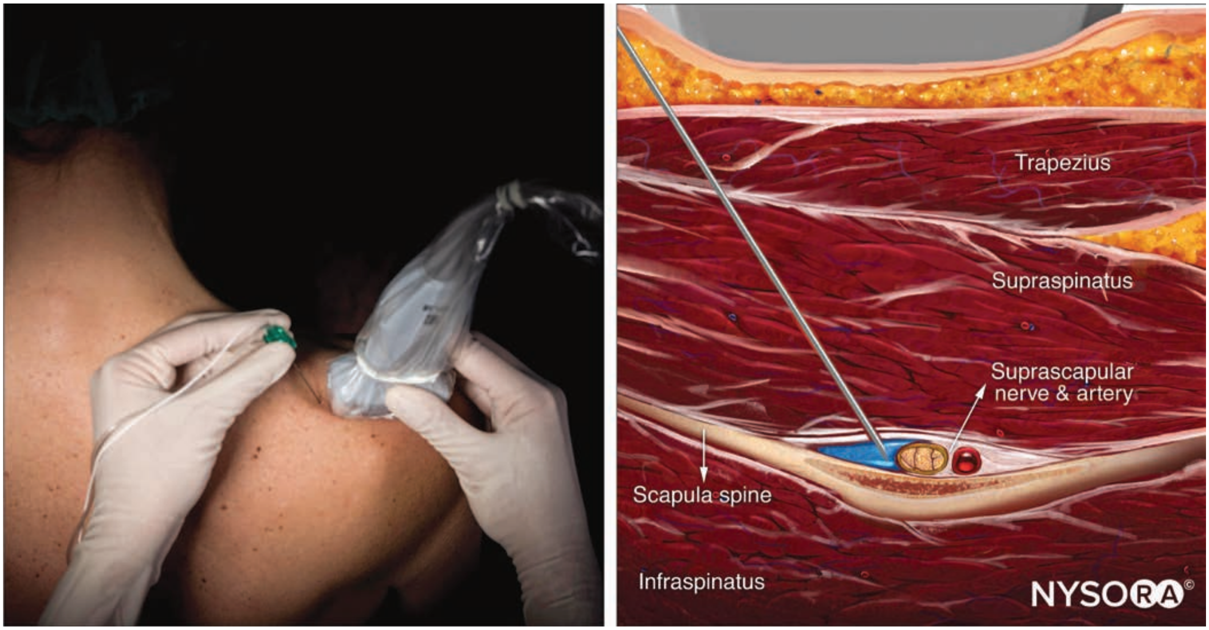

FIGURE 18-11. Reverse ultrasound anatomy with needle insertion in-plane from medial to lateral for a suprascapular nerve block at the supraspinous fossa.

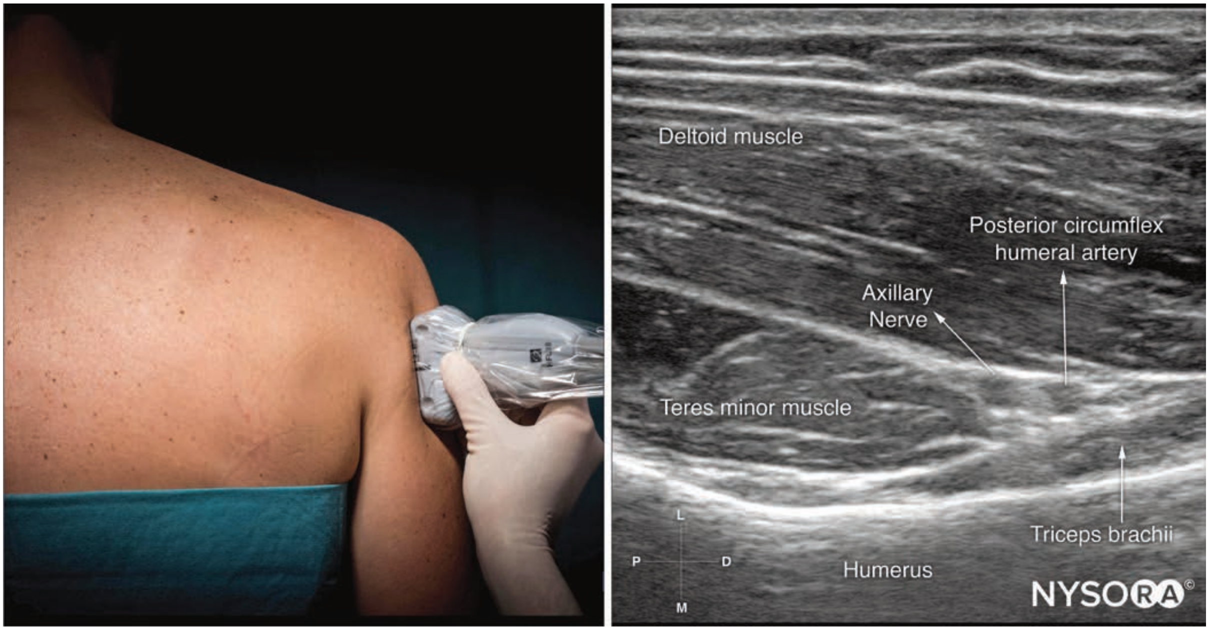

FIGURE 18-12. Transducer position and ideal ultrasound image for an axillary nerve block.

For infraclavicular approaches of the brachial plexus, see Chapters 15 and 16.

Problem-Solving Tips

- In some patients, the position of the clavicle to cephalad in the neck may impede the identification and selective block of the suprascapular nerve at the supraclavicular fossa. In these cases, the posterior approach is indicated.
- To optimize the view of the suprascapular nerve in the suprascapular fossa, adjust the tilt and the rotation of the probe so that the lateral end of the probe is over the acromion and the posterior (medial) over the scapular spine.

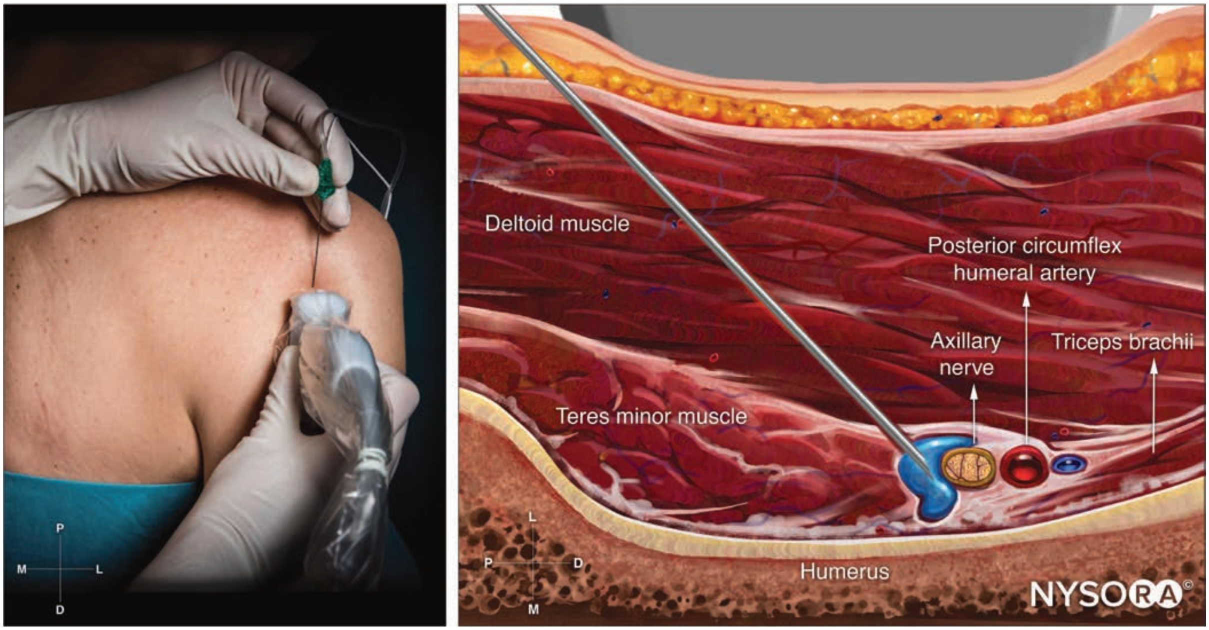

FIGURE 18-13. Reverse ultrasound anatomy with needle insertion in-plane to perform an axillary nerve block.

Flowchart

Shoulder Block Technique Algorithm

Patient position
Sitting, with arm adducted and shoulder relaxed

Ultrasound settings
- Depth: 3-4 cm
- High-frequency linear transducer

Transducer position

Suprascapular nerve block (Posterior approach)	**Axillary nerve block**
Coronal oblique over the shoulder, parallel to the scapular spine	Sagittal, over the posterior aspect of the upper arm

Scanning technique

Tilt anteriorly, while applying pressure to visualize the supraspinous fossa deep to the trapezius and supraspinatus muscles	Slide the transducer laterally/medially or proximally/distally to visualize the surface of the humerus and the posterior circumflex humeral artery
The bony surface of the supraspinous fossa is visualized as an hyperechoic line with a concave depression where the suprascapular nerve, artery, and vein travel	The posterior circumflex humeral artery is visualized as a small round anechoic structure between the teres minor, deltoid, and triceps muscles

TIP: Use color Doppler to identify the arteries routinely before needle insertion

Needle insertion

In-plane from medial to lateral until bone contact is felt next to the suprascapular artery	In-plane or out-of-plane until bone contact is felt next to the posterior circumflex humeral artery

Apply the "RAPT" method of communication before injection of the local anesthetic

R= Motor **R**esponse absent at 0.5 mA
A= **A**spiration negative
P= Opening injection **P**ressure <15 psi
T= **T**otal volume

Complete the block with 5-10 mL per injection site

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19 Blocks About the Elbow

BLOCK AT A GLANCE

Blocks of the terminal branches of the brachial plexus at the level of the elbow.

- **Indications**: Anesthesia and analgesia for hand and wrist procedures
- **Goal:** Injection of local anesthetic (LA) into the tissue plane containing the radial, median, and/or ulnar nerves
- **Local anesthetic volume:** 4 to 5 mL per nerve

General Considerations

Distal peripheral nerve blocks of the upper extremity are very useful for hand and wrist procedures, either as a standalone technique or as a supplement for partial brachial plexus blocks. Ultrasound (US) imaging of individual nerves in the distal upper limb allows for reproducible custom-tailored nerve block anesthesia for a range of clinical indications. Distal nerve blocks are equally suited for hand surgery, like more proximal approaches to the brachial plexus block, but with less extensive motor blockade. A combination of a short-acting proximal brachial plexus block with distal blocks with long-acting LAs also decreases onset time and consistently prolongs analgesia after painful wrist or hand surgery, without the inconvenience of a long-lasting block of the whole arm.

Limitations

Complete anesthesia of the forearm requires five specific nerve blocks. Two of these are cutaneous nerves (cutaneous antebrachial and musculocutaneous nerves) that can be accomplished by subcutaneous infiltrations distal to the elbow. Separate blocks of five nerves may be less time-efficient, compared to single-injection blocks of the brachial plexus. However, the time efficiency is similar with training. The use of a tourniquet, either on the arm or forearm, usually requires sedation and/or additional analgesia.

Specific Risks

Distal peripheral nerve blocks require small-gauge, long-bevel (15°) needles for patient comfort and precision of placement into the delicate fascial sheaths enveloping the nerves. Therefore, additional precautions should be exercised to decrease the risk of intraneural injections when using smaller-gauge, sharp needles (e.g., 25-gauge) for superficial blocks. At the time of this writing, no major manufacturer produced small-gauge, adequately sharpened, 30°, stimulating needles. Note: Full circumferential spread of the LA to surround the nerves is not necessary for a successful block, although this can increase the onset speed.

Anatomy

The Radial Nerve

After emerging from the spiral groove on the lateral aspect of the humerus, the radial nerve passes through the lateral intermuscular septum to enter the anterior compartment of the arm. It continues its path distally between the brachialis and brachioradialis muscles along with the radial collateral artery (Figure 19-1). When the nerve reaches the elbow joint, it divides into the superficial (cutaneous) and deep branches. The superficial branch descends between the brachioradialis and supinator muscles, lateral to the radial artery. The deep branch (also known as the posterior interosseous nerve) reaches the back of the forearm traveling between the two heads of the supinator muscle. The radial nerve provides innervation to most structures in the posterior forearm and wrist of the forearm and wrist.

The Median Nerve

In the arm, the median nerve courses distally between the biceps and brachialis muscles in close relationship with the brachial artery (Figure 19-2). The position of the nerve relative to the artery changes from lateral in the axilla to

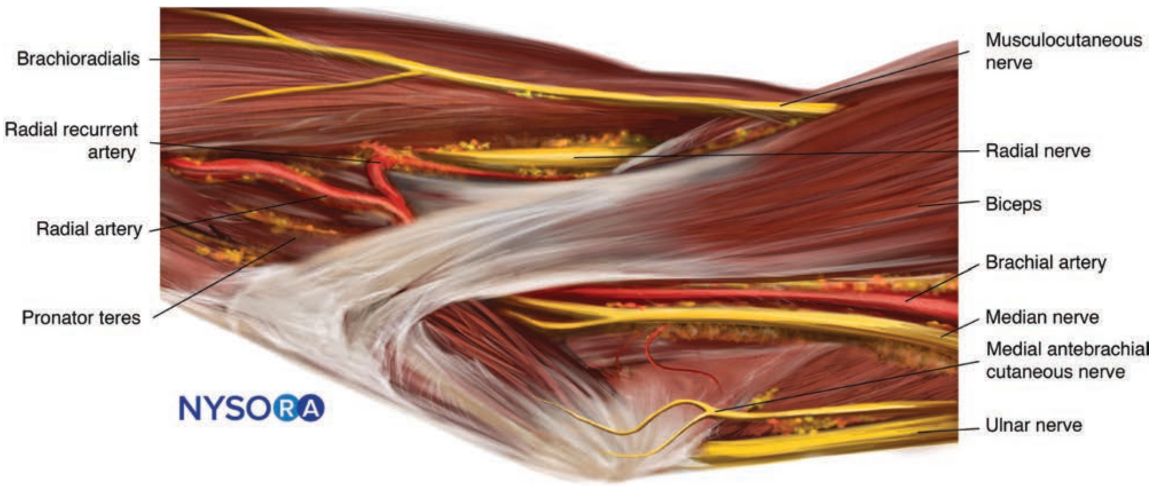


FIGURE 19-1. Anatomy of the terminal branches of the brachial plexus at the elbow.

medial in the antecubital fossa. Distally to the level of insertion of the coracobrachialis, the median nerve separates from the artery and courses deep to the pronator teres muscle. The median nerve innervates the bones, muscles, and skin of the lateral aspect of the palm, including the lateral three digits.

The Ulnar Nerve

The ulnar nerve runs along the posteromedial aspect of the humerus over the triceps just deep to the investing fascia and posterior to the medial intermuscular septum (Figure 19-1). At the elbow, the nerve passes behind the medial epicondyle (through the cubital tunnel) to enter the anterior compartment between the two heads of the flexor carpi ulnaris. The ulnar nerve provides innervation to the structures on the medial side of the forearm and hand (Figure 19-2).

Cutaneous Nerves of the Forearm

The lateral antebrachial cutaneous nerve (a branch of the musculocutaneous nerve) runs between the biceps and

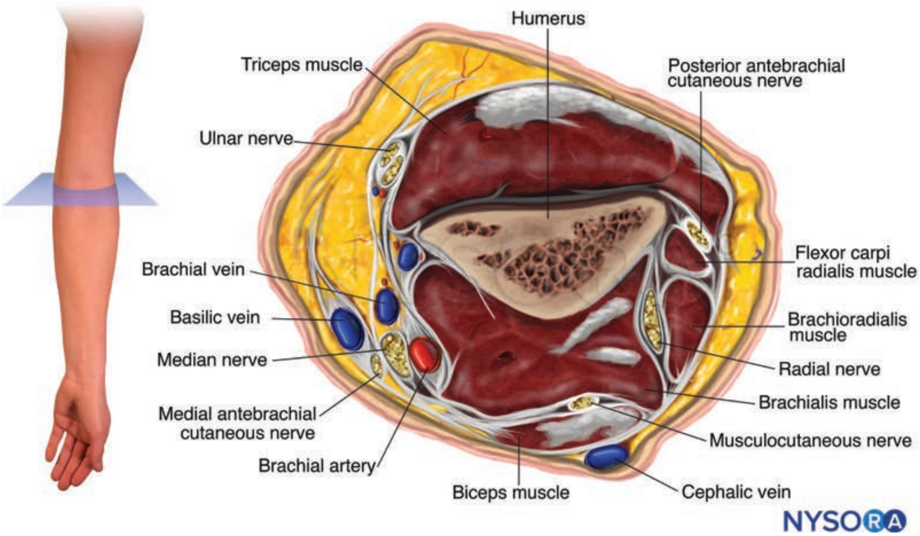


FIGURE 19-2. Cross-section above the elbow crease, illustrating the anatomical distribution of the terminal branches of the brachial plexus.

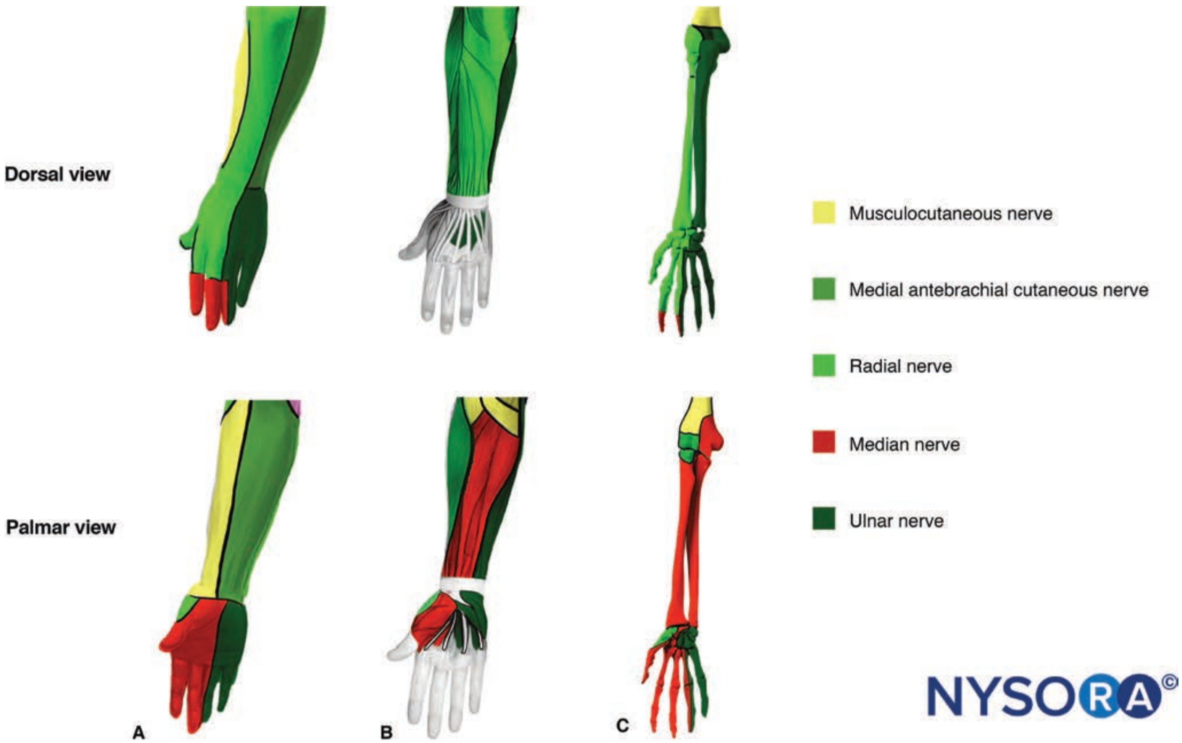


FIGURE 19-3. Dorsal and palmar views of the sensory and motor block distribution of the terminal nerves of the brachial plexus. (A) cutaneous innervation, (B) myotomes, and (C) osteotomes.

the brachialis muscles to exit the fascia on the lateral side of the elbow close to the cephalic vein (Figure 19-3).

The medial antebrachial cutaneous nerve (a branch of the medial cord of the brachial plexus) runs superficially on the medial side of the arm. At the medial elbow, the nerve is located next to the basilic vein (Figure 19-3).

The posterior antebrachial cutaneous nerve (a branch of the radial nerve) exits the fascia on the posterior side of the elbow between the lateral epicondyle and olecranon, providing sensory innervation to the posterior aspect of the forearm (Figure 19-2).

Cross-Sectional Anatomy and Ultrasound View

Proximally to the elbow, the **radial nerve** is located laterally in the fascial plane between the brachioradialis and brachialis muscles (Figure 19-2). US images of the nerve appear as a hyperechoic triangular or oval structure, positioned between the hypoechoic muscles, superficial to the bone.

The **median nerve** is located superficially on the medial side of the biceps tendon and just medial to the artery (Figure 19-2). When imaged by US, the nerve appears as a hyperechoic structure, similar in size to the artery.

The **ulnar nerve** is located in the posteromedial aspect of the elbow (Figure 19-2) and visualized as a hyperechoic oval structure superficial to the triceps muscle underneath the investing fascia and posterior to the medial intermuscular septum.

The **cutaneous nerves** are seen emerging out of the fascia at the lateral, medial, and posterior aspect.

Distribution of Anesthesia and Analgesia

Anesthetizing the radial, median, and/or ulnar nerves provides sensory anesthesia and analgesia to the respective territories of the hand, forearm, and wrist (Figure 19-3).

To achieve a complete block of the forearm, it is necessary to anesthetize the superficial nerves supplying the skin by a subcutaneous wheal distal to the elbow on the lateral and medial side (Figure 19-4).

It must be taken into account that the use of a tourniquet, either on the arm or forearm, usually requires sedation and/or additional analgesia.

Block Preparation

Equipment

- Transducer: High-frequency linear transducer
- Needle: 25-gauge, short-bevel, insulated, stimulating needle (optional)

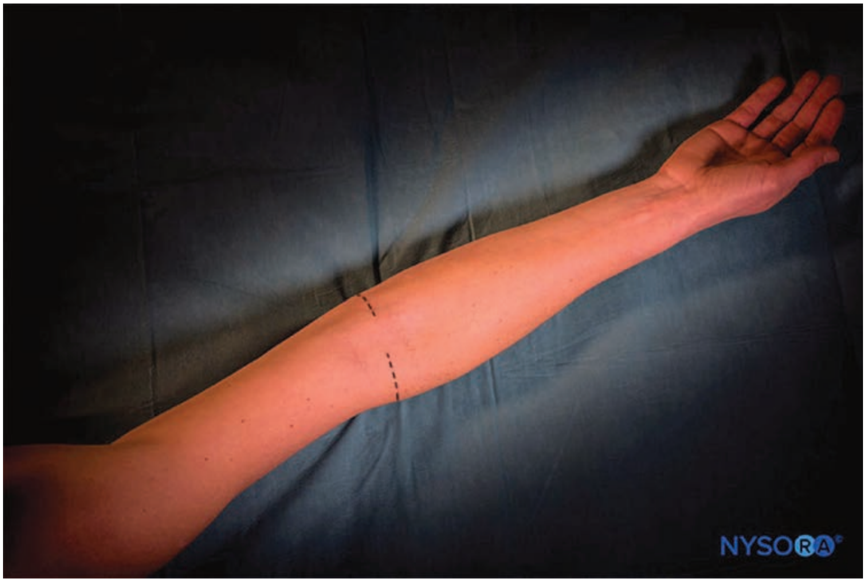


FIGURE 19-4. Subcutaneous wheal distal to the elbow on the lateral and medial side.

Local Anesthetic

A volume of 3 to 5 mL of a short-acting LA (e.g., lidocaine 2%) around each nerve suffices to provide adequate anesthesia for hand and finger procedures. Long-acting LAs could be used to prolong postoperative analgesia.

Patient Position

The patient is positioned in supine, with the arm abducted 90° and resting on a side support or a table. This position allows for easy access to all nerves by flexing or rotating the extremity (Figure 19-5).

FIGURE 19-5. Patient position to perform nerve blocks above the elbow.

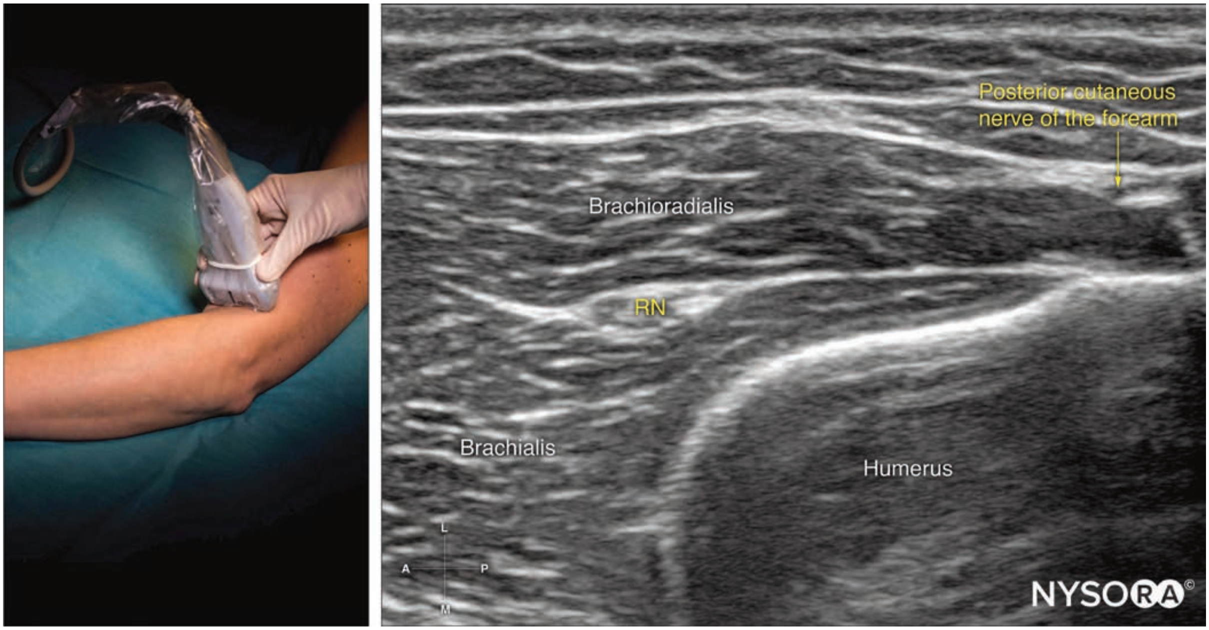


FIGURE 19-6. Probe position and ultrasound image of the radial nerve (RN) above the elbow.

Technique

Radial Nerve

Identify the lateral epicondyle of the elbow and place the transducer in a transverse orientation 3 to 4 cm proximal to it. Scan proximally and distally applying pressure and adjusting the tilt of the probe until the nerve is visualized superficial to the bone surface in the intermuscular fascial plane (Figure 19-6).

The needle is inserted in-plane, from anterior or posterior, and advanced through the brachioradialis muscle until the tip is seen next to the radial nerve. If nerve stimulation is used, a wrist or finger extension response could be elicited (Figure 19-7).

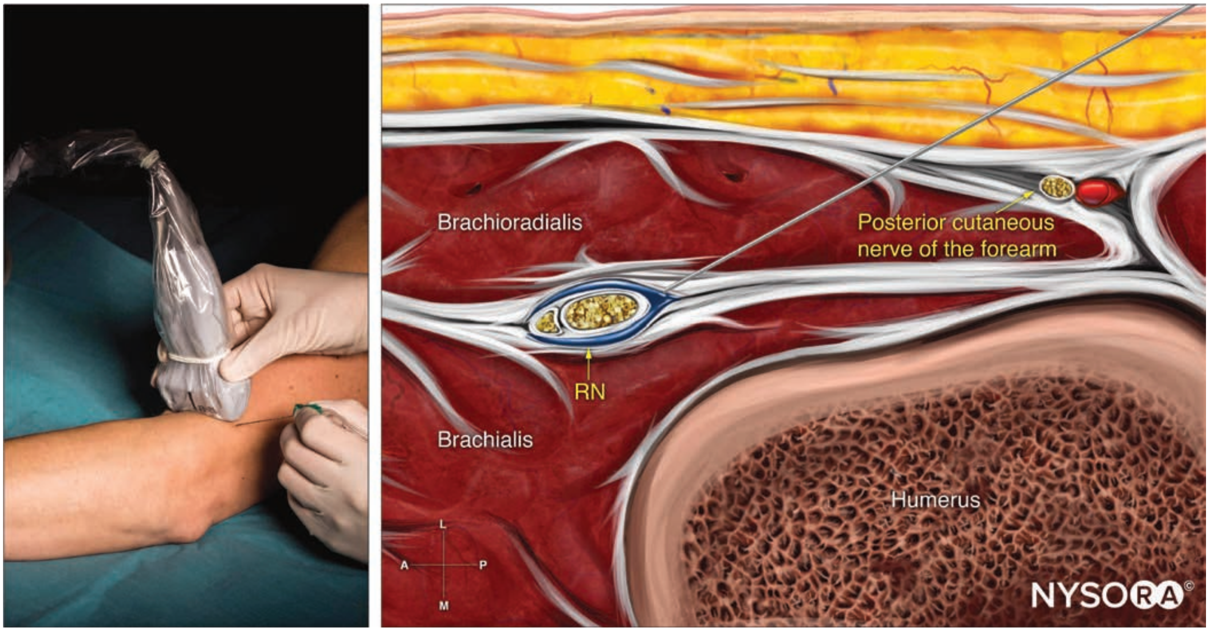


FIGURE 19-7. Reverse ultrasound anatomy with needle insertion in-plane to block the radial nerve (RN) above the elbow.

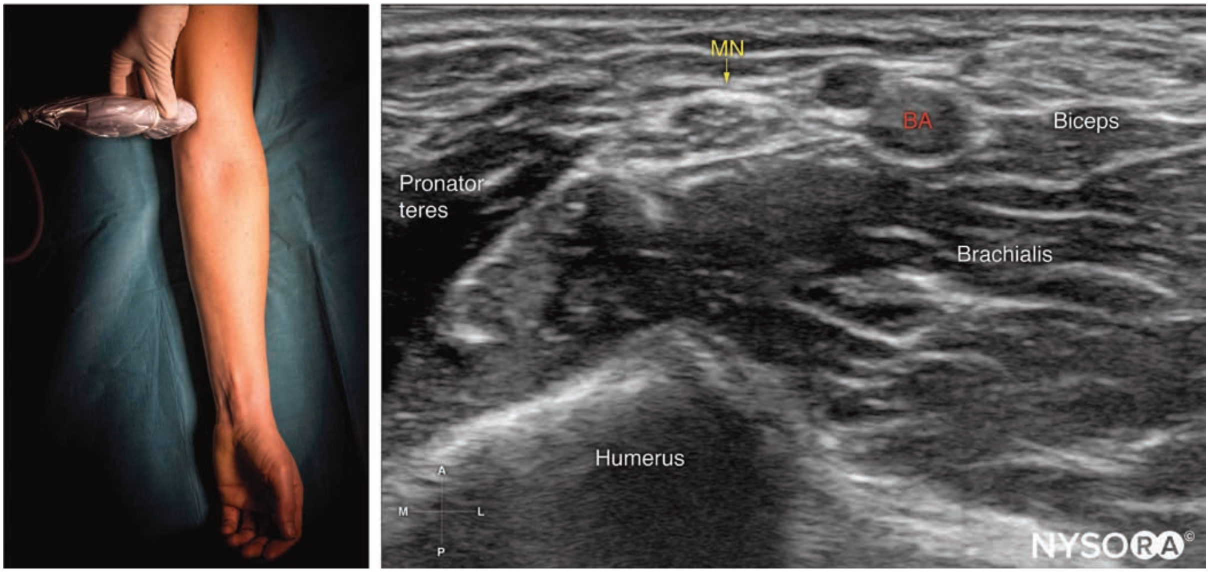


FIGURE 19-8. Probe position and ultrasound image of the median nerve (MN) above the elbow. BA, brachial artery.

Median Nerve

The transducer is positioned in a transverse orientation on the antecubital fossa, just proximally to the elbow crease. After identifying the brachial artery, the median nerve is visualized next to it on the medial side. Color Doppler may be useful if the artery is not readily apparent (Figure 19-8).

The needle is inserted in-plane from either side of the transducer, although a medial-to-lateral approach is usually more convenient to avoid the artery (Figure 19-9).

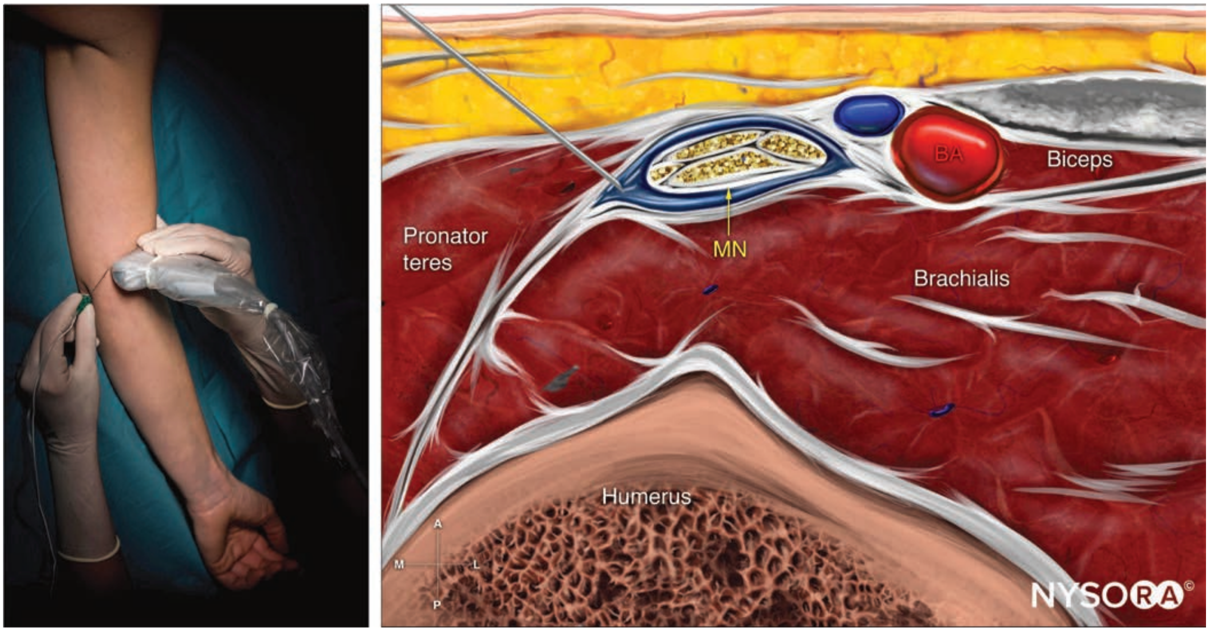


FIGURE 19-9. Reverse ultrasound anatomy with needle insertion in-plane to block the median nerve (MN) above the elbow. BA, brachial artery.

Ulnar Nerve

The transducer is positioned in a transverse orientation proximal to the medial epicondyle and moved posteriorly to identify the ulnar nerve superficial to the triceps muscle (Figure 19-10).

The needle is inserted in-plane from anterior to posterior and advanced next to the ulnar nerve (Figure 19-11).

Local Anesthetic Distribution

After negative aspiration, 1 to 2 mL of LA is injected. Slight adjustments of the needle tip may be necessary to ensure an adequate spread into the space that contains the nerves before injecting the intended volume. It is not necessary to pursue a circumferential spread around the nerves.

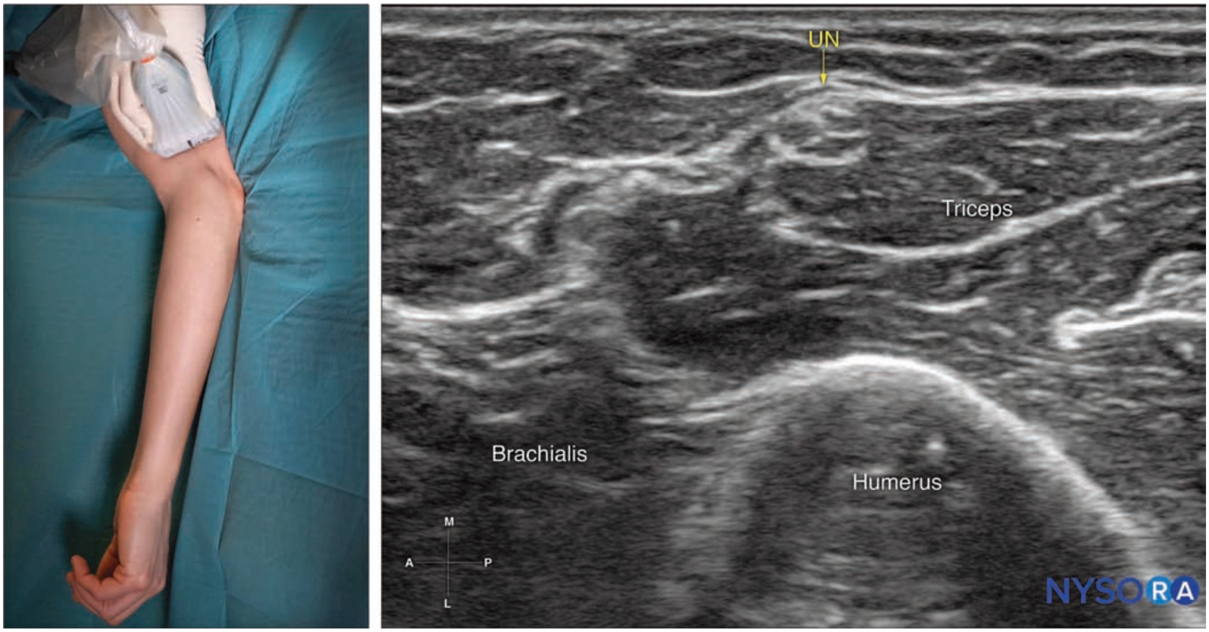


FIGURE 19-10. Probe position and ultrasound image of the ulnar nerve (UN) above the elbow.

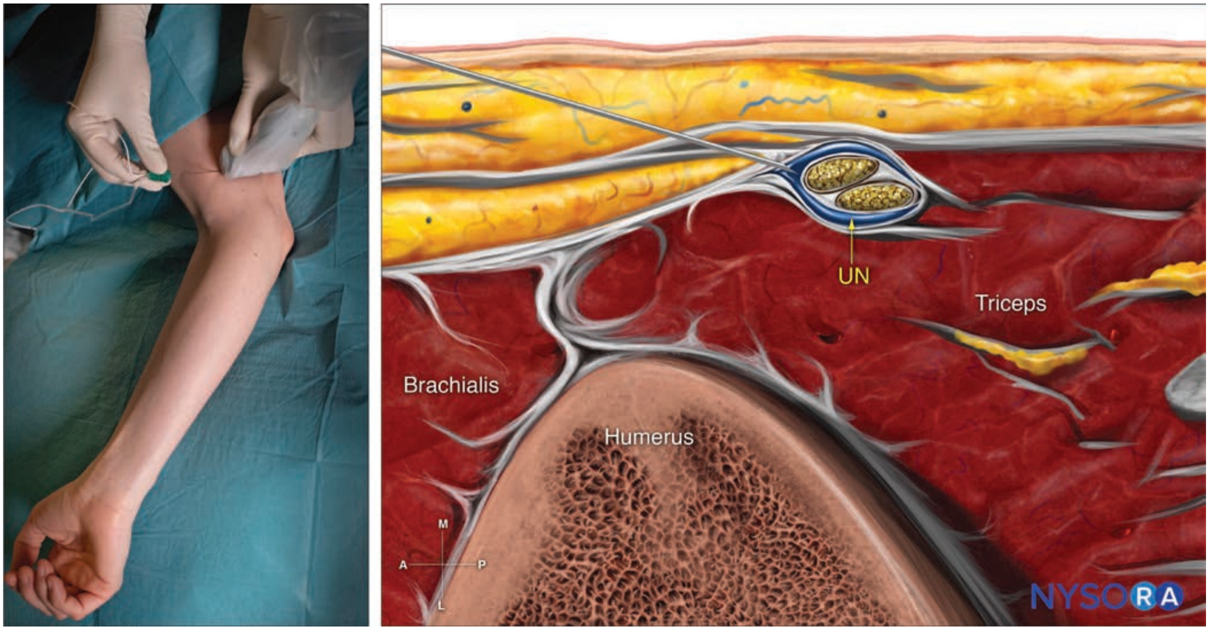


FIGURE 19-11. Reverse ultrasound anatomy with needle insertion in-plane to block the ulnar nerve (UN) above the elbow.

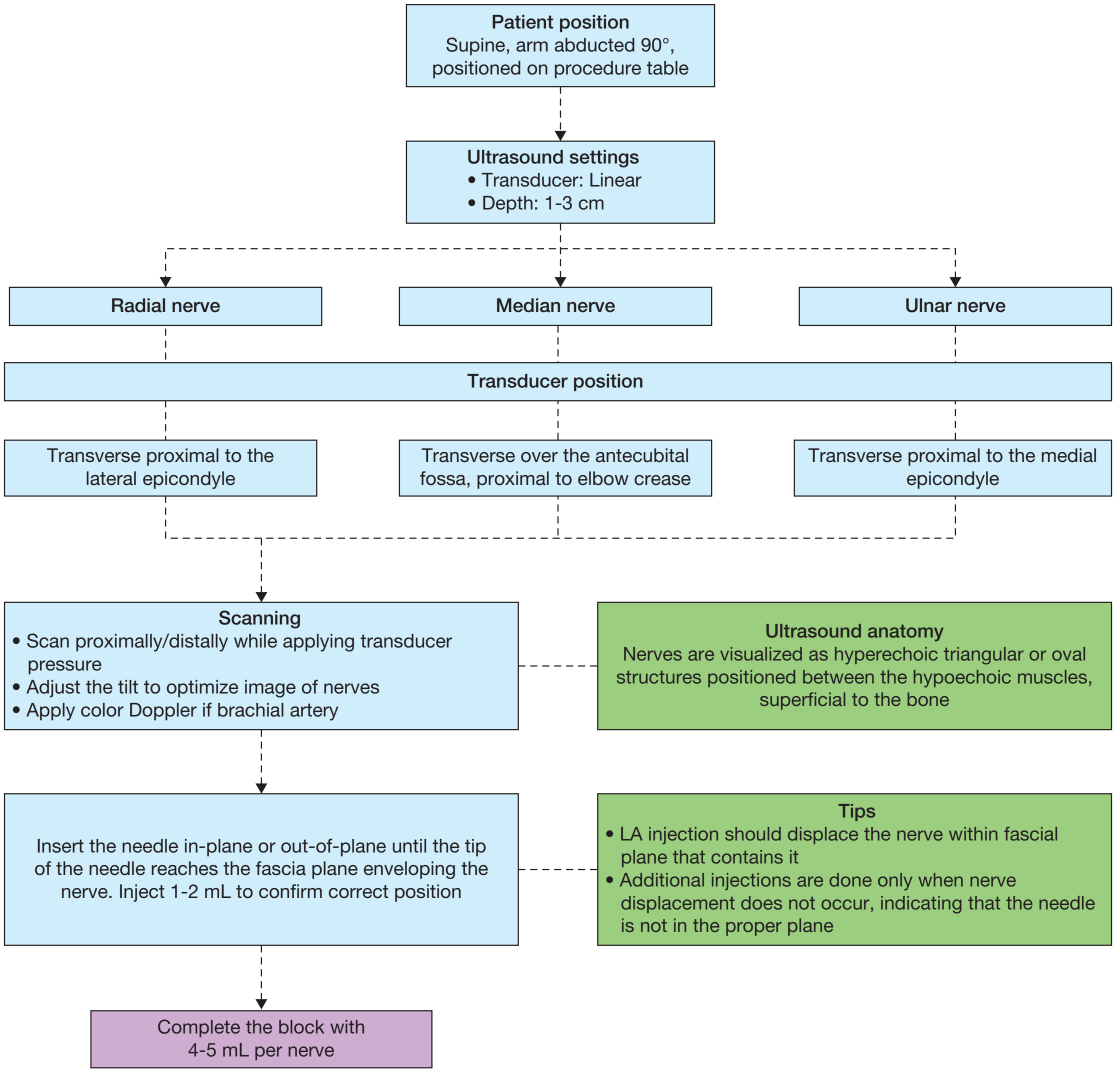
The lateral cutaneous nerve of the forearm can be blocked infiltrating 2 to 3 mL of LA around the cephalic vein. The medial cutaneous nerve of the forearm can be blocked next to the basilic vein.

Problem-Solving Tips

- When in doubt, nerve stimulation (0.5-1.0 mA) can be used to confirm the localization of each nerve.
- Either in-plane or out-of-plane techniques can be used for all three blocks. Ergonomics often dictate which is the best approach.
- If distal blocks are to be performed after a proximal brachial plexus block, it is of paramount importance to clearly visualize the needle tip at all times in order to avoid intraneural injection.

Flowchart

Blocks About The Elbow Technique Algorithm



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20 Wrist Block

BLOCK AT A GLANCE

Block of the median and ulnar nerves (and superficial branch of the radial nerve) at the level of the forearm.

- **Indications**: Hand and finger surgeries not involving the deep structures of the dorsum of the hand and thumb
- **Goal:** Injection of local anesthetic (LA) within the vicinity of the median, ulnar, and the superficial branch of the radial nerve (if needed)
- **Local anesthetic volume:** 3 to 5 mL per nerve

General Considerations

The wrist block is a commonly used technique for hand and finger surgeries, in particular for short procedures involving soft tissues on the palmar side. The main advantage of the block is that it provides effective anesthesia (and eventually, long-lasting analgesia) while preserving the mobility of the wrist. The landmark-based technique relied on the superficial location of the nerves running in between the flexor tendons (median nerve) or next to the artery (ulnar nerve), and was often complemented with subcutaneous infiltrations according to the incision site. Ultrasound (US) guidance allows for precise identification of the nerves along their course in the forearm and the most convenient level for a reliable injection within the spaces that contain the nerves. However, the complex innervation of the wrist and hand, involving branches of five different nerves overlaping between them, is responsible for the variability observed in the distribution of anesthesia after a wrist block.

Limitations

The wrist block does not result in a complete block of the hand and fingers. For instance, the territory of the deep branch of the radial nerve (deep structures on the dorsum of the hand, and first-to-third fingers) will not be blocked. To anesthetize this area, it is necessary to block the radial nerve proximal to the elbow crease (see Chapter 19). Likewise, the skin over the wrist crease is not completely anesthetized, as it is also supplied by the lateral and medial antebrachial cutaneous nerves, the superficial branch of the radial nerve, and occasional contribution from the interosseous nerves. For carpal tunnel surgery, for instance, a subcutaneous infiltration at the level of the wrist crease is necessary to block all these small terminal branches.

Specific Risks

When using small-gauge (e.g., 25-gauge) needles, special attention should be given in order to avoid intraneural injection, even more so when nerve stimulation is not used. Care must be taken when performing ulnar and radial nerve blocks, because they are intimately associated with arteries, to avoid inadvertent arterial puncture and injection.

Anatomy

Below the elbow, the **median nerve** courses toward the wrist deep to the pronator teres and flexor digitorum superficialis muscles. Commonly, there is a communicating branch with the ulnar nerve at this level (anastomosis of Martin-Gruber). The palmar branch of the median nerve takes off 3 to 8 cm proximally to the wrist crease and exits the antebrachial fascia to innervate the skin over the thenar eminence and midpalm. As the muscles taper toward tendons near the wrist, the nerve assumes an increasingly superficial position, between the tendons of the flexor carpi radialis and palmaris longus muscles, until it is located beneath the flexor retinaculum in the carpal tunnel (Figure 20-1).

The **ulnar nerve** enters the anterior compartment of the forearm between the two heads of the flexor carpi ulnaris coursing deep to the muscle and its tendon down to the wrist. Distally to the mid-forearm, the nerve runs right next to the ulnar artery on its medial side. The palmar branch of the ulnar nerve exits 3 to 8 cm proximal to the wrist crease to innervate the skin over the hypothenar eminence (Figure 20-1).

The radial nerve divides just below the elbow crease into the superficial (sensory) and deep branches. The **superficial branch of the radial nerve** runs lateral to the radial artery deep

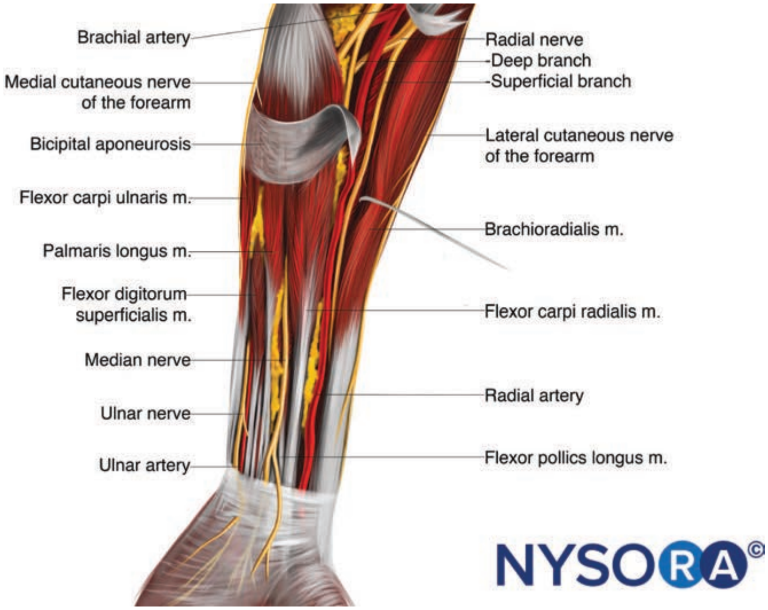


FIGURE 20-1. Anatomy of the median, ulnar, and radial nerves at the mid-forearm.

to the brachioradialis muscle. At mid-forearm, the nerve exits the antebrachial fascia between the tendons of the brachioradialis and the extensor carpi radialis muscles to innervate the skin of the dorsum of the hand on its lateral side (Figure 20-2).

Cross-Sectional Anatomy and Ultrasound View

In a cross-section view at the level of mid-forearm, the **median nerve** is located in a fascial plane between the superficial and deep flexors of the hand. (Figure 20-3). On US, the nerve appears as a triangular hyperechoic structure that can be differentiated from the hypoechoic muscles.

The **ulnar nerve** is located medially to the ulnar artery, deep to the flexor carpi ulnaris muscle and its tendon (Figure 20-3). On US, it appears as a triangular or oval hyperechoic structure in close contact with the artery.

The **thin superficial branch of the radial nerve** can be seen deep to the brachioradialis muscle, lateral to the radial artery, and superficial to the insertion of the pronator teres muscle (Figure 20-3). On US, it can be identified as a small hyperechoic oval structure lateral to the radial artery.

Distribution of Anesthesia and Analgesia

The wrist block results in anesthesia of the palmar side of the hand and a variable extension on the posterior side, according to the distribution of the distal nerves. When the sensory branch of the radial nerve is included, the skin over the dorsum will also be anesthetized (Figure 20-4).

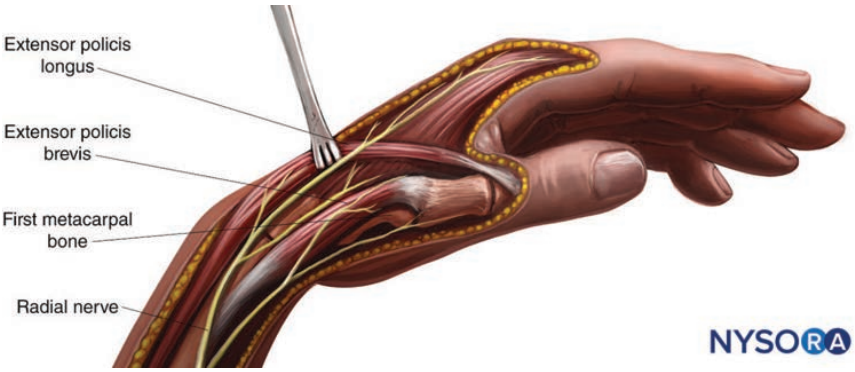


FIGURE 20-2. Illustration of the distribution of the superficial branch of the radial nerve in the hand.

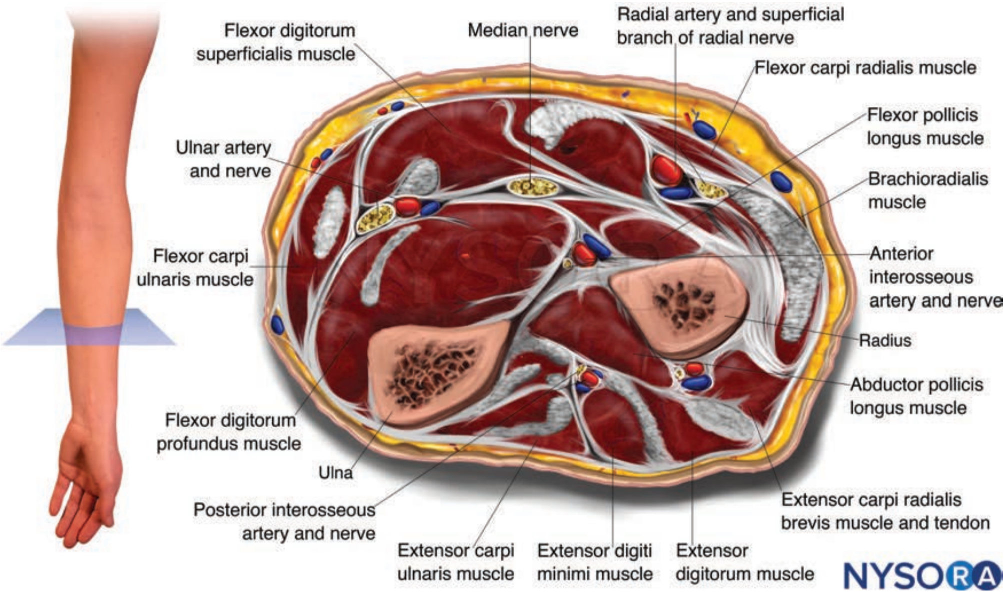


FIGURE 20-3. Cross-section anatomy at the level of the mid-forearm.

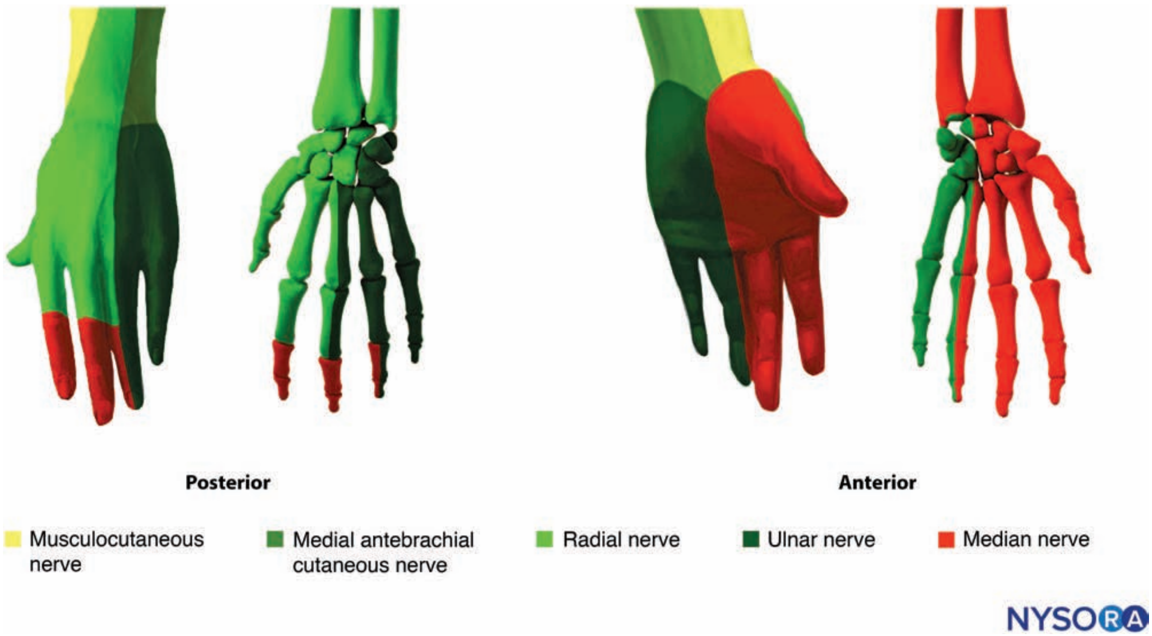


FIGURE 20-4. Anesthesia distribution after a wrist block.

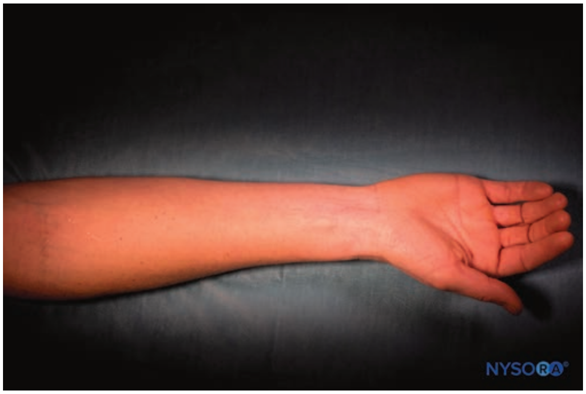


FIGURE 20-5. Patient position.

Block Preparation

Equipment

- Transducer: High-frequency linear transducer
- Needle: 25-gauge, insulated stimulating needle (optional)

Local Anesthetic

For a wrist block, an injection of 3 to 5 mL of lidocaine 2% around each nerve should be enough to provide adequate anesthesia for hand procedures. Longer-acting LAs could be used to prolong the postoperative analgesia.

Patient Positioning

The wrist block is most easily performed with the patient in the semi-sitting position with the arm abducted resting on a side support and the volar (palmar) surface facing up (Figure 20-5).

Technique

Median Nerve

The transducer is positioned in a transverse orientation over the anterior aspect of the mid-forearm (at least 5-10 cm proximal to the wrist crease to ensure the block of the palmar branches of the median and ulnar nerves) (Figure 20-6). With a slight tilt toward the hand, the median nerve appears as an oval hyperechoic structure in the fascial plane between the deep and superficial flexor muscles of the fingers. If necessary, scanning proximally will help to differentiate the nerve from the tendons of the flexor digitorum superficialis or the flexor pollicis longus.

The needle is inserted in-plane or out-of-plane toward the fascial plane that envelopes the nerve; ergonomics often dictates which is more effective (Figure 20-7).

Ulnar Nerve

The transducer should be placed in a transverse orientation over the anteromedial aspect (ulnar side) of the forearm. After identifying the ulnar artery, the ulnar nerve will be imaged as a triangular or oval hyperechoic structure medial to it (Figure 20-8). The tendon of the flexor carpi ulnaris lies just superficial to them and might be mistaken with the ulnar nerve. Scanning proximally-distally will help to identify the ulnar nerve: proximally it deviates from the artery; distally it is close to the artery.

The best point of injection is where the artery and nerve start separating. For the in-plane approach, it is usually more suitable inserting the needle from medial to lateral to avoid arterial puncture (Figure 20-9).

Superficial Branch of the Radial Nerve

The transducer is placed in transverse orientation at the anterolateral aspect (radial side) of the mid-forearm to identify the pulsation of the radial artery. The sensory branch of the radial nerve is imaged as a hyperechoic structure lateral to the artery and superficial to the radius bone. If the identification of the nerve at this level proves difficult, it is useful to trace it from its location above the elbow and follow it down until it divides into the superficial and deep branches (Figure 20-10).

The needle can be inserted either in-plane or out-of-plane, ergonomics often dictates which approach is better for performing this block. Likewise, a medial-to-lateral or lateral-to-medial needle direction can be used; always choose the best option to avoid arterial puncture (Figure 20-11).

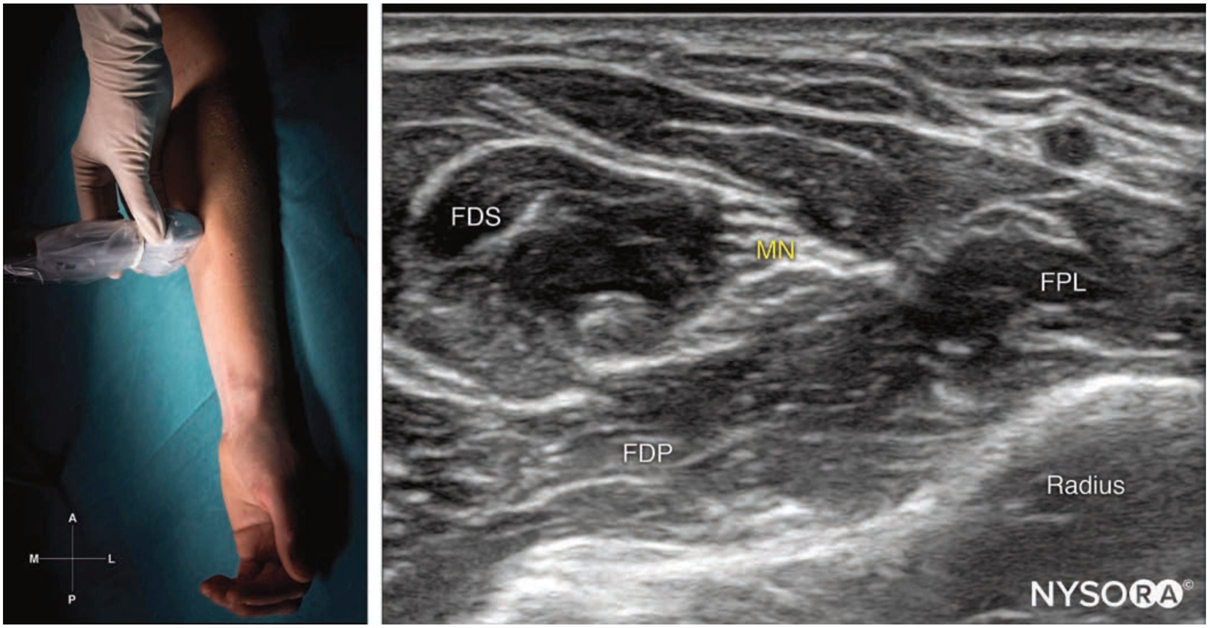


FIGURE 20-6. Transducer position and sonoanatomy of the median nerve (MN) at the level of the mid-forearm. FPL, flexor pollicis longus muscle; FDS, flexor digitorum superficialis muscle; FDP, flexor digitorum profundus.

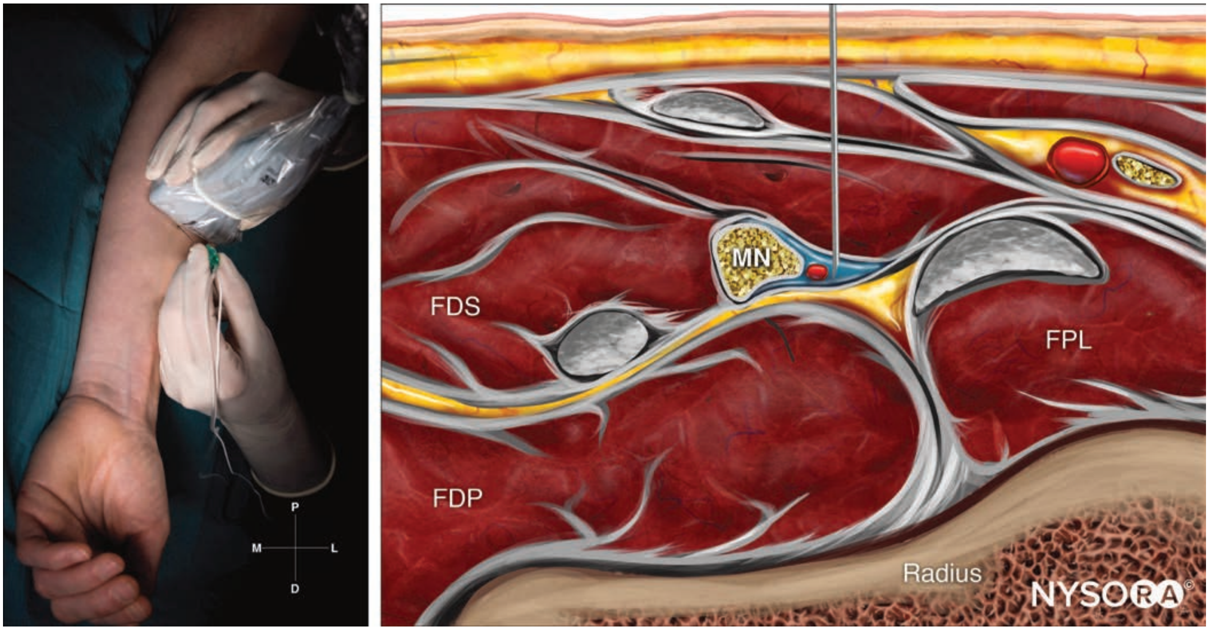


FIGURE 20-7. Reverse ultrasound anatomy of the median nerve (MN) at the level of the mid-forearm with needle insertion out-of-plane. FPL, flexor pollicis longus muscle; FDS, flexor digitorum superficialis muscle; FDP, flexor digitorum profundus.

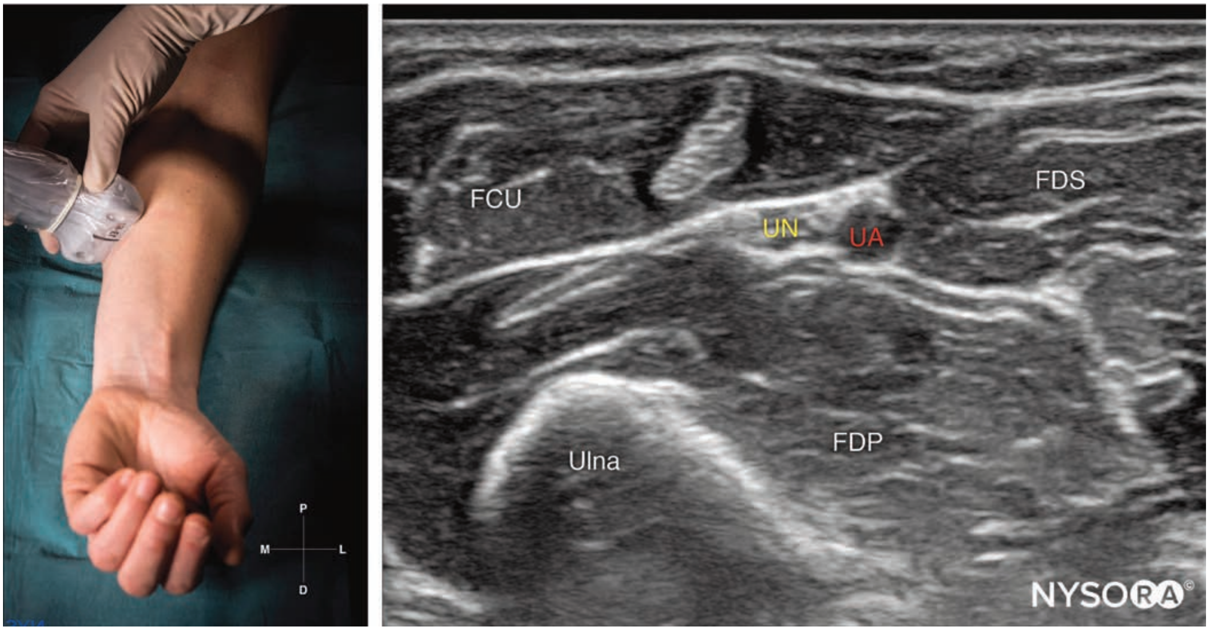


FIGURE 20-8. Transducer position and sonoanatomy of the ulnar nerve (UN) at the level of the mid-forearm. UA, ulnar artery; FCU, flexor carpi ulnaris; FDP, flexor digitorum profundus muscle; FDS, flexor digitorum superficialis muscle.

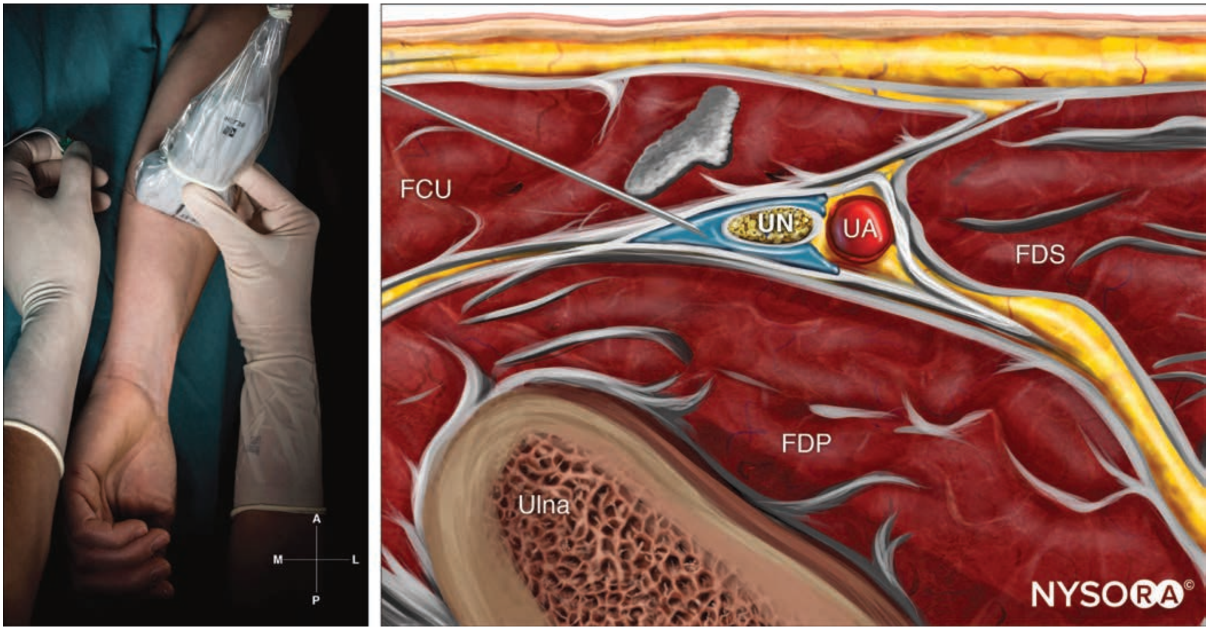


FIGURE 20-9. Reverse ultrasound anatomy of the ulnar nerve at the mid-forearm with needle in-plane and local anesthetic injection in blue. FDS, flexor digitorum superficialis muscle; FDP, flexor digitorum profundus muscle; FPL, flexor pollicis longus.

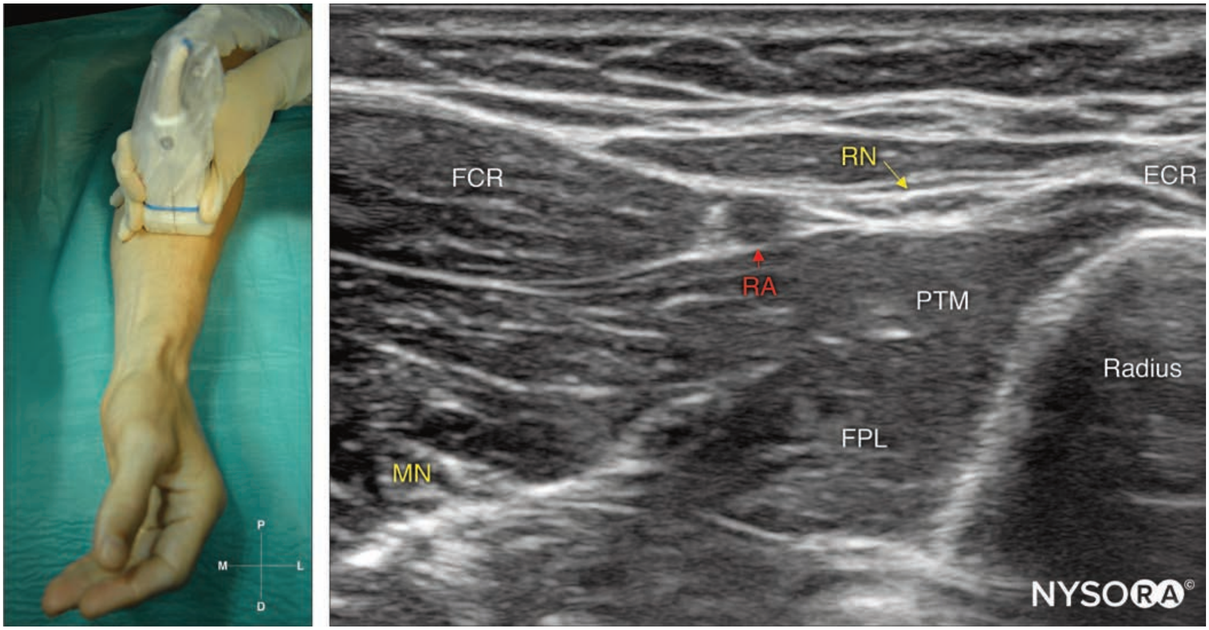


FIGURE 20-10. Sonoanatomy and transducer position for radial nerve (RN) block at the level of the mid-forearm. FCR, flexor carpi radialis; MN, median nerve; FPL, flexor pollicis longus; PTM, pronator teres muscle; ECR, extensor carpi radialis.

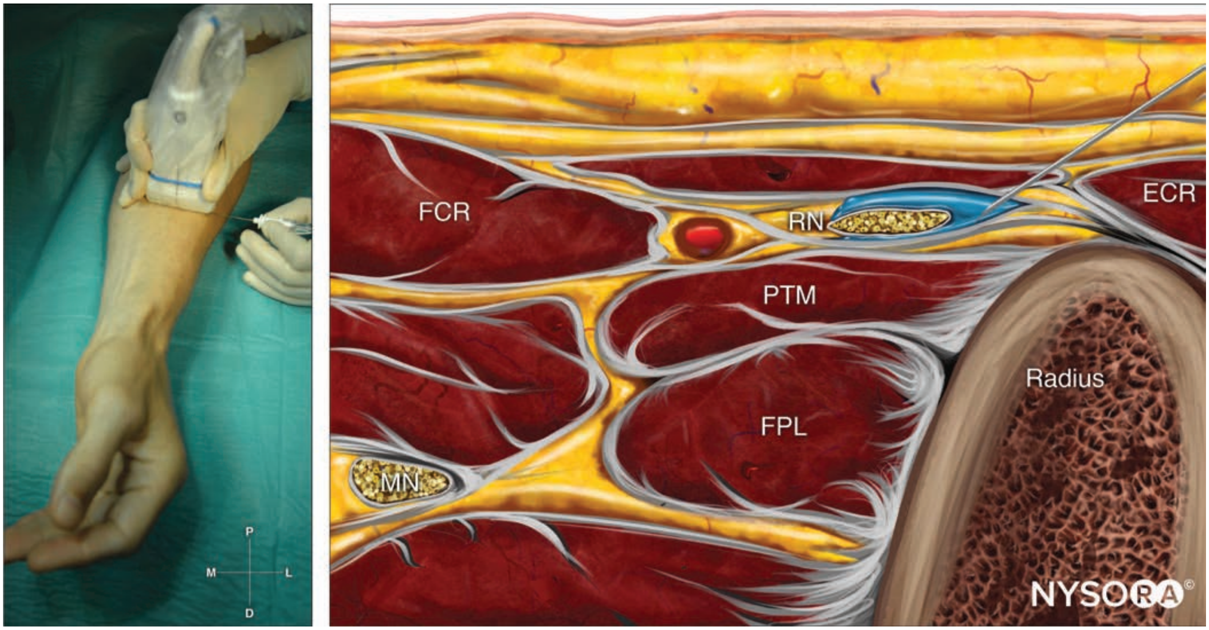


FIGURE 20-11. Reverse ultrasound anatomy of the superficial branch of the radial nerve (RN) at the level of the mid-forearm with needle insertion in-plane. FCR, flexor carpi radialis; MN, median nerve; FPL, flexor pollicis longus; PTM, pronator teres muscle; ECR, extensor carpi radialis.

Local Anesthetic Distribution

After negative aspiration, inject 1 to 2 mL of LA to confirm correct needle tip position; spread is visualized in the fascia plane enveloping the nerve. If not, reposition the needle and further inject 1 to 2 mL. Multiple injections to achieve circumferential spread are usually not necessary.

For carpal tunnel surgery, a subcutaneous infiltration at the level of the wrist crease should be performed with 5 mL of LA. Also, a “K” infiltration can be performed, following first the wrist crease and then directing the needle to thenar and hypothenar eminences. These approaches would block any small terminal branches of the brachial plexus that may reach the palmar crease (Figure 20-12).

Problem-Solving Tips

- The median nerve exhibits pronounced anisotropy, so tilting the transducer slightly will make the nerve appear alternately brighter (more contrast) or darker (less contrast) with respect to the background.
- When in doubt, nerve stimulation (0.5-1.0 mA) can be used to confirm the localization of the correct nerve.
- Either the in-plane or out-of-plane approaches can be used for all three blocks.
- It is not necessary to pursue a circumferential spread of LA around the nerves, but it is essential to confirm that the injection occurs in the correct fascial plane by scanning up and down during injection.

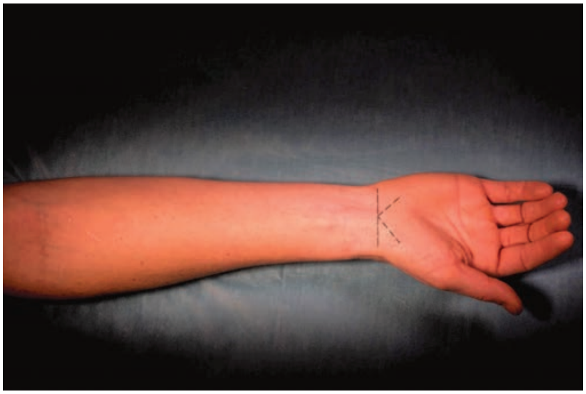
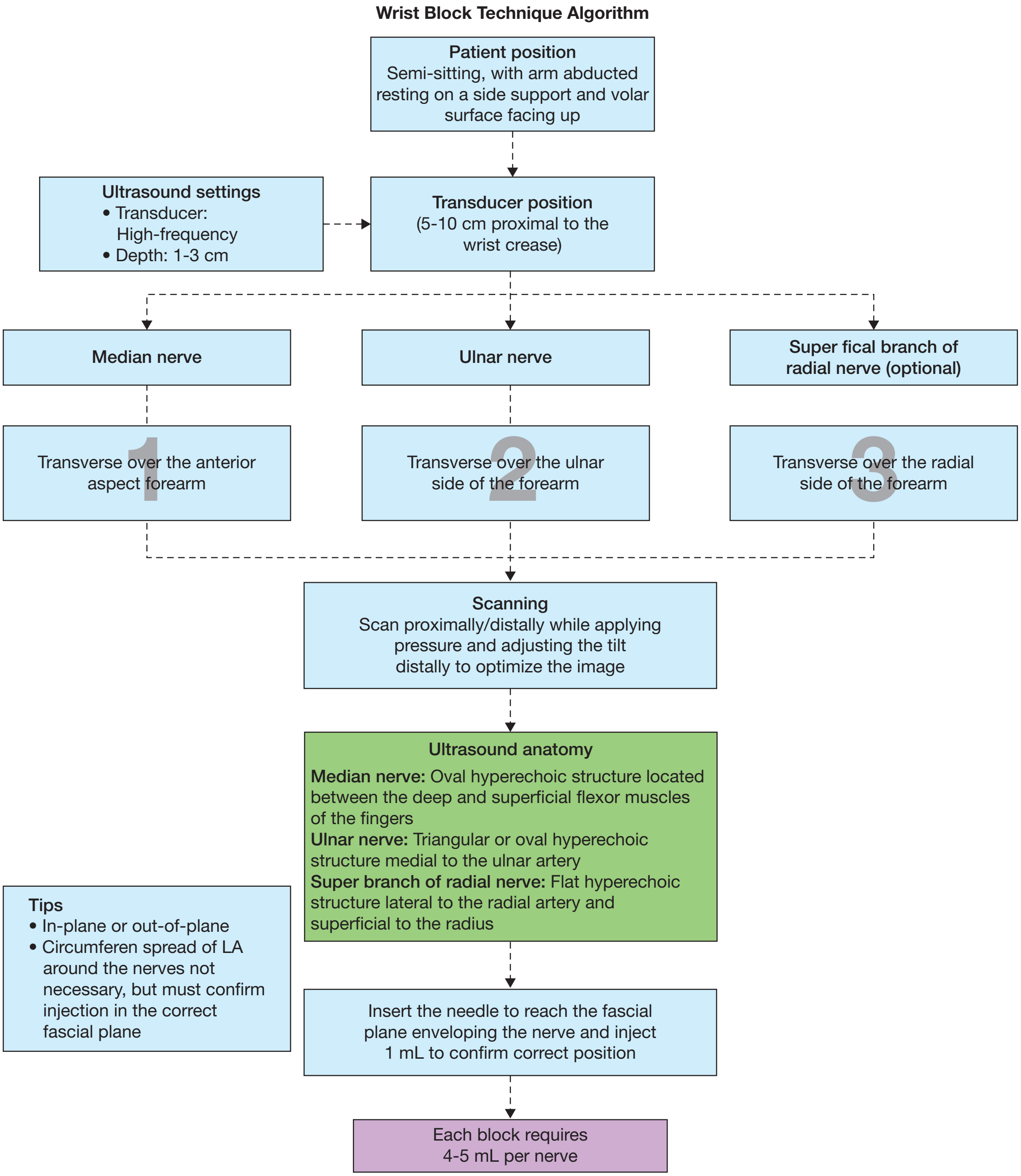


FIGURE 20-12. Subcutaneous infiltration (dotted line) at the level of the wrist crease for carpal tunnel surgery.

Flowchart


Wrist Block Technique Algorithm
Patient position
Semi-sitting, with arm abducted resting on a side support and volar surface facing up
Ultrasound settings
• Transducer: High-frequency
• Depth: 1-3 cm
Transducer position
(5-10 cm proximal to the wrist crease)
Median nerve
Ulnar nerve
Super fical branch of radial nerve (optional)
1
Transverse over the anterior aspect forearm
2
Transverse over the ulnar side of the forearm
3
Transverse over the radial side of the forearm
Scanning
Scan proximally/distally while applying pressure and adjusting the tilt distally to optimize the image
Ultrasound anatomy
Median nerve: Oval hyperechoic structure located between the deep and superficial flexor muscles of the fingers
Ulnar nerve: Triangular or oval hyperechoic structure medial to the ulnar artery
Super branch of radial nerve: Flat hyperechoic structure lateral to the radial artery and superficial to the radius
Tips
• In-plane or out-of-plane
• Circumferen spread of LA around the nerves not necessary, but must confirm injection in the correct fascial plane
Insert the needle to reach the fascial plane enveloping the nerve and inject 1 mL to confirm correct position
Each block requires 4-5 mL per nerve

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SECTION 4

Lower Extremity Blocks

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21 Lumbar Plexus Block

BLOCK AT A GLANCE

Block of the lumbar plexus (femoral, lateral femoral cutaneous, and obturator nerves) at the level of the lumbar paravertebral space in the psoas muscle compartment.

- **Indications:** Anesthesia and analgesia for the hip, knee, and lower extremity surgery. Combined with a proximal sciatic nerve block produces complete anesthesia of the ipsilateral lower extremity
- **Goal:** Spread of local anesthetic around the lumbar plexus in the psoas muscle compartment
- **Local anesthetic volume:** 20 to 30 mL

General Considerations

The lumbar plexus block is an advanced regional anesthesia technique for hip and knee procedures. Its use has decreased over time due to the technique's complexity and potential for complications. The main disadvantages of the lumbar plexus block are the deep location of the neural elements and their close proximity to the epidural space, lumbar arteries, and the kidneys. Although ultrasound (US) can be used to help guide needle advancement and local anesthetic (LA) spread, this still requires a high degree of skill. An assessment of the risk-benefit ratio should be made for each patient. The indications for lumbar plexus blocks are declining in favor of more specific, distal nerve blocks, particularly blocks targeting only the sensory branches to the lower extremity joints. These considerations explain the paucity of data on ultrasound-guided lumbar plexus block.

Limitations and Complications

Obtaining adequate US images of the psoas compartment and tracking the needle can be challenging due to its deep location and the complexity of the sonoanatomy. Consequently, the lumbar plexus block is associated with a relatively high-risk failure rate and epidural spread. Given the vascularity of the lumbar paravertebral region, LA toxicity and hematomas have all been reported.

Anatomy

The lumbar plexus is formed by the union of the anterior primary rami of L1, L2, L3, and a part of L4. It also receives a variable contribution from T12 (subcostal nerve) and L5 (Figure 21-1). After exiting the intervertebral foramen, the nerve roots of the lumbar plexus enter the lumbar paravertebral space, a wedge-shaped compartment between the anterior and posterior insertions of the psoas muscle. The lumbar paravertebral space also contains branches of the lumbar artery and vein. The roots follow a steep caudal course through the psoas compartment within the posterior third of the psoas muscle, close to the lumbar transverse processes. The terminal nerves originating from the lumbar plexus course caudally and laterally along the pelvis in a fan-shape distribution (Figure 21-2).

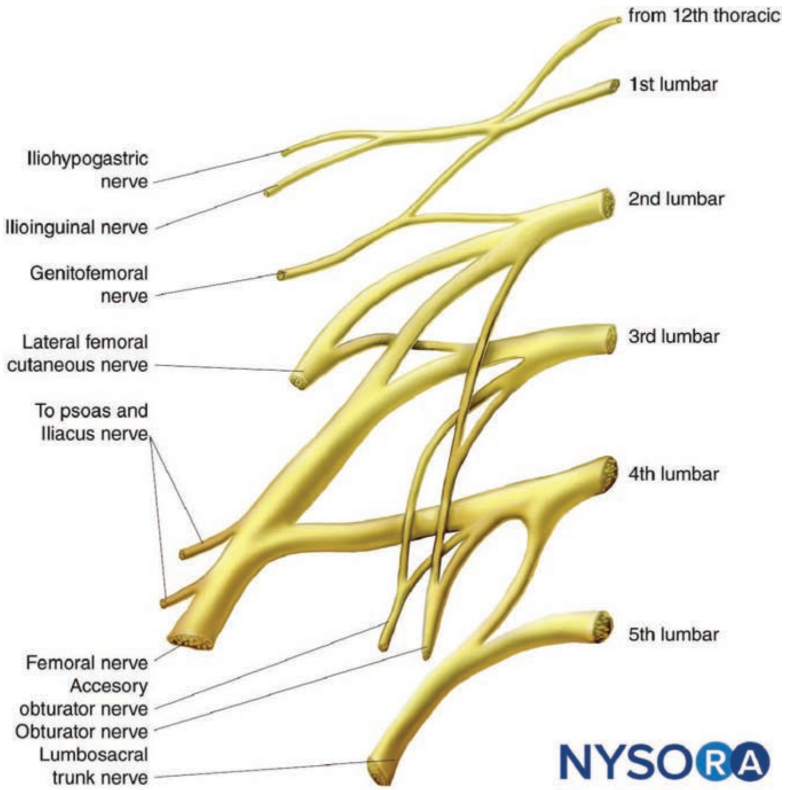


FIGURE 21-1. Organization of the lumbar plexus.

Cross-Sectional Anatomy and Ultrasound View

A cross-section at the level of L4-L5 shows the transverse view of the lumbar plexus elements exiting the intervertebral foramen and advancing into the psoas muscle compartment (Figure 21-3). The corresponding segmental lumbar artery courses posterolaterally near the intervertebral foramen and divides into lateral, posterior, and radicular branches.

To obtain a transverse view of the lumbar plexus, a curved US transducer is placed posteriorly, 4 cm laterally to the midline directed slightly medially (transverse oblique view) and adjusted to insonate the intertransverse space (Figure 21-4A). The erector spinae and psoas muscles lie superficially to the spinous process and vertebral body. The lumbar plexus appears as a hyperechoic structure within the hypoechoic psoas muscle (Figure 21-4B). Alternatively, the transducer is placed on the flank, between the iliac crest

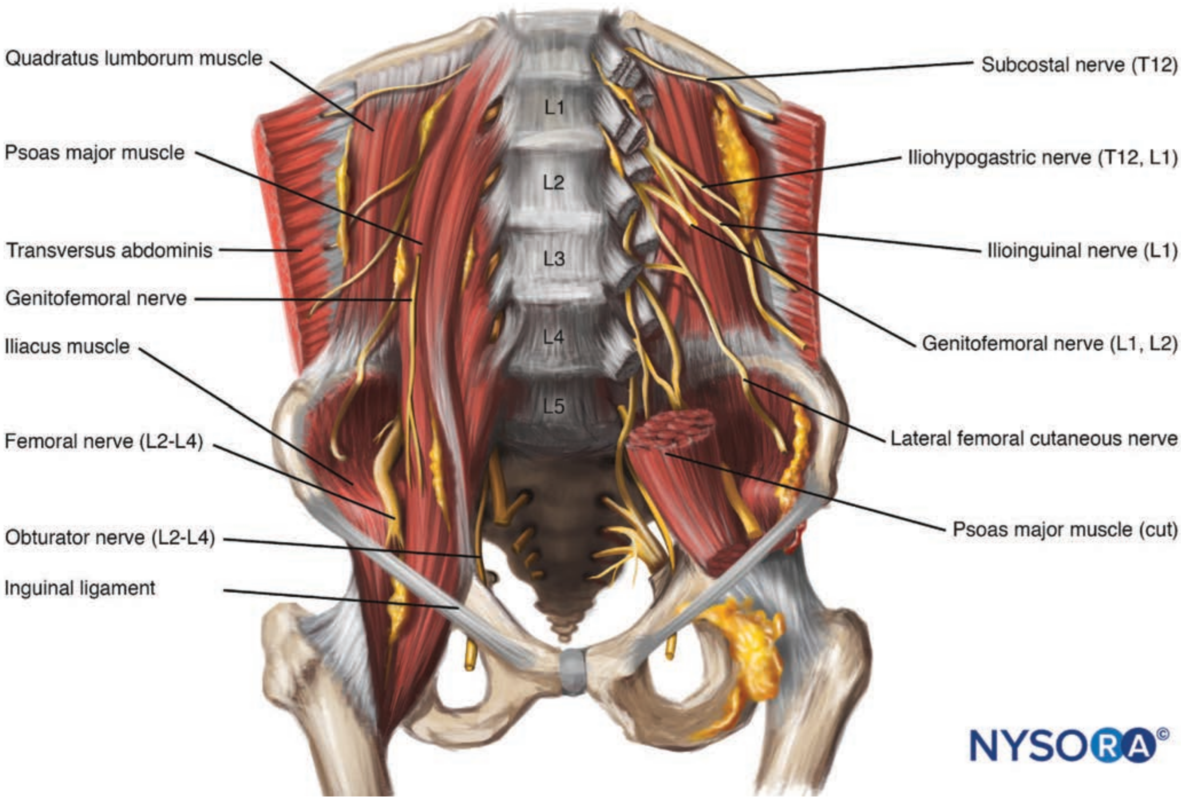


FIGURE 21-2. Anatomy of the lumbar plexus and the posterior abdominal wall.

and the costal border, oriented medially (shamrock view) (Figure 21-5).

Distribution of Anesthesia and Analgesia

The lumbar plexus block results in a motor and sensory block of the anterior aspect of the thigh, hip, and knee (Figure 21-6).

Block Preparation

Equipment

- Transducer: Low-frequency curved transducer
- Needle: 80- to 100-mm, 22-gauge stimulating needle

Local Anesthetic

Long-lasting LAs (e.g., bupivacaine 0.5% or ropivacaine 0.5%) are commonly used to prolong postoperative analgesia

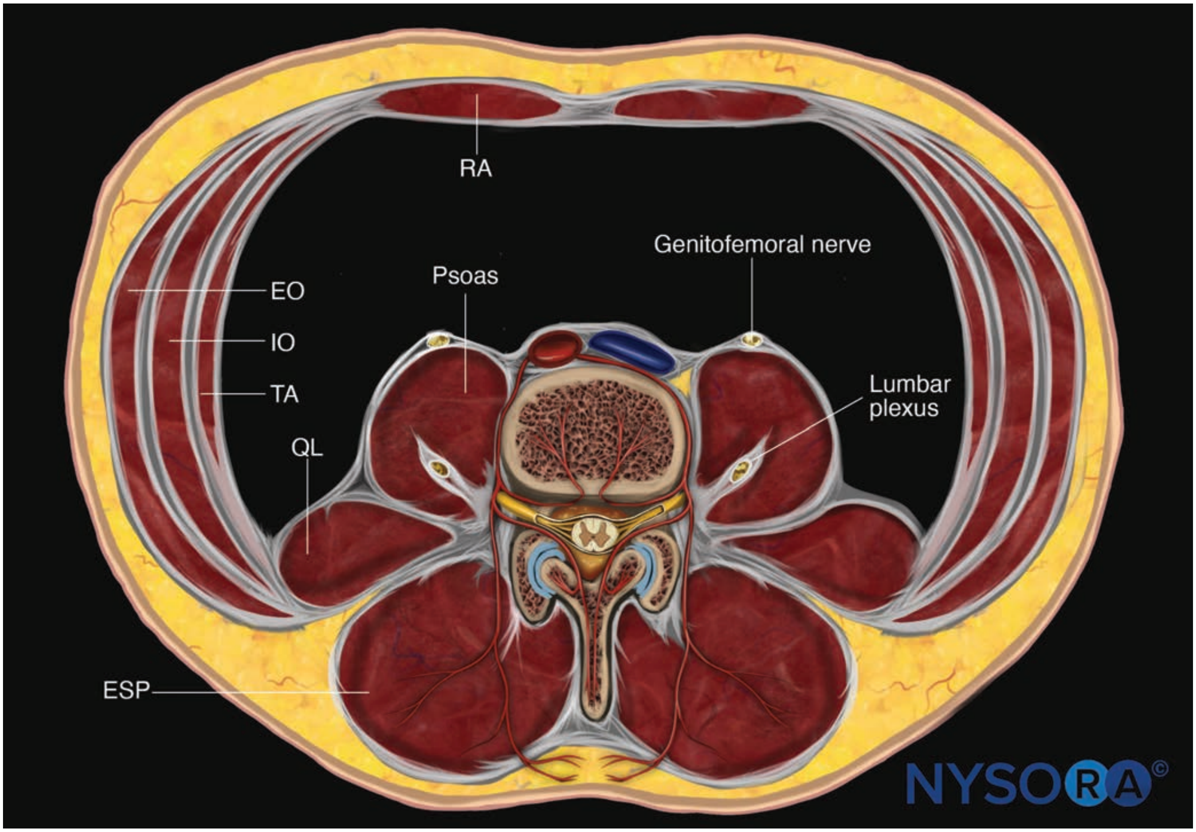
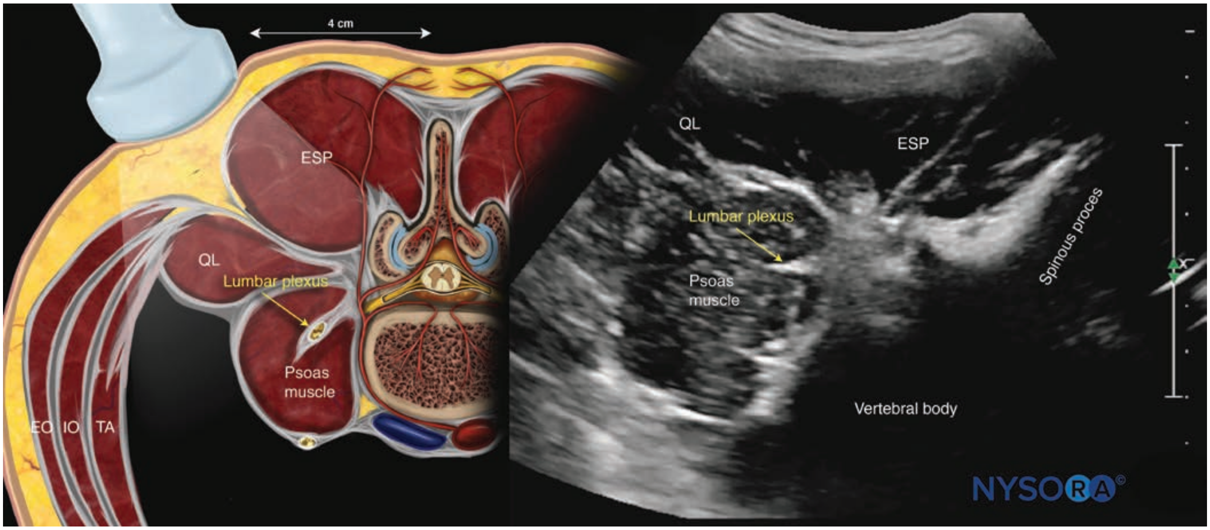
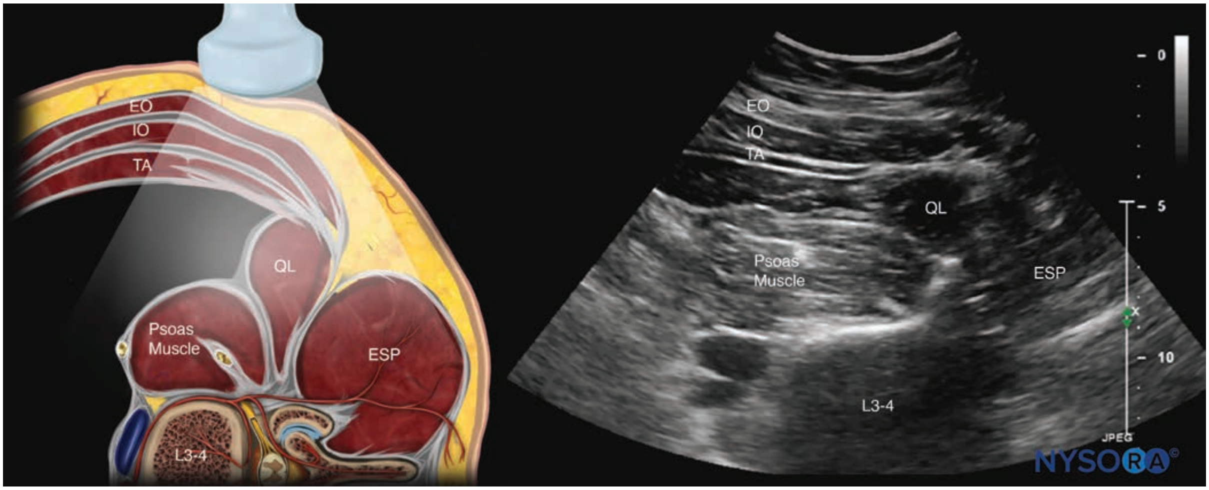


FIGURE 21-3. Cross-section of the lumbar plexus at the level of L4-L5. RA, rectus abdominis; EO, external oblique muscle; IO, internal oblique muscle; TA, transversus abdominis muscle; QL, quadratus lumborum muscle; ESP, erector spinae muscle.



A B

FIGURE 21-4. Illustration showing the transducer position to obtain a transverse oblique view of the lumbar plexus (A) and the corresponding ultrasound image (B). QL, quadratus lumborum; ESP, erector spinae muscles; EO, external oblique; IO, internal oblique; TA, transversus abdominis muscle.



A B

FIGURE 21-5. Illustration showing the transducer position to obtain a transverse "shamrock" view (A) and the corresponding ultrasound image (B). QL, quadratus lumborum; ESP, erector spinae muscles; EO, external oblique; IO, internal oblique; TA, transversus abdominis muscle.

FIGURE 21-6. Sensory and motor block distribution of a lumbar plexus block.

FIGURE 21-7. Patient position to perform a lumbar plexus block.

after joint surgery. The recommended volume is 20 to 25 mL depending on the quality of LA visualization.

Patient Positioning

Place the patient in the sitting or lateral position with the side to be blocked upwards (Figure 21-7).

Technique

Landmarks, Initial Probe Transducer Position, and Scanning Techniques

The lumbar plexus block can be performed with the transducer in a sagittal or transverse orientation.

1. **Sagittal**

   The transducer is placed in a sagittal paramedian orientation, 4 cm lateral to the midline to identify the lumbar transverse processes. The transverse process appears as a hyperechoic reflection with an anterior acoustic shadow (Figure 21-8). With the curved transducer, the acoustic shadows show a sonographic pattern known as the "trident sign." The psoas muscle is visualized through the acoustic windows as a thick hypoechoic muscular structure with hyperechoic striations. The lumbar plexus is seen as longitudinal hyperechoic structures in the posterior third of the psoas muscle that can be differentiated from the intramuscular tendons as it is thicker and takes an oblique course anteriorly. If the transverse processes are not visualized, the transducer is moved medially and slightly tilted toward the midline until the trident sign is seen.

2. **Transverse**

   There are two options to perform the block in the transverse orientation:

   - Transverse oblique view: The transducer is placed 4 cm laterally to the spinous processes along the intercristal line, just above the iliac crest and the beam is directed slightly medially (Figure 21-9).
   - Shamrock view: The transducer is placed on the flank above the iliac crest and oriented medially (Figure 21-10).

The target vertebral level for the US scan (L3 or L4) is identified in both cases. From posterior to anterior, the erector spinae, the quadratus lumborum, and the psoas muscles are seen as hypoechoic muscular structures around the vertebral contour. If the transverse process is identified, the transducer is displaced craniocaudal and tilted to isonate the intertransverse space at the level of the articular process. The lumbar paravertebral space is seen between the articular process and the vertebral body; the lumbar plexus is seen in continuity entering the psoas muscle compartment.

Needle Approach and Trajectory

For the sagittal approach, the needle is inserted out-of-plane or in-plane from the caudal end of the transducer and guided through the acoustic window of the transverse processes of

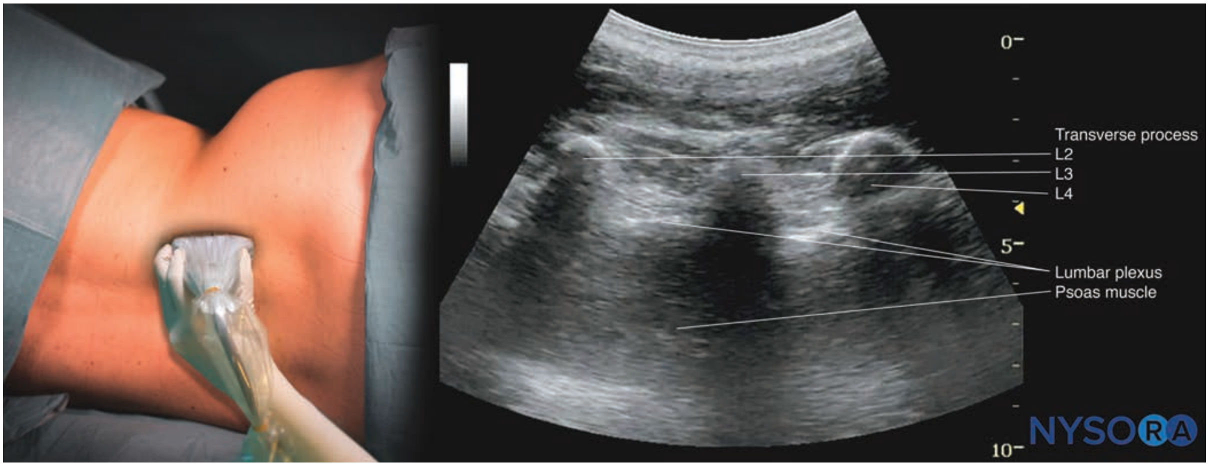


FIGURE 21-8. Transducer position in a sagittal orientation and the corresponding sonoanatomy of the lumbar plexus.

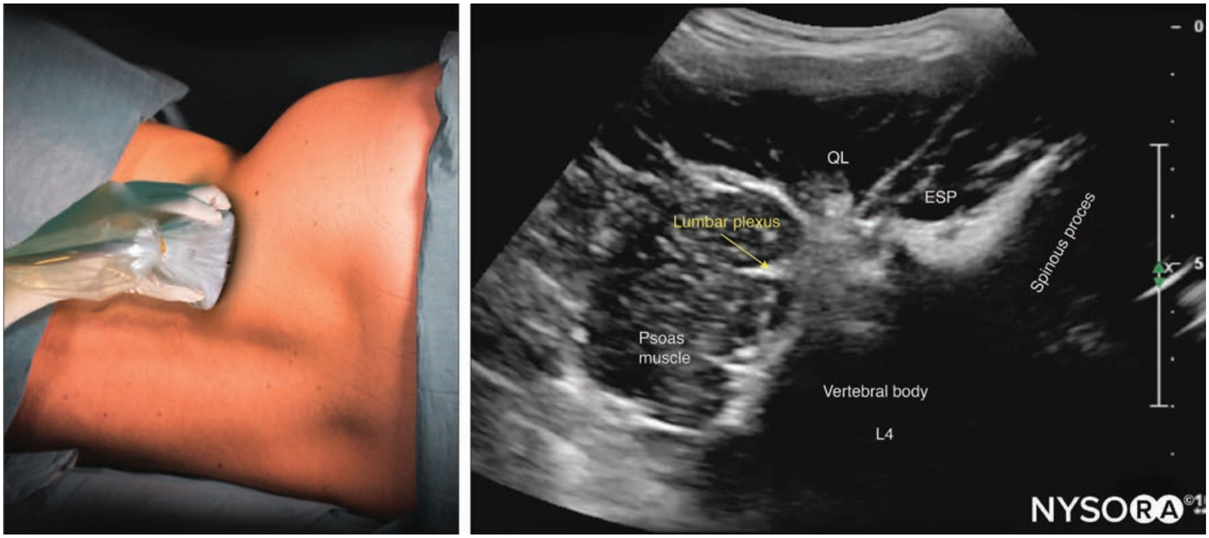


FIGURE 21-9. Transducer position in a transverse oblique orientation and the corresponding sonoanatomy of the lumbar plexus. QL, quadratus lumborum; ESP, erector spinae muscles.

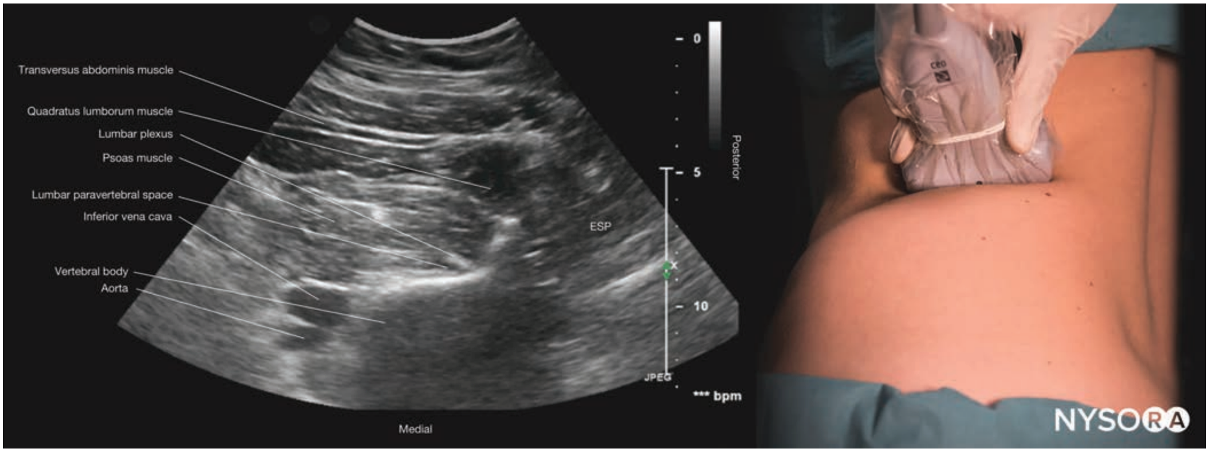


FIGURE 21-10. Transducer position in a transverse orientation to obtain a shamrock view and the corresponding sonoanatomy of the lumbar plexus.

L3 and L4 into the posterior aspect of the psoas major muscle next to the lumbar plexus (Figure 21-11).

For the transverse approach (Figure 21-12) and shamrock approach (Figure 21-13), the needle is inserted 4 cm lateral to the midline and slowly advanced in-plane to the posterior aspect of the psoas muscle. Correct the direction if needed until the tip is located next to the lumbar plexus in the fascial compartment.

Local Anesthetic Distribution

After negative aspiration, 1 to 2 mL of LA is injected to confirm the correct injection site. The block is completed while observing the spread of the injection within the lumbar compartment around the lumbar plexus, which is better visualized as it is surrounded by the hypoechoic LA.

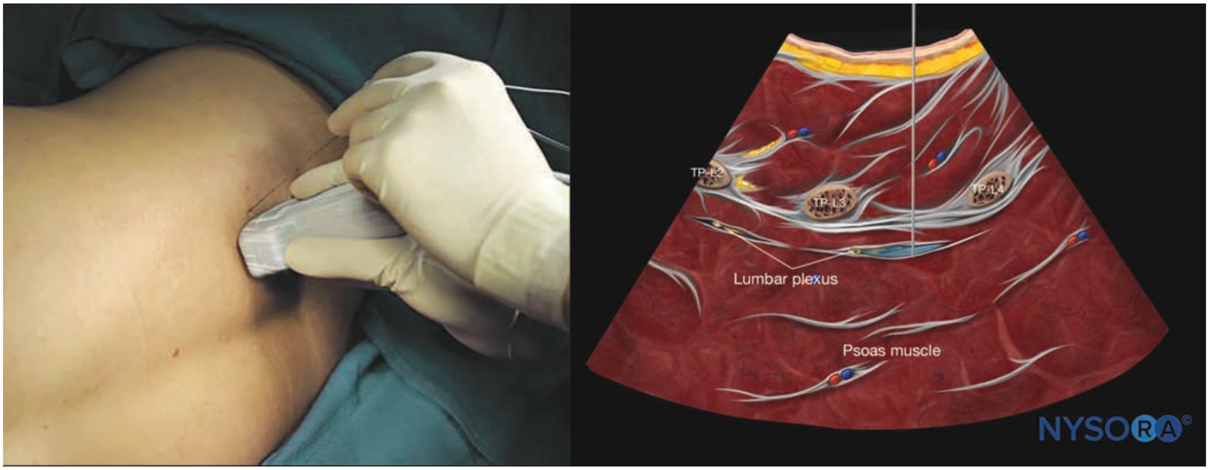


FIGURE 21-11. Reverse ultrasound anatomy of a lumbar plexus block in a sagittal approach with the needle inserted out-of-plane.

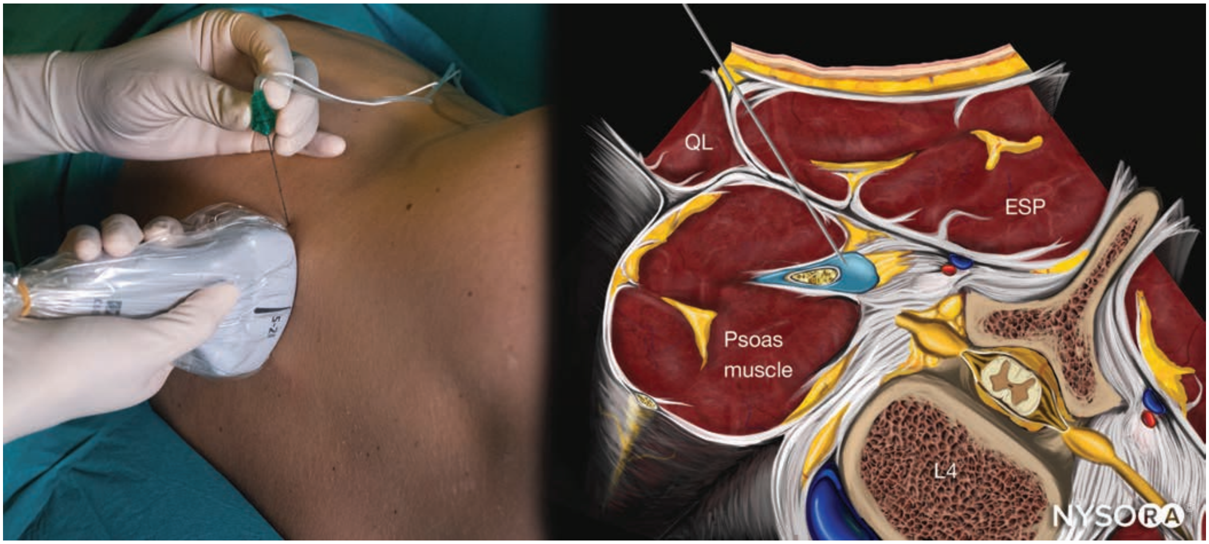


FIGURE 21-12. Reverse ultrasound anatomy of a lumbar plexus block using the transverse oblique approach. QL, quadratus lumborum; ESP, erector spinae muscles.

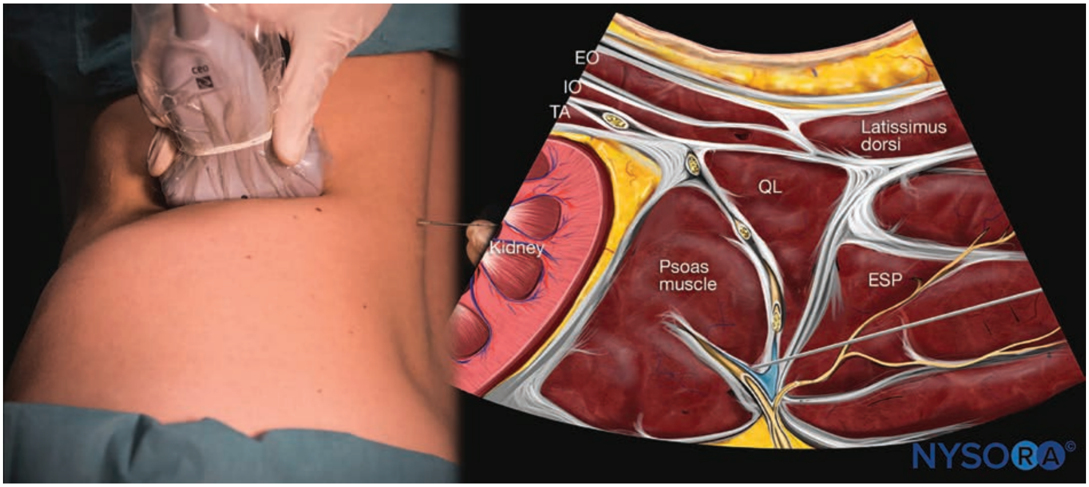


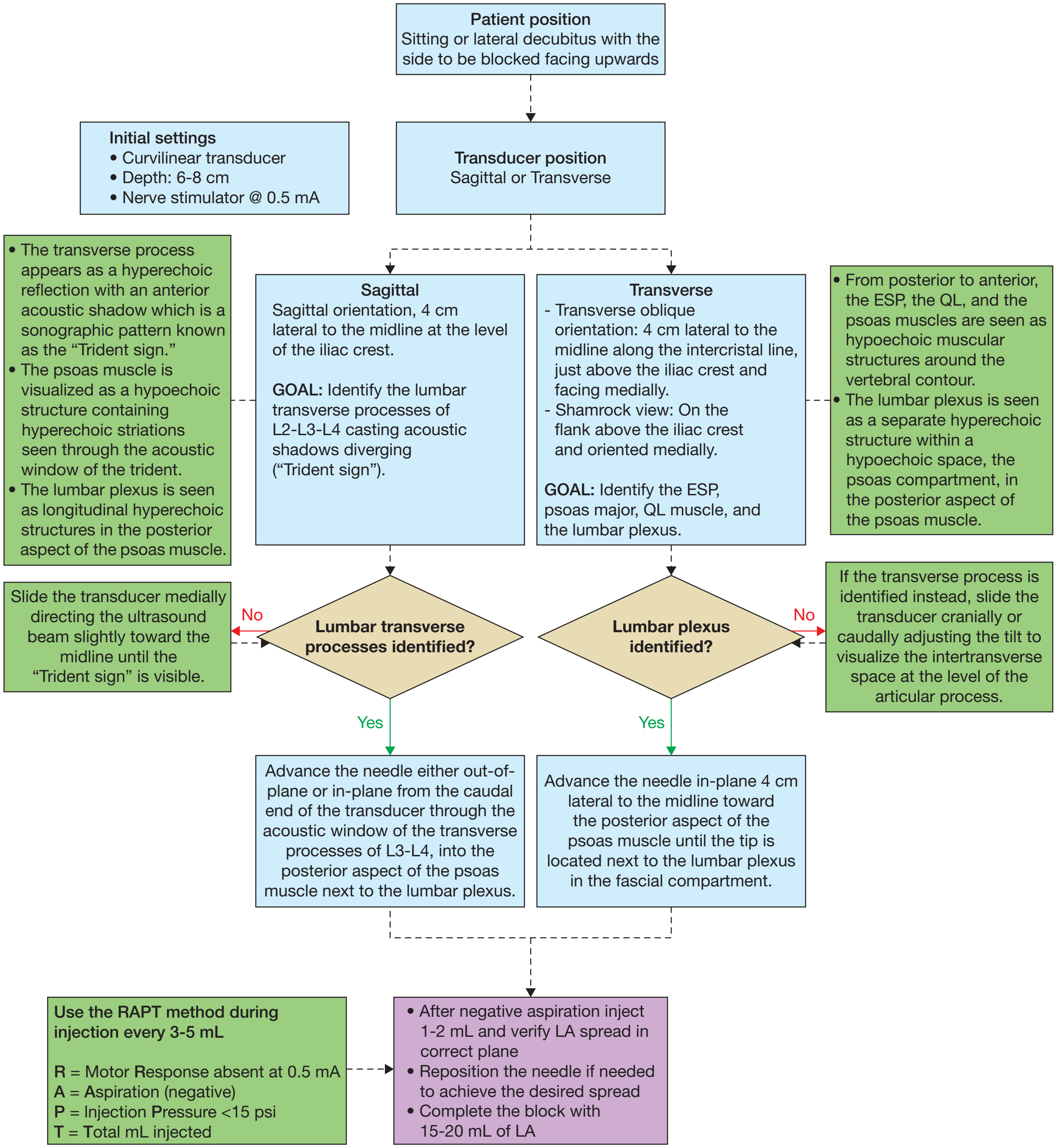
FIGURE 21-13. Reverse ultrasound anatomy of a lumbar plexus block using the shamrock view. QL, quadratus lumborum; ESP, erector spinae muscles; EO, external oblique; IO, internal oblique; TA, transversus abdominis muscle.

Problem-Solving Tips

- Obtaining the optimal view on the transverse process requires minor adjustments of the transducer (tilting, pressing, and sliding) to insonate the intertransverse space.
- Due to vascularity and deep location, the lumbar plexus block is not recommended in patients with coagulopathy or receiving thromboprophylaxis.
- US imaging of the psoas muscle may be more challenging in older patients due to the lower roots soft tissue image contrast as compared to the younger patients.
- Large body mass index (BMI) makes imaging of the lumbar paravertebral anatomy and needle guidance difficult.
- High injection pressures (20 psi) are associated with higher incidence of epidural spread.

Flowchart

Lumbar Plexus Block Technique Algorithm



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22 Fascia Iliaca Block

BLOCK AT A GLANCE

Block of the nerves of the lumbar plexus under the fascia iliaca at the level of the inguinal ligament (femoral and lateral femoral cutaneous nerves).

- **Indications**: Analgesia for hip and femur fractures, analgesia after hip and knee surgery, and procedures on the anterior thigh
- **Goal:** Medial, lateral, and cranial spread of local anesthetic (LA) under the fascia iliaca
- **Local anesthetic volume:** 20 to 40 mL

General Considerations

The fascia iliaca block, also called the fascia iliaca compartment block, is a well-established alternative to lumbar plexus or femoral nerve blocks to provide analgesia for hip procedures. Its effectiveness in the preoperative pain management of hip fracture patients has been well-documented, prompting several societies and institutions to recommend its use as part of the routine multimodal analgesic protocols for this indication.

The analgesic efficacy of this technique assumes that injection of the LA beneath the fascia iliaca spreads underneath the fascia and reaches the femoral, lateral femoral cutaneous, and (eventually) the obturator nerve proximally, although an obturator nerve block is not consistent. This block has been performed for decades using landmarks and loss-of-resistance technique; however, with the introduction of ultrasound (US), it became apparent that many of these “blind” injections do not occur in the proper plane. The fascia iliaca block has evolved from the infrainguinal “classic” approach to a suprainguinal technique with the aim to spread the LA injection cranially, more consistently reaching the lumbar plexus, and resulting in analgesic efficacy superior to the infrainguinal approach.

Limitations

Although the spread of LA toward the femoral nerve can be confirmed by US, the extent of the LA proximal toward the lumbar plexus cannot be monitored or ensured. Because the spread cannot be entirely controlled, this technique is primarily used for analgesia, not anesthesia.

Specific Risks

Overall complications involving the fascia iliaca compartment block are low. Being considered a fascial plane technique, intravascular injections or neurologic injury are uncommon as the injection site is remote from the major neurovascular structures. The most commonly reported complications include hematomas at the injection point and local anesthetic systemic toxicity (LAST). The plasma levels after an injection of 30 mL of 0.25% levobupivacaine are below the toxic threshold, even in elderly patients, who are the most common beneficiaries of the technique. However, pneumoperitoneum and bladder puncture have been reported.

Anatomy

The fascia iliaca covers the iliacus muscle throughout its descent from the pelvic crest into the upper thigh and merges medially with the fascia overlying the psoas muscle. The femoral nerve (L2-L4) and the lateral femoral cutaneous nerve (L2-L3) emerge from the lateral border of the psoas major muscle and travel under the fascia iliaca over the ventral surface of the iliacus muscle in their intrapelvic and inguinal course (Figure 22-1). As it descends distal to the inguinal ligament, the femoral nerve gives off a number of sensory and motor nerves to the quadriceps and sartorius muscles. However, the articular branches to the hip joint leave both

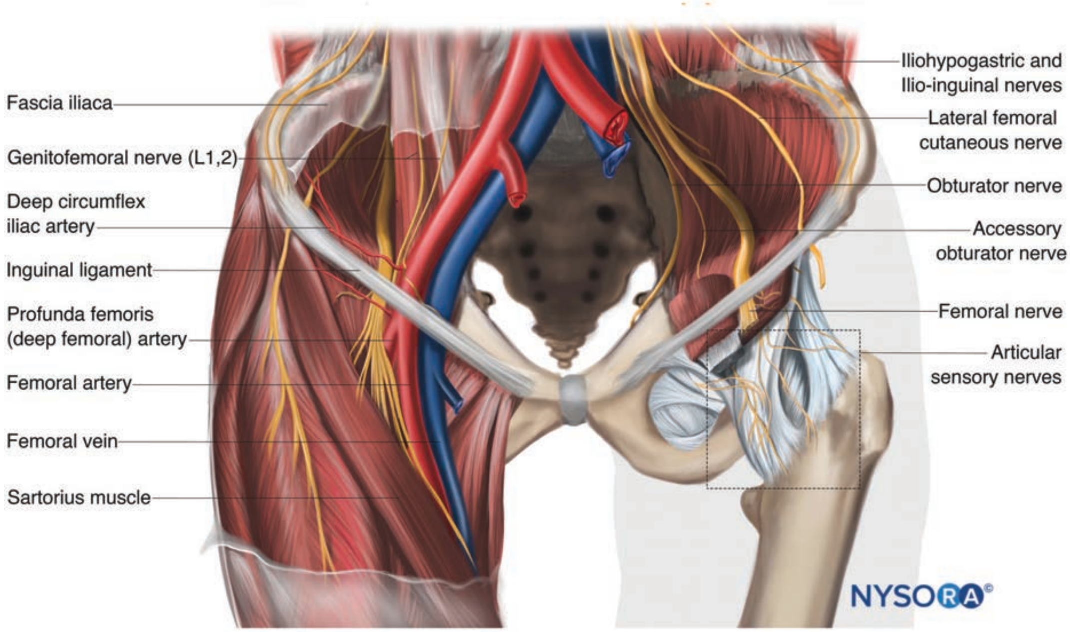


FIGURE 22-1. Fascia iliaca anatomy and relation with the femoral, lateral femoral cutaneous, and obturator nerves.

proximal and distal to the inguinal ligament to provide innervation to the anterolateral surface of the capsule.

The obturator nerve (L2-L4) emerges from the medial border of the psoas muscle and travels posteriorly behind the common iliac arteries toward the obturator foramen. During its intrapelvic course, it is separated from the fascia iliaca compartment by the psoas muscle; therefore, it is not consistently anesthetized by a fascia iliaca block. The articular branches arise before passing the obturator foramen to supply the inferomedial aspect of the hip capsule (Figure 22-1).

When the accessory obturator nerve is present (10-50%, depending on the studies), it leaves the obturator nerve laterally, proximally in the pelvic fossa and crosses over the pubic ramus. In those cases, it contributes to the innervation of the anteromedial aspect of the hip capsule (Figure 22-1). (See Chapter 23 for a more detailed description of the hip joint innervation.)

Cross-Sectional Anatomy and Ultrasound View

At the level of the inguinal ligament, the iliacus muscle appears at its most superficial location. Thus, this location is the most convenient to access the fascia iliaca compartment. Cranially and medially, the muscle lines the iliac bone and is covered by the abdominal wall muscles. Caudally and laterally, the iliopsoas muscle is covered by the sartorius muscle (Figure 22-2). The femoral nerve is located just deep to the fascia iliaca and separated from the femoral vessels by the iliopectineal arch. The deep and superficial iliac circumflex arteries course cranially and laterally superficial to the fascia iliaca at this level.

With the transducer placed perpendicular to the inguinal ligament, the fascia iliaca is seen as a hyperechoic line covering the hypoechoic iliopsoas muscle. The sartorius can be seen as a superficial triangular shape on the lateral-caudal side, and the internal oblique muscle is visualized on the cranial-medial side. The deep circumflex iliac artery appears between this muscle and the fascia iliaca (Figure 22-2).

With the transducer placed distally to the inguinal ligament, the femoral nerve and femoral vessels are readily apparent on the medial side of the fascia iliaca (Figure 22-2).

Distribution of Anesthesia and Analgesia

The distribution of the sensory and motor block depends on the cranial extent of the LA and the nerves involved, although blockade of the femoral and lateral femoral cutaneous nerves is consistently achieved with both approaches. Depending on the concentration of LA used, the motor block of the quadriceps will vary from weakness to complete paralysis (Figure 22-3).

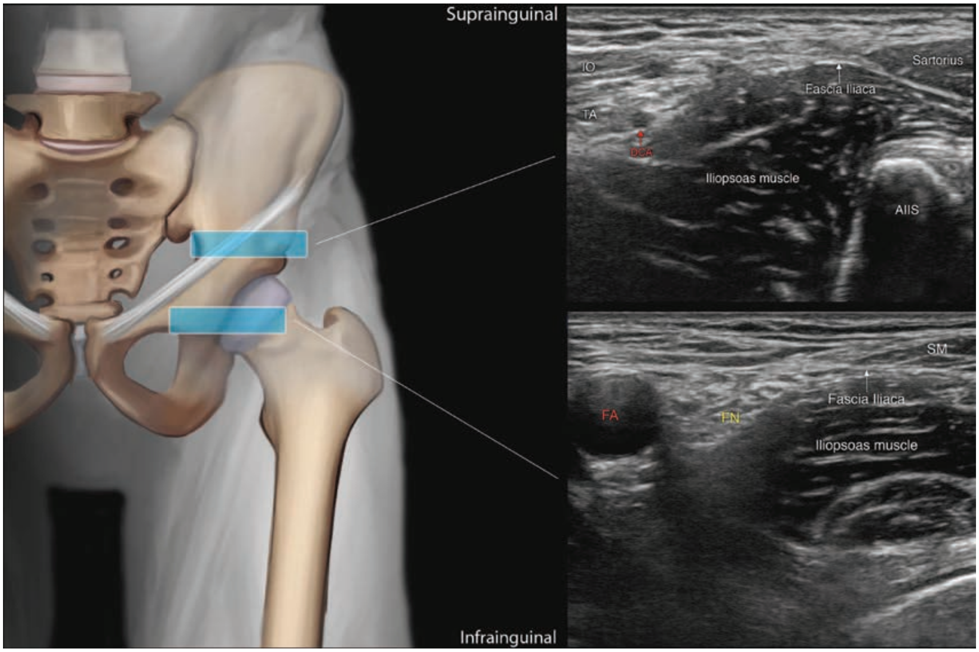


FIGURE 22-2. Bony landmarks and transducer positions to perform a suprainguinal and infrainguinal fascia iliaca block.

Block Preparation

Equipment

- Transducer: High-frequency linear transducer
- Needle: 50- to 100-mm, 22-gauge, short-bevel, insulated stimulating needle

Local Anesthetic

Because this fascial compartment block depends on the distribution of a high volume of LA (30-40 mL) underneath the fascia, diluted concentrations of long-lasting LAs are most commonly used, such as bupivacaine, levobupivacaine, and ropivacaine at concentrations of 0.2% to 0.3%. Higher concentrations may result in a prolonged motor block, numbness, delayed ambulation, and risk of LAST. Recent data in cadavers and volunteers suggest that a volume of 40 mL is required to reach the obturator nerve. However, in clinical practice, volumes of 20 to 30 mL result in effective analgesia for hip procedures. The addition of liposome bupivacaine to the mixture should prolong analgesia for hip surgery, although studies are required to confirm this.

Patient Positioning

The patient should be in a supine position, with the bed flattened to maximize access to the inguinal area (Figure 22-4).

TECHNIQUES

A. Infrainguinal Fascia Iliaca Block

Landmarks and Initial Transducer Position

The transducer is placed in a transverse orientation at the femoral crease, distal to the inguinal ligament to identify the femoral artery, the iliopsoas muscle, and fascia iliaca.

Scanning Technique

Tilting and pressing the transducer help to identify the hyperechoic fascia iliaca on the surface of the hypoechoic iliopsoas muscle. The femoral nerve lies deep to the fascia and lateral to the artery. The transducer is then moved laterally until the sartorius muscle is identified by its typical triangular shape when compressed by the transducer (Figure 22-5).

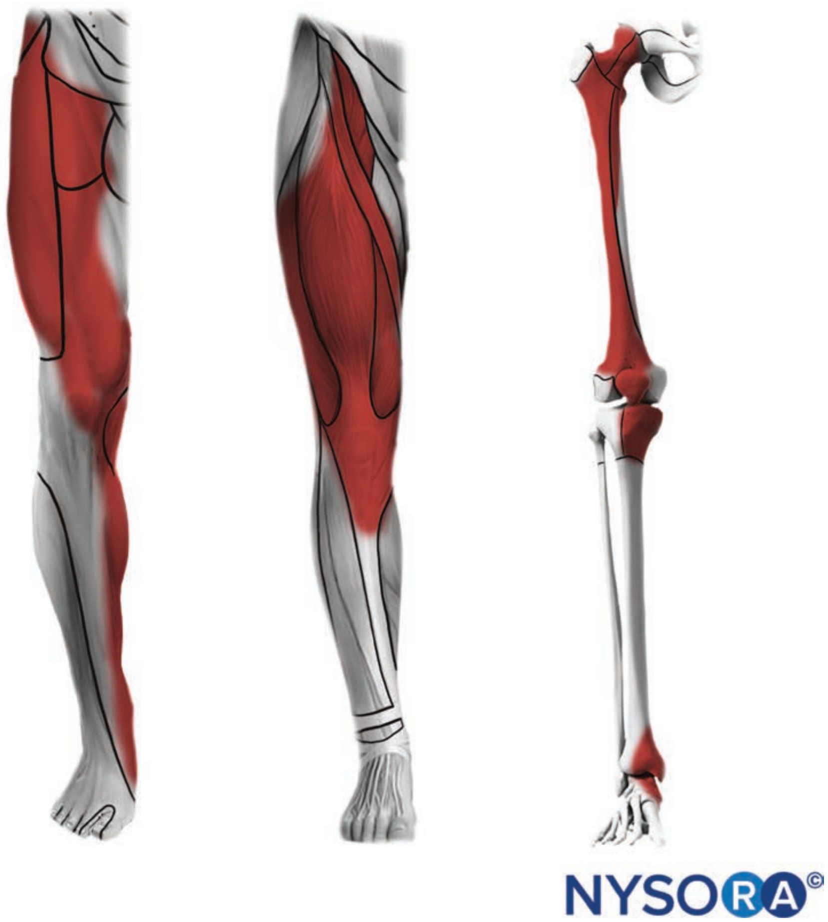


FIGURE 22-3. Expected sensory and motor block distribution of a fascia iliaca block.

Needle Approach and Trajectory

The needle is inserted in-plane in a lateral-to-medial direction, often through the sartorius muscle toward the fascia iliaca. As the needle encounters the fascia iliaca, indented by the needle, a loss of resistance follows when the needle tip pierces the fascial plane. After negative aspiration, 1 to 2 mL of LA is injected to confirm proper distribution of the LA in the fascial plane between the fascia and the iliopsoas muscle (Figure 22-6).

Local Anesthetic Distribution

The spread of LA progresses in the medial-lateral and cranial-caudal direction from the point of injection, separating the fascia from the muscle. When the injection occurs above

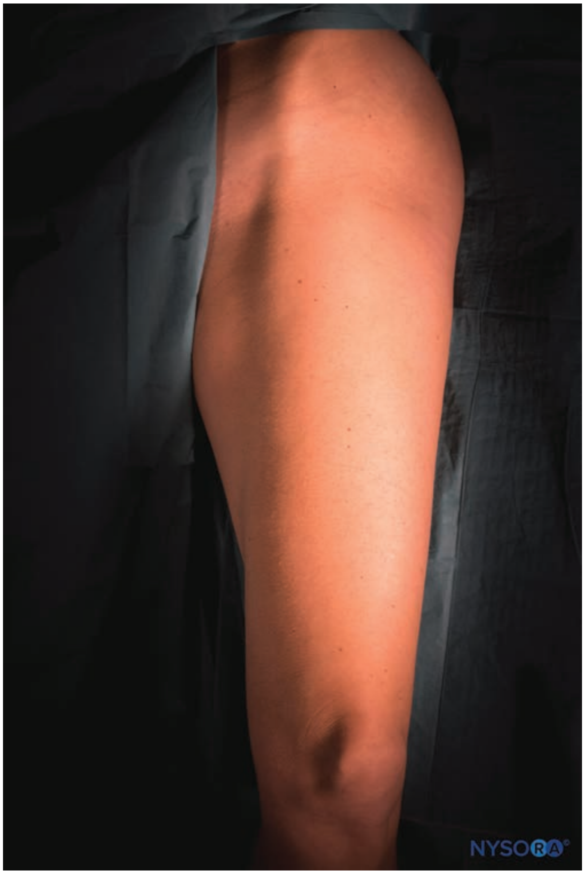


FIGURE 22-4. Patient position for a fascia iliaca block.

the fascia, between the fascia layers (intrafascial injection), or within the muscle, the needle tip should be repositioned.

B. Suprainguinal Fascia Iliaca Block

Landmarks and Initial Transducer Position for a Sagittal Oblique Orientation

The anterior superior iliac spine (ASIS) is palpated and the transducer is placed medial to it in a sagittal oblique orientation perpendicular to the inguinal ligament in a line between the ASIS and the pubic tubercle.

Scanning Technique

From the initial position, slide the transducer caudally and medially along the inguinal ligament until the triangular shape of the anterior inferior iliac spine (AIIS) is visualized with a hyperechoic outline deep to the iliacus muscle. Superficially to the fascia iliaca, the sartorius muscle is seen lateral and the internal oblique medial (forming the so-called bowtie or hourglass image) (Figure 22-7). The deep circumflex iliac artery is identified between the abdominal muscles and the fascia iliaca, 1 to 2 cm and cranial to the inguinal ligament, as it is an important landmark for needle placement.

Alternative Scanning Technique

The transducer is placed in a *transverse orientation* over the femoral crease to identify the femoral artery, the iliopsoas muscle, and the fascia iliaca. The transducer is first moved laterally until the sartorius muscle is identified and then cranially until the AIIS is visualized deep to the iliacus muscle. The US image is the same as described for the oblique approach and may be easier to obtain, in particular, in patients who are obese or cannot be well-positioned.

Needle Approach and Trajectory

The needle is inserted in-plane from lateral to medial and advanced until the tip pierces the fascia iliaca at its most superficial point, under the inguinal ligament. After confirming correct needle position deep to the fascial plane by injecting 1 to 2 mL of LA, the needle can be advanced more securely further medially within the space created by the pool of LA (Figure 22-8).

Local Anesthetic Distribution

When injected correctly, the spread of the LA results in the separation of the fascia iliaca and the iliacus muscle, deep to the muscles of the abdominal wall (internal oblique and transversus abdominis) and the circumflex iliac artery, which is often seen displaced anteriorly with the injection.

Problem-Solving Tips

- In obese patients, it is useful to tape away the abdominal redundant tissue to facilitate access to the inguinal area.
- After starting the injection, moving the transducer medially and tilting to find again the femoral artery may help to confirm that the spread of the LA occurs deep to the fascia iliaca.
- If the spread occurs into the iliacus muscle, the needle is withdrawn and directed more superficially.

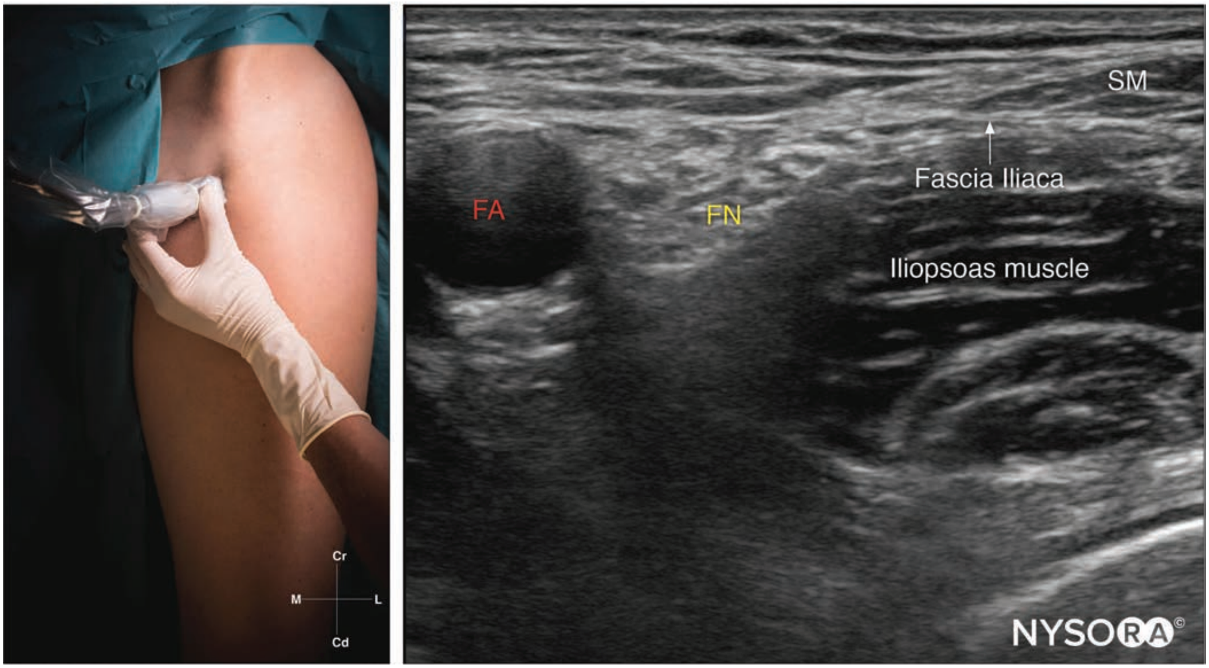


FIGURE 22-5. Transducer position and ultrasound image of an infrainguinal fascia iliaca block. FA, femoral artery; FN, femoral nerve; SM, sartorius muscle.

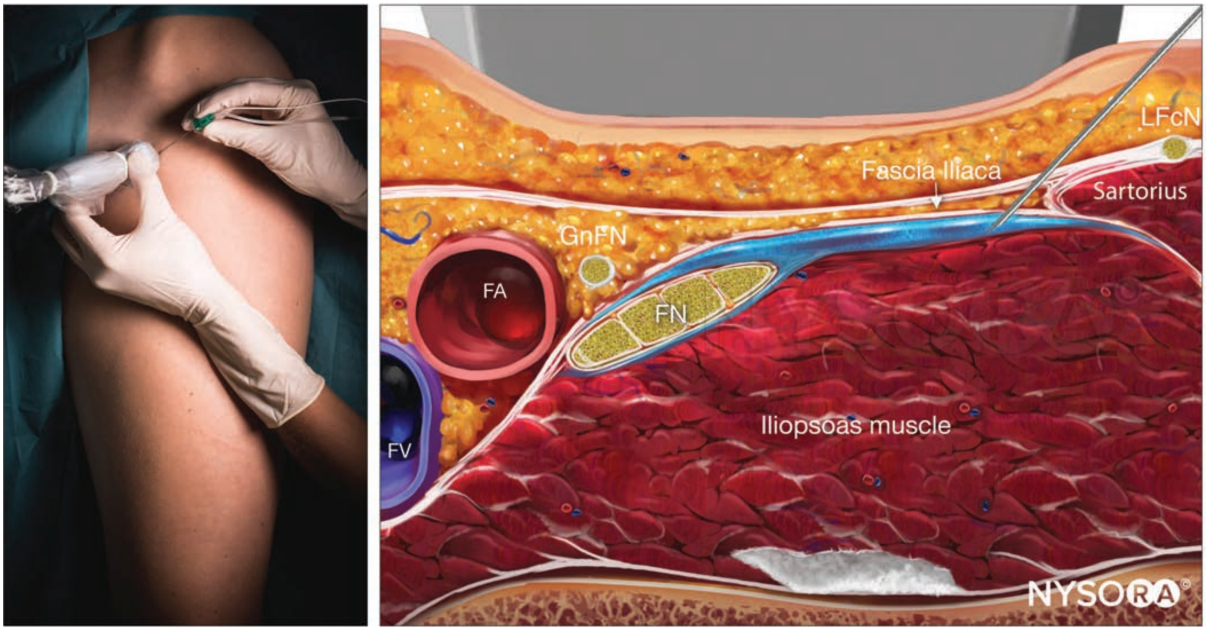


FIGURE 22-6. Reverse ultrasound anatomy for an Infrainguinal fascia iliaca block with needle insertion in-plane. FV, femoral vein; FA, femoral artery; FN, femoral nerve; GnFN, genitofemoral nerve; LFcN, lateral femoral cutaneous nerve.

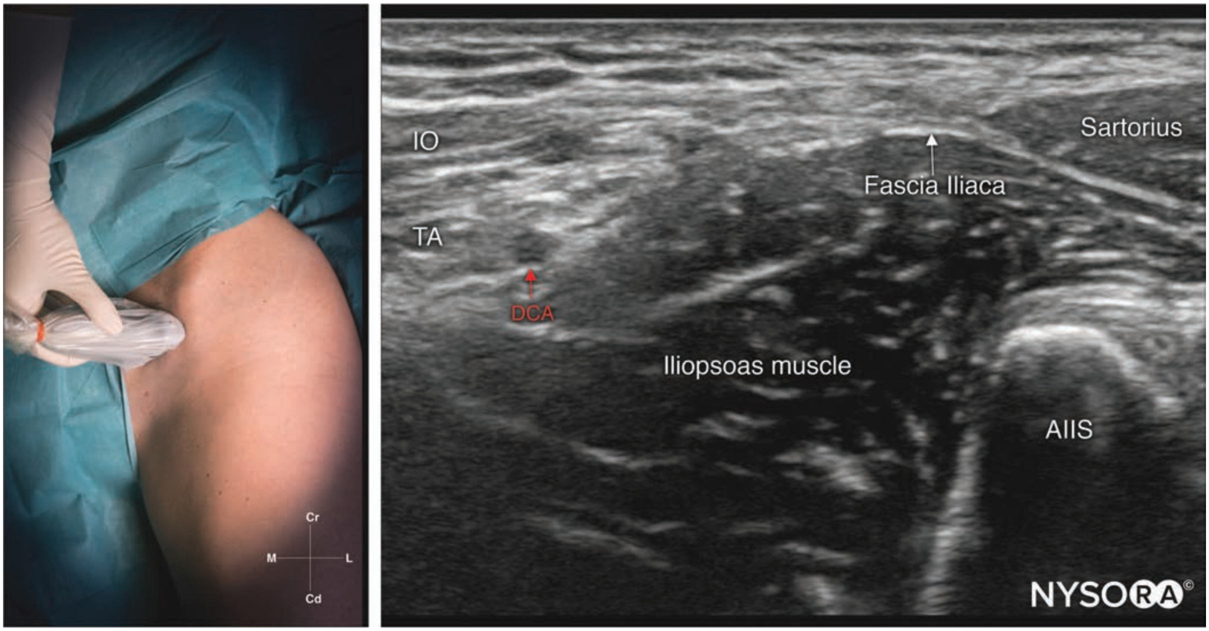


FIGURE 22-7. Transducer position and ultrasound image of a suprainguinal fascia iliaca block. IO, internal oblique muscle; TA, transversus abdominis muscle; DCA, deep circumflex artery; AIIS, anterior inferior iliac spine.

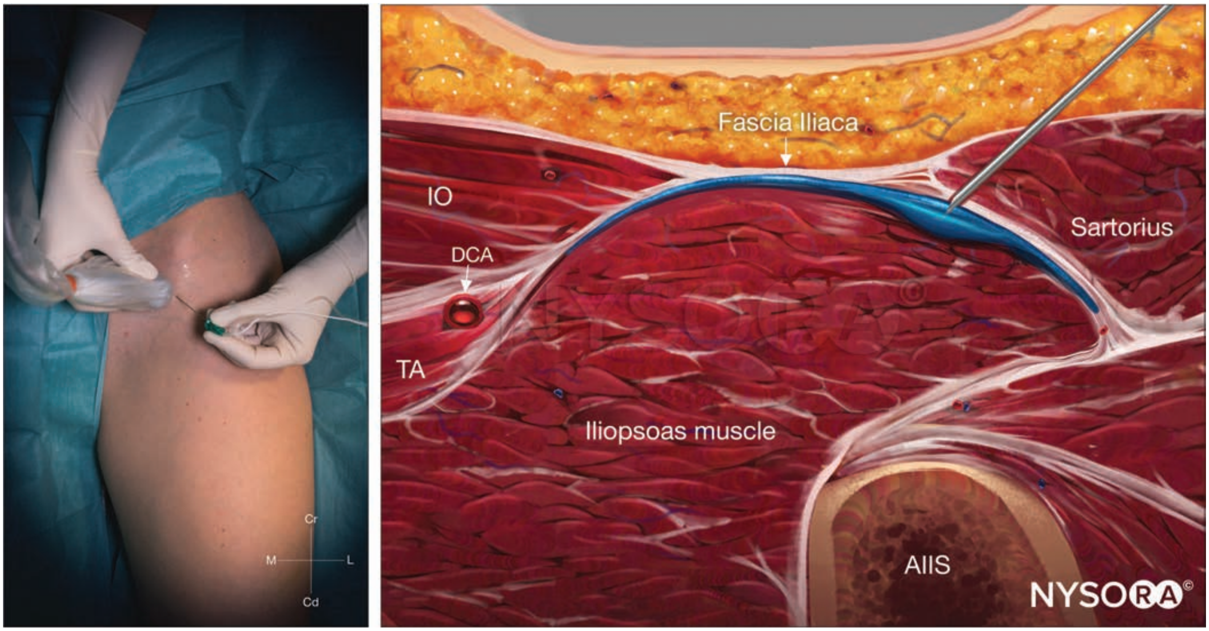
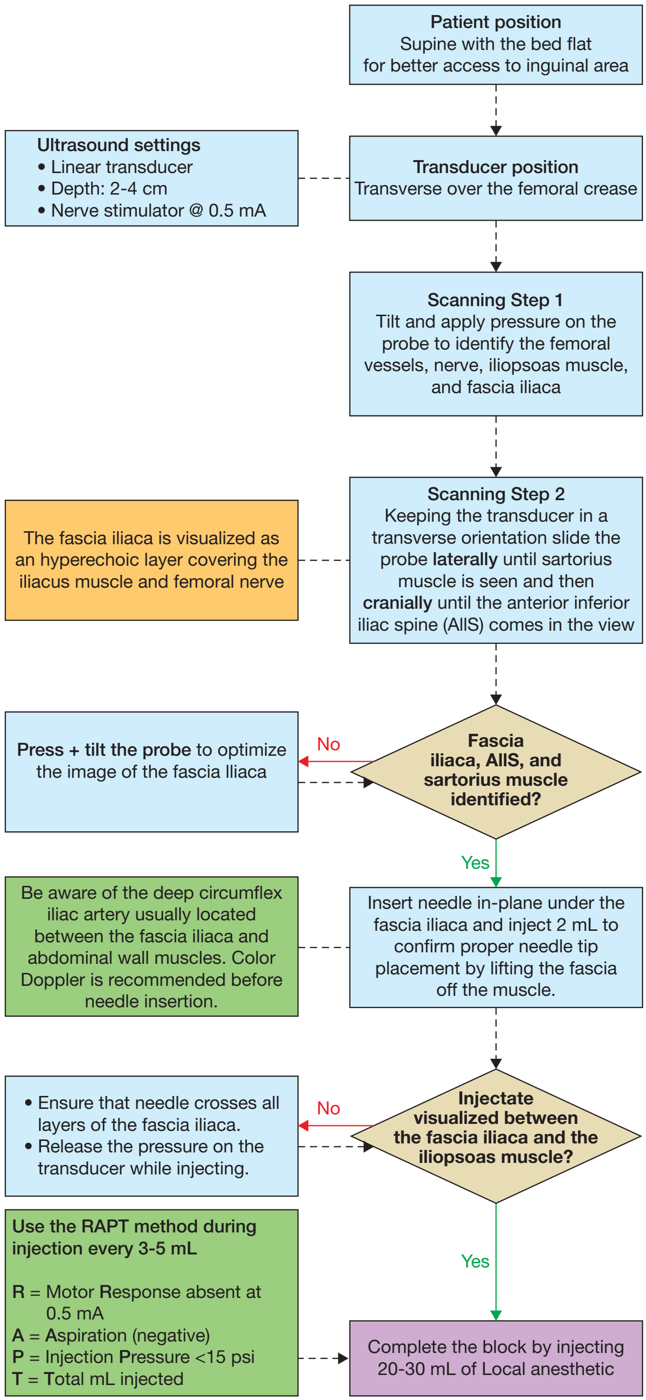


FIGURE 22-8. Suprainguinal fascia iliaca reverse ultrasound anatomy illustration with needle insertion (in-plane). IO, internal oblique muscle; TA, transversus abdominis muscle; DCA, deep circumflex artery; AIIS, anterior inferior iliac spine.

Flowchart

Suprainguinal Fascia Iliaca Block Technique Algorithm



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23 Blocks for Hip Analgesia

BLOCK AT A GLANCE

The hip (PENG) block consists of an infiltration of local anesthetic (LA) along the proximal insertion of the anterior hip capsule, deep to the iliopsoas muscle, to block the sensory branches supplying the hip joint. In addition to the infiltration, a lateral femoral cutaneous nerve (LFCN) block can be performed for hip surgery.

- **Indications**: Analgesia after total hip arthroplasty or other hip surgeries resulting in moderate to severe postoperative pain and chronic hip pain
- **Goal:** LA spread in the plane between the iliopsoas muscle and anterior capsule of the hip cranially to the acetabular rim
- **Local anesthetic volume:** 10 to 12 mL

General Considerations

The pericapsular block of the hip aims to provide analgesia for hip procedures while preserving its motor function to allow for early postoperative ambulation. Fascia iliaca and femoral nerve blocks are the most commonly performed regional anesthesia techniques to treat acute hip pain. However, they result in motor weakness of the quadriceps muscle, limiting their utility in enhanced recovery protocols and potentially increasing the risk of falls. As a result of the search for alternative interventional analgesia modalities to provide a selective articular sensory block, several pericapsular infiltration techniques have been proposed. They all consist of an injection of a LA around the acetabulum in the plane between the iliopsoas muscle and the proximal insertion of the anterior hip capsule, but they differ in the transducer orientation, needle approach, and recommended volumes of LA. Thus, the optimal injection site with respect to the iliopsoas tendon (lateral, below, or medial) and the resulting implications of the injectate's spread are not well-defined. Initial reports suggest that this block may be effective for analgesia after hip fractures and hip replacement surgeries.

Limitations

Deep musculofascial planes may be difficult to visualize with ultrasound (US), often requiring low-frequency, curved transducers for adequate imaging. The location and extent of LA spread may be inconsistent when using low volumes or may reach motor branches of the femoral nerve when using large volumes.

Specific Risks

The femoral nerve and artery may not be readily visible when using curvilinear transducers, increasing the risk of unintentional puncture. Likewise, the LFCN can be injured inadvertently due to its location in the superficial plane deep to the fascia lata and lateral to the transducer, close to needle entry. Additionally, when performing a hip block, needle insertion could be rather deep, or follow a long path, or both, possibly resulting in intra-abdominal (pelvis) and intra-articular needle placement.

Anatomy

The analgesic techniques for hip procedures target the nociceptive innervation, predominantly located in the anterior surface of the hip capsule, which is innervated by nerves of the lumbar plexus (Figure 23-1).

- **Femoral nerve:** The articular branches from the femoral nerve travel over the surface of the iliopsoas notch, which is located between the anterior inferior iliac spine (AIIS) and medial aspect of the iliopubic eminence. These nerve endings reach the plane between the iliopsoas muscle and the iliofemoral ligament (iliopsoas plane) and innervate the anterior and lateral aspects of the hip capsule.

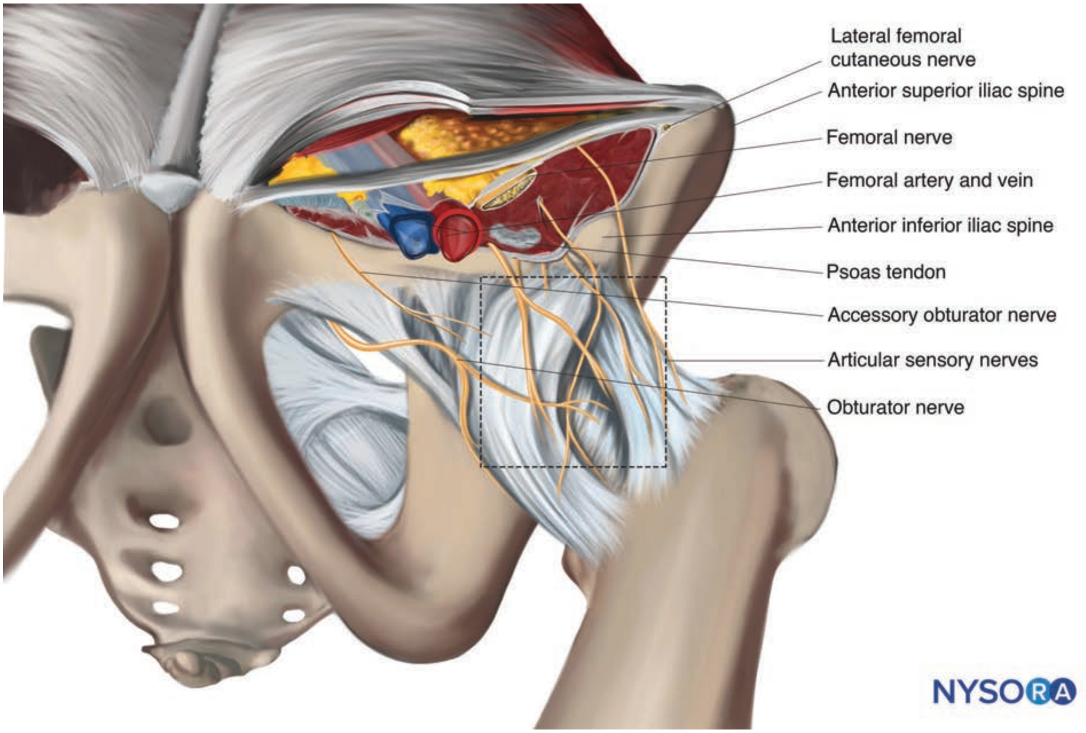


FIGURE 23-1. Innervation of the anterior aspect of the hip capsule.

- **Obturator nerve:** The articular branches exit the pelvis through the obturator foramen between the external obturator and pectineus muscles to innervate the antero-medial aspects of the hip capsule.
- **Accessory obturator nerve:** This nerve is formed by the ventral divisions of L2-L5 and is present in 10% to 30% of cases. It travels deep to the psoas muscle and over the superior pubic ramus, supplying the anterior and medial aspects of the hip capsule.

The cutaneous innervation of the anterolateral thigh is mostly provided by the LFCN that travels underneath the inguinal ligament, medially to the anterior superior iliac spine (ASIS) and courses distally, superficial to the sartorius muscle.

The posterior part of the hip is innervated by the sciatic nerve and branches of the sacral plexus such as the superior and inferior gluteal nerves, and an articular branch from the quadratus femoris nerve.

Cross-Sectional Anatomy and Ultrasound View

A cross section along the anterior border of the pelvis at the level of the iliopsoas notch, bordered laterally by the AIIS and medially by the iliopubic eminence, shows the iliopsoas muscle and tendon passing into the thigh. At this level, the articular branches of the femoral and accessory obturator nerves enter the hip capsule deep to the iliopsoas fascial plane (although not visible). When imaged by US the AIIS, iliopsoas notch, and iliopubic eminence are visualized as a hyperechoic rim (pelvic rim) deep to the hypoechoic iliacus muscle and the hyperechoic round-shaped psoas tendon. Superficially, the femoral artery, vein, and nerve are located on the medial side and the sartorius muscle and LFCN on the lateral side (Figures 23-1 and 23-2).

Figure 23-2 shows a sagittal oblique section of the hip joint along the head and neck axis and lateral to the iliopsoas tendon. The iliopsoas muscle covers the head of the femur, acetabulum, labrum, and ligaments of the anterior capsule superficially.

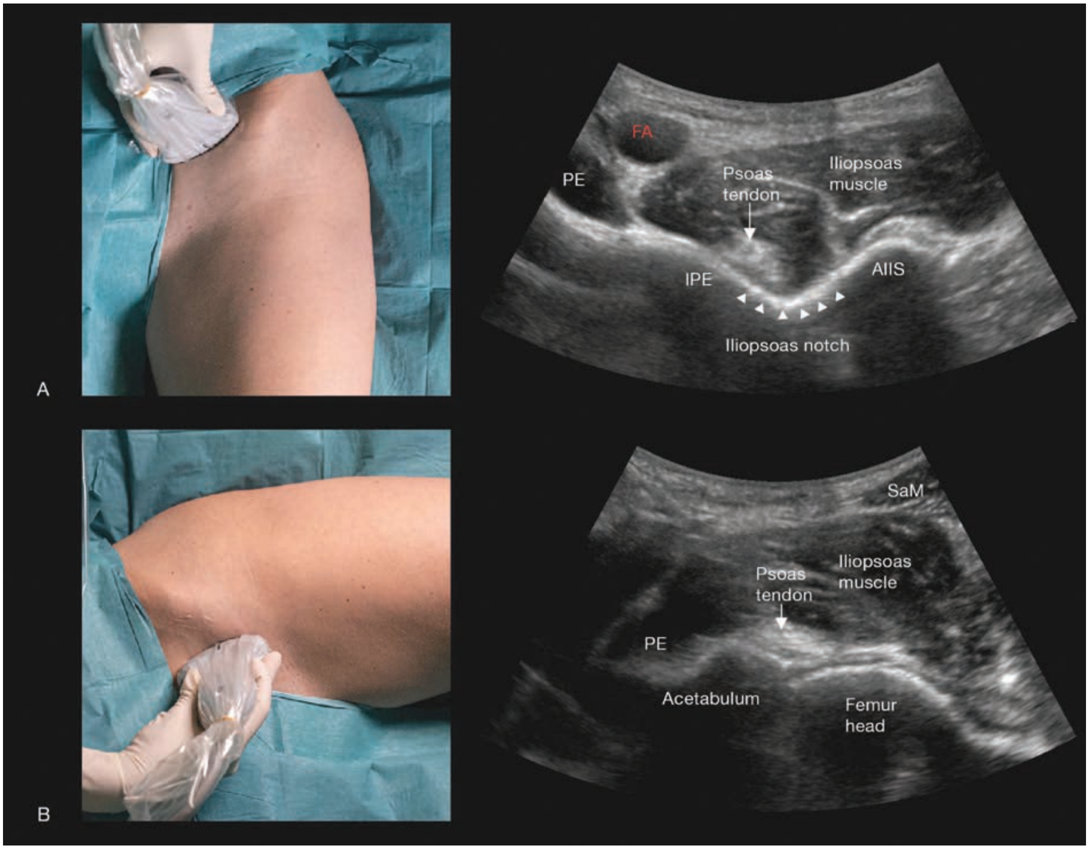


FIGURE 23-2. Transducer position and sonoanatomy to perform a hip block. A. Pericapsular nerve group block B. Iliopsoas plane block. FA, femoral artery; PE, pectineus muscle; IPE, iliopubic eminence; AIIS, anterior inferior iliac spine; SaM, sartorius muscle.

Distribution of Analgesia

The extent of the sensory block depends on the spread of the LA; it confers analgesia to most of the anteromedial aspect of the hip joint.

To provide cutaneous analgesia of the incision site, an additional block of the lateral femoral cutaneous nerve is recommended (see Chapter 26).

Block Preparation

Equipment

- Transducer: Low-frequency transducer (or high-frequency linear transducer in patients with a low body mass index)
- Needle: 80- to 100-mm, 22-gauge, short-bevel, insulated stimulating needle

Local Anesthetic

The available evidence on the duration of the pericapsular hip block is still scarce; however, high concentrations of long-lasting LAs (e.g., bupivacaine 0.5% or ropivacaine 0.5-0.75%) are indicated to provide prolonged analgesia after a hip surgery. Similarly, as in many other fascial plane infiltrations, adding liposome bupivacaine to bupivacaine may extend the analgesia duration.

Patient Positioning

Place the patient in the supine position with the leg fully extended and slightly rotated externally (Figure 23-3).

FIGURE 23-3. Patient position to perform a hip block.

TECHNIQUES

Three approaches have been described to perform this block, according to the transducer orientation (A, B, and C) (Figure 23-4).

A. Transverse Oblique (Pericapsular Nerve Group Block and Hip Block)

Landmarks and Initial Transducer Position

The optimal US image of the pelvic rim at the level of the iliopsoas notch can be obtained following two scanning strategies:

- **Option 1:** The transducer is placed over the AIIS in a transverse orientation and then rotated approximately 45° to align the transducer with the pelvic rim.

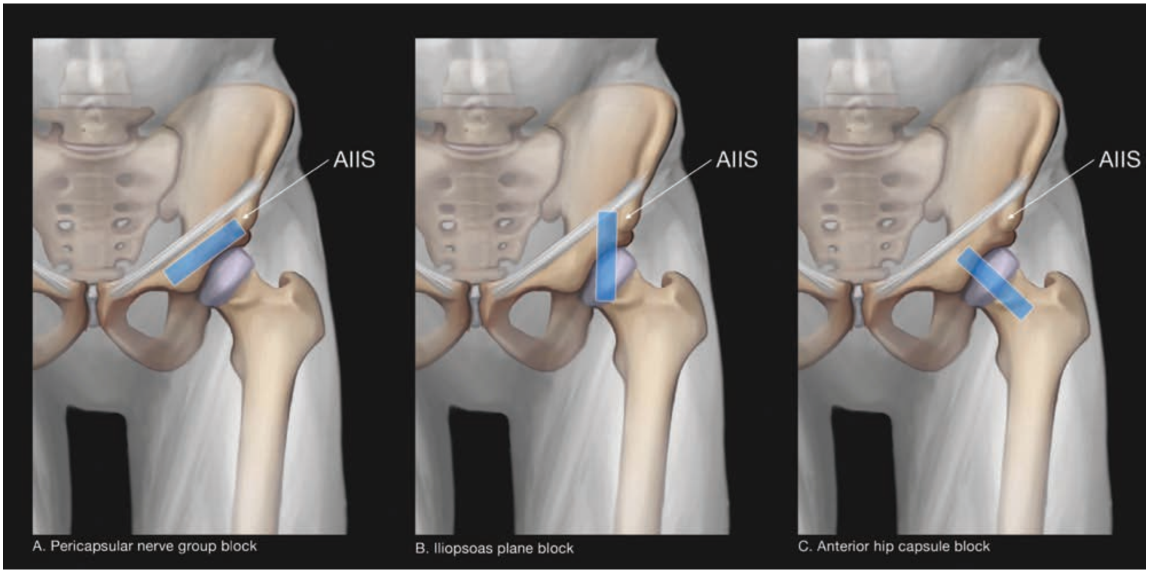


FIGURE 23-4. Transducer positions to perform a hip block. (A) Transverse oblique. (B) Sagittal. (C) Sagittal oblique.

- **Option 2:** The transducer is placed over the femoral crease in an oblique orientation, parallel to the inguinal ligament, to image the head of the femur and then moved cranially until the surface of the iliopsoas notch is visualized.

Scanning Technique

Applying slight transducer movements such as sliding, rotating, tilting, and pressing may improve the view of the hyperechoic iliopsoas notch between the AIIS and iliopubic eminence, the hypoechoic iliopsoas muscle, and hyperechoic oval shape of the tendon. It is also important to identify the femoral artery and nerve superficial to the iliopsoas muscle to avoid injury to these structures (Figure 23-2).

Needle Approach and Trajectory

The needle is inserted in-plane from lateral to medial through the iliopsoas muscle toward the plane between the iliopsoas tendon and bone (Figure 23-5).

Local Anesthetic Distribution

After negative aspiration, 10 to 12 mL of LA are injected in incremental steps while observing for an adequate spread along the fascial plane. The needle is further advanced if the injection is intramuscular or slightly withdrawn if high resistance is perceived.

B. Sagittal (Iliopsoas Plane Block) and C. Sagittal Oblique (Anterior Hip Capsule Block)

Landmarks and Initial Transducer Position

These two approaches aim to visualize both the head of the femur and acetabular rim/labrum in the long axis. There are two scanning strategies to obtain this US image:

1. **Sagittal:** The transducer is placed over the ASIS in a sagittal orientation and then moved medially until the femur head and acetabulum, covered by the iliacus muscle, are visualized. If the thick iliopsoas tendon is seen in the long axis, the transducer is slightly moved laterally.
2. **Sagittal oblique:** The transducer is placed over the femoral crease in a 45° oblique sagittal orientation to visualize the head and neck of the femur in the long axis. Then, the transducer is moved cranially until the acetabulum is also visualized deep to the iliacus muscle.

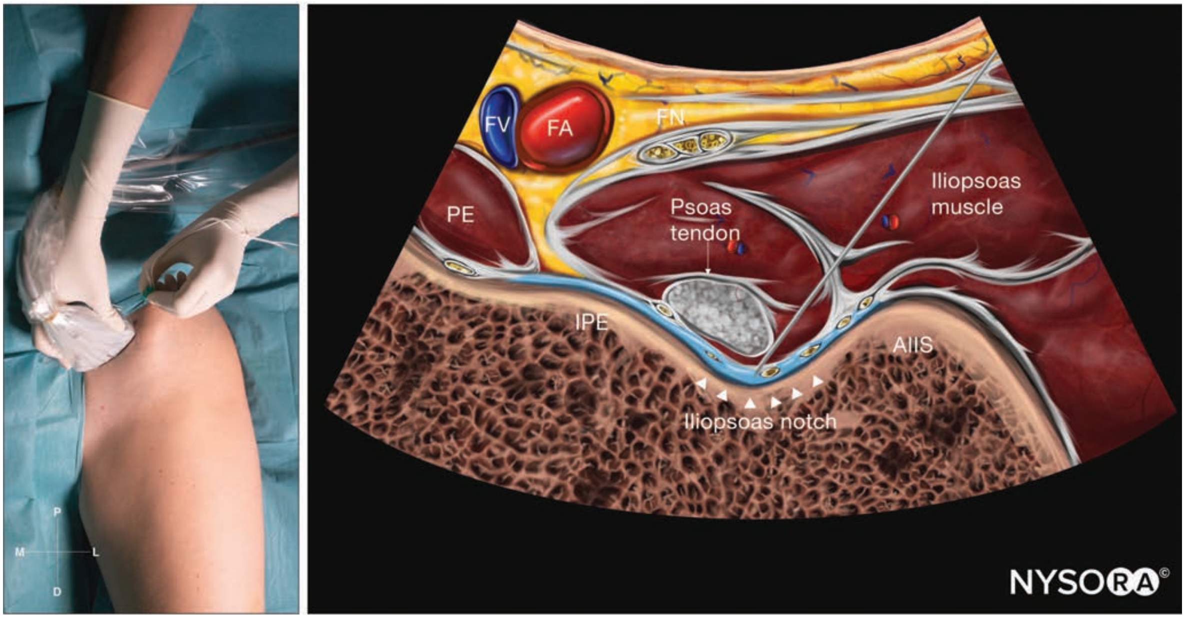


FIGURE 23-5. Hip block; reverse ultrasound anatomy with needle insertion in-plane. FV, femoral vein; FA, femoral artery; FN, femoral nerve; PE, pectineus muscle; IPE, iliopubic eminence; AIIS, anterior inferior iliac spine.

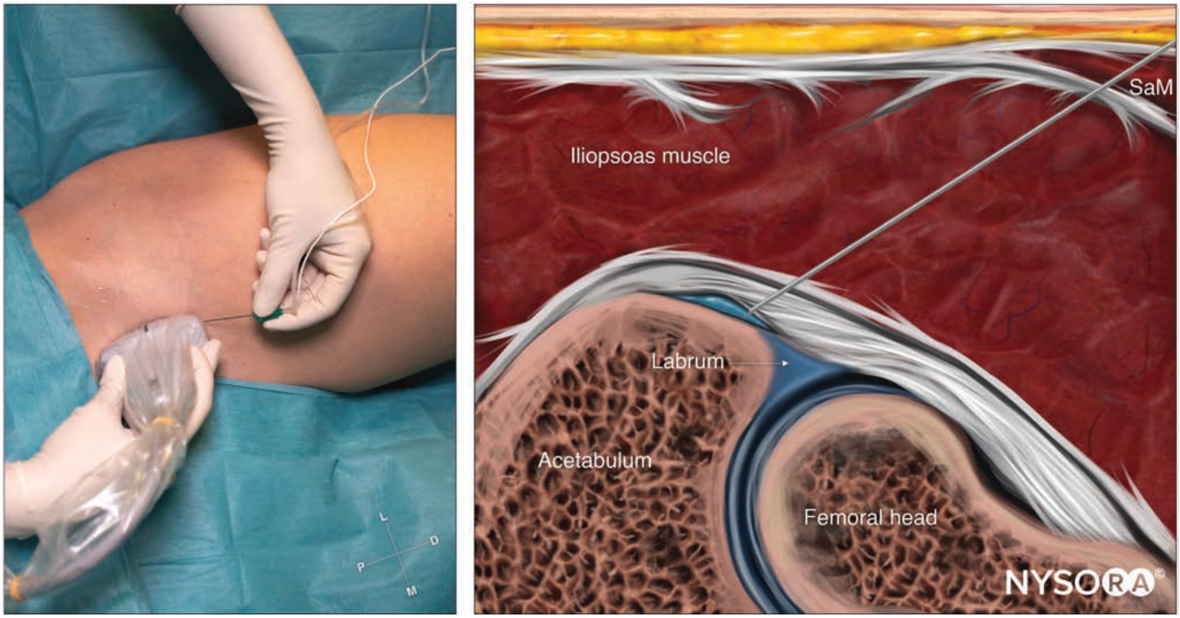


FIGURE 23-6. Iliopsoas plane block; reverse ultrasound anatomy with needle insertion in-plane. SaM, sartorius muscle.

Scanning Technique

Similar to the previously described scanning technique, slight adjustments of the transducer position and angulation help to image the femoral condyle, the acetabular rim, and ligaments of the anterior capsule as hyperechoic structures connecting them (Figure 23-2).

Needle Approach and Trajectory

The needle is inserted in-plane from distal to proximal toward the labrum/acetabulum until bone contact is felt or until the needle tip is located superficial to the iliofemoral plane (Figure 23-6).

Local Anesthetic Distribution

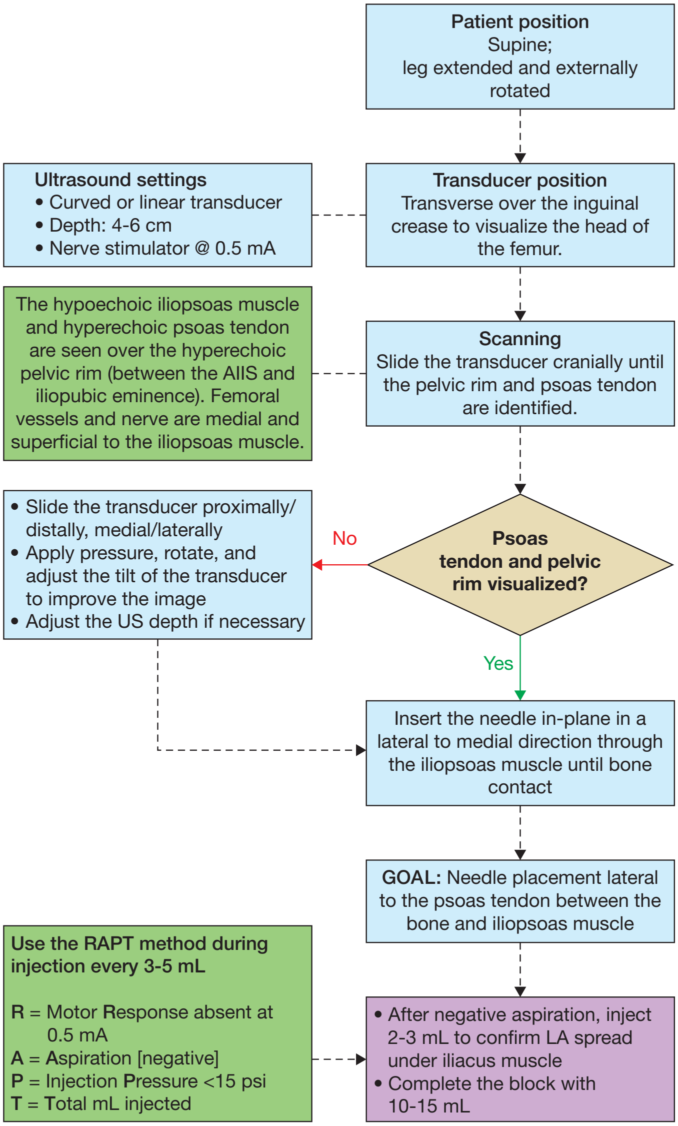
After negative aspiration, the LA is injected while confirming the spread between the iliopsoas muscle and acetabular rim/labrum and superficial to the capsule ligaments. In the sagittal approach, the injection occurs lateral to the iliopsoas tendon, while in the sagittal oblique orientation the injection occurs medially to the tendon. This may have implications on the extent of the block, in particular when using low volumes.

Problem-Solving Tips

- Use color Doppler to identify the femoral vessels when they are not clearly visualized.
- Adjust the settings of the US machine carefully (depth, gain, and focus) to optimize the view of deep structures with the curvilinear probe.
- Choose a needle of appropriate length and stiffness to reach the target.
- When using a transverse oblique approach, inserting the needle in a steep angle is required to avoid puncture of the femoral nerves and vessels.

Flowchart

Hip Block Algorithm



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24 Femoral Nerve Block

BLOCK AT A GLANCE

Block of the femoral nerve (FN) proximally to its division at the inguinal crease.

- **Indications**: Anesthesia and analgesia after hip, femur, anterior thigh, knee, and patella procedures
- **Goal:** Local anesthetic (LA) spread around the FN
- **Local anesthetic volume:** 10 to 20 mL

General Considerations

The FN block is a well-established regional anesthesia technique. It is the single most powerful analgesic method to treat pain after major knee surgery, either as a single injection or continuous block. However, an FN block invariably results in quadriceps muscle paresis, which may impede early active mobilization and ambulation. The protocols for enhanced recovery after surgery include early mobilization as a requirement, and therefore, an FN block may interfere with this goal. Alternatively, more distal interventional analgesia techniques with less impairment of ambulation may be better suited for some patients and surgeries. These options include blocks of the distal branches of the FN at different levels in the subsartorial space, pericapsular or soft tissue infiltration with an LA. Lower doses and concentrations of LAs for FN block and periarticular infiltration of LAs can also be used.

Regardless, the FN block is still widely used in patients with hip fractures both as an analgesic modality in the emergency department and to facilitate patient positioning for spinal anesthesia. In clinical situations where early mobilization is not required, the femoral block is the most effective and consistent interventional analgesic method. Finally, an FN block is often used as the sole anesthetic for quadriceps muscle tear and tendon rupture repairs, evacuation of the knee hematoma after total knee replacement surgery, and for surgery on the patella.

Limitations

The FN block has been associated with a risk of postoperative falls in the ward, due to the quadriceps muscle weakness. Protocols for specifying the risk and risk preventions are necessary whenever lower extremity nerve blocks are used, particularly for femoral and sciatic blocks. The incidence of FN injury reported in the literature is lower than that of upper extremity nerve blocks. However, the disability associated with FN injury is significant. Therefore, we advise strict adherence to triple monitoring (i.e., ultrasound [US], nerve stimulation, and opening injection pressure).

Anatomy

The FN originates from the dorsal divisions of the ventral rami of the L2-L4 lumbar nerves. Approximately at the level of the fifth lumbar vertebral body, the FN exits the psoas muscle in a medial-to-lateral direction deep to the iliac fascia. It continues caudally and enters the anterior compartment of the thigh passing deep to the inguinal ligament, anterior to the iliopsoas muscle, and lateral to the femoral artery and vein (Figure 24-1). At the femoral triangle, the nerve divides quickly into multiple terminal branches. Deep branches innervate the anterior aspect of the hip, femur, and knee; muscular branches innervate the iliacus, psoas major, pectineus, rectus femoris, vastus lateralis, vastus intermedius, vastus medialis, and sartorius muscles; cutaneous branches innervate the skin on the anterior aspect of the thigh and knee. The saphenous nerve arises from the FN and continues to travel with the femoral artery on the medial side of the leg and distally to the midfoot, innervating the skin on this trajectory. Below the patella, the infrapatellar branch crosses the knee and further divides into three branches that combine with cutaneous nerves of the thigh and form the patellar plexus.

Cross-Sectional Anatomy and Ultrasound View

At the level of the femoral crease, the FN lies superficial to the iliacus muscle covered by the fascia iliaca just lateral to the vascular compartment. The disposition of the nerve, lateral

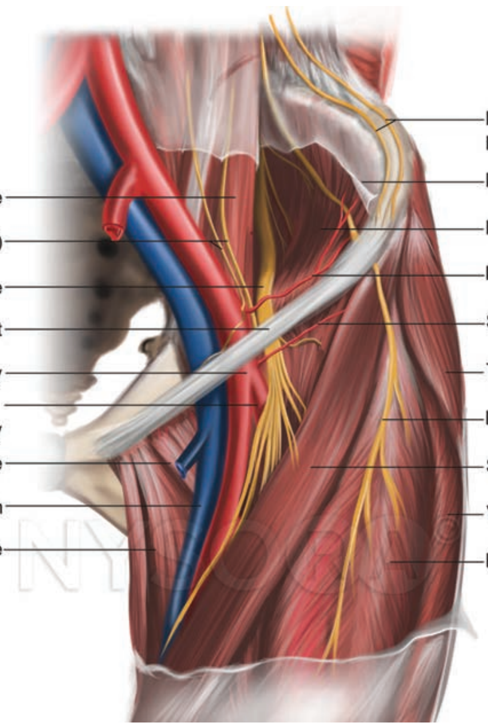


FIGURE 24-1. Anatomy of the femoral at the femoral crease.

to the femoral artery and vein, is relatively consistent. On US, the nerve is seen as a flattened triangular or oval group of fascicles enveloped within two layers of the fascia iliaca, typically at a depth of 2 to 4 cm (Figure 24-2). The superficial circumflex iliac artery takes off the femoral artery in the femoral triangle and courses lateral and cephalad superficial to the fascia iliaca. By scanning more distally, the take-off of the profunda femoris (deep femoral artery) and the branching of the FN can be identified (Figure 23-1).

Distribution of Anesthesia and Analgesia

The FN block results in anesthesia of the anterior aspect of the femur, hip, knee joint, muscles, and skin of the anterior thigh, as well as the skin on the medial aspect of the ankle and foot (Figure 24-3).

Block Preparation

Equipment

- Transducer: High-frequency linear transducer
- Needle: 50-mm, 22-gauge, stimulating needle

Local Anesthetic

Long-lasting LAs (e.g., bupivacaine 0.5% or ropivacaine 0.5%) are used for anesthesia or analgesia after knee surgery. Diluted mixtures of these LAs (e.g., 0.125-0.25%) may be used to diminish, but not to eliminate the quadriceps weakness. A volume of 10 to 15 mL is usually sufficient for an effective block.

The addition of liposomal bupivacaine for an FN block has been described. Studies show a decrease in pain scores and opioid consumption for up to 48 hours. To date, this extended-release formulation of LAs has not been approved for FN block.

Patient Positioning

The patient is positioned in supine with the lower extremity fully extended and slightly rotated externally (Figure 24-4). In obese patients, taping away adipose abdominal tissue can help to optimize the access to the inguinal crease (Figure 24-5). The US machine should be placed next to the patient on the contralateral side and facing the practitioner.

Technique

Landmarks, Transducer Position, and Scanning Technique

The transducer is placed in a transverse orientation over the inguinal crease. The femoral artery is visualized as a round anechoic pulsating structure with the easily compressible femoral vein medial to it. When the bifurcation of the femoral artery and profunda femoris is seen, the transducer should be moved proximally if a block of the entire trunk of

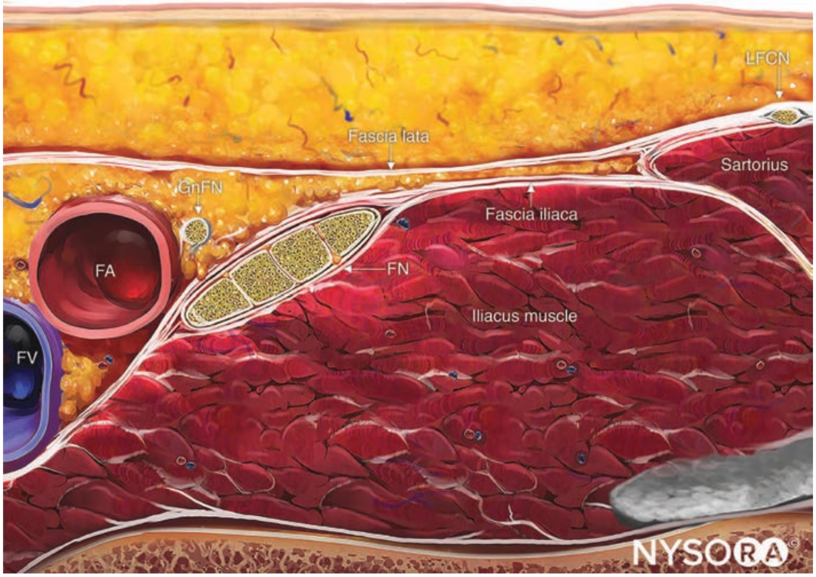


FIGURE 24-2. Cross-sectional anatomy of the femoral nerve. FN, femoral nerve; FA, femoral artery; FV, femoral vein; LFCN, lateral femoral cutaneous nerve; GnFN, genitofemoral nerve.

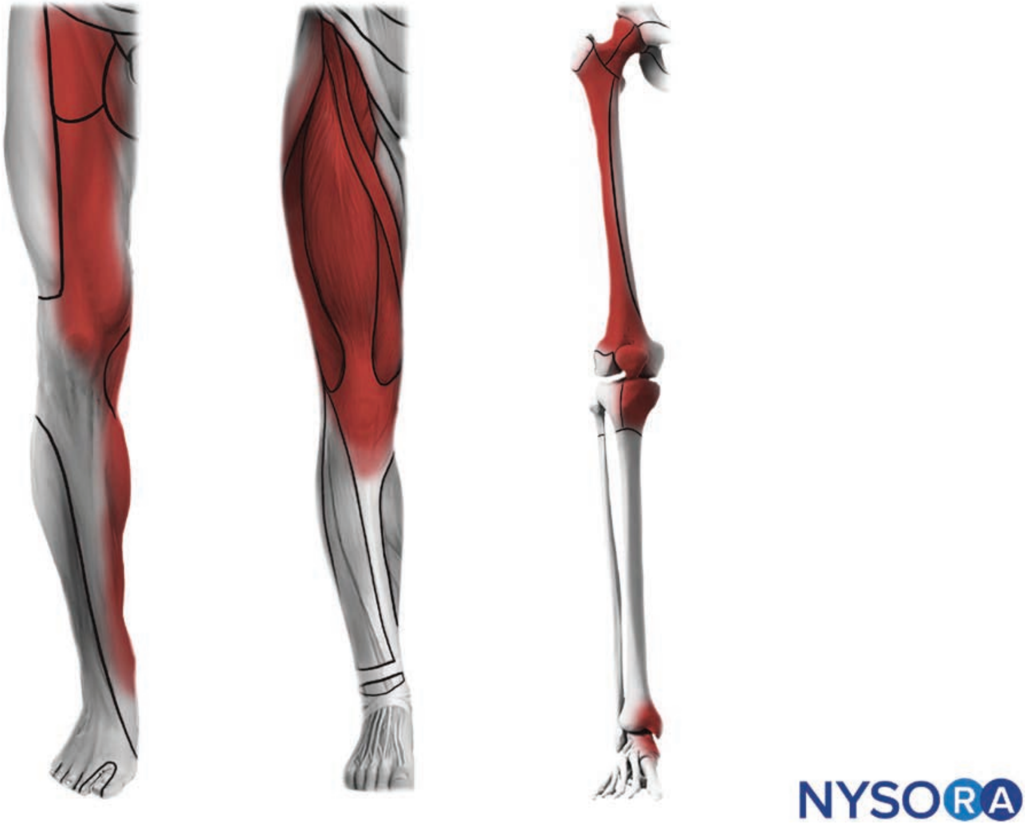


FIGURE 24-3. Distribution of anesthesia with a femoral nerve block. From left to right: dermatomes, myotomes, and osteotomes.

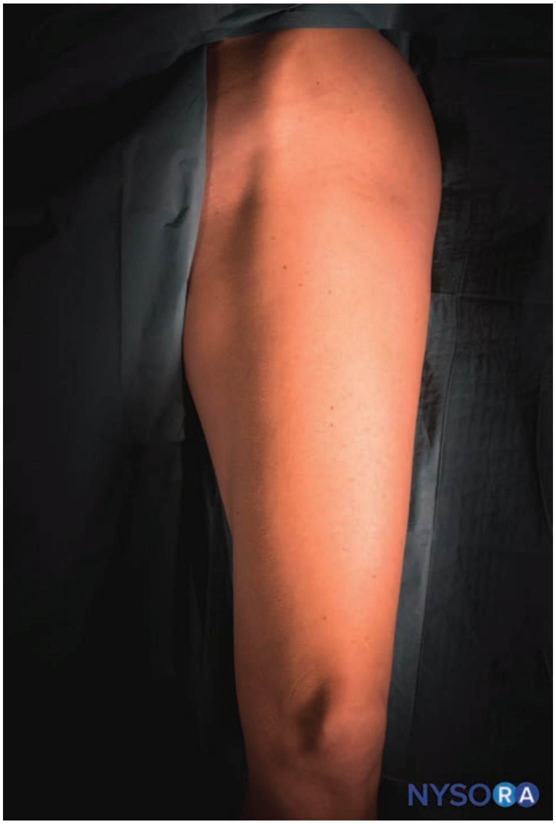


FIGURE 24-4. Patient position for a femoral nerve block.

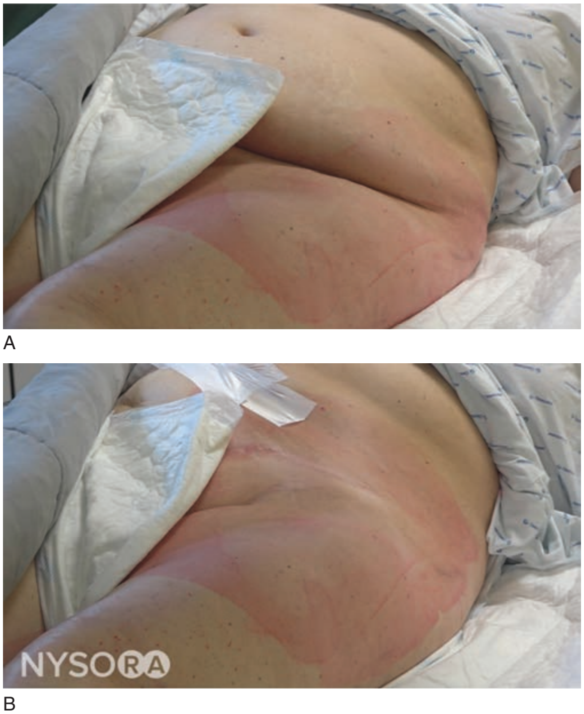


FIGURE 24-5. NYSORA's technique to facilitate exposure to the femoral crease in obese patients.

the FN is required (Figure 24-6). By applying pressure to the transducer and adjusting the tilt, both the FN and fascia iliaca can be better visualized. (Figure 24-7).

Needle Approach and Trajectory

The needle is advanced in-plane from lateral to medial toward the lateral edge of the FN, with the goal of entering through the fascia iliaca covering the nerve. After piercing the fascia, the needle tip is further advanced until it is in the space between the two layers of the fascia that contain the FN (Figure 24-8).

Local Anesthetic Distribution

Before injection, the RAPT checklist is done to rule out a motor response (R) to nerve stimulation, negative aspiration (A) to avoid intravascular needle placement, low opening injection pressure (P) to avoid intraneural injection, and the total (T) volume to be administered. After the RAPT, 1 to 2 mL of LA is injected to evaluate the distribution of injectate

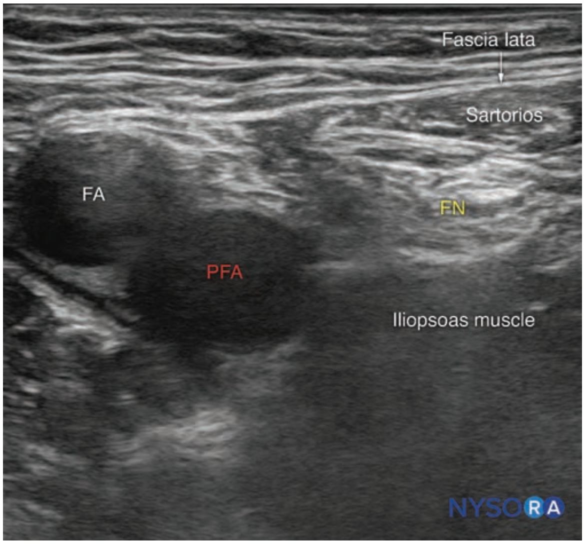


FIGURE 24-6. Bifurcation of the femoral artery (FA) into the profunda femoris artery (PFA). For a complete femoral nerve (FN) block, the injection is made proximal to the bifurcation where only a single artery is seen in the ultrasound.

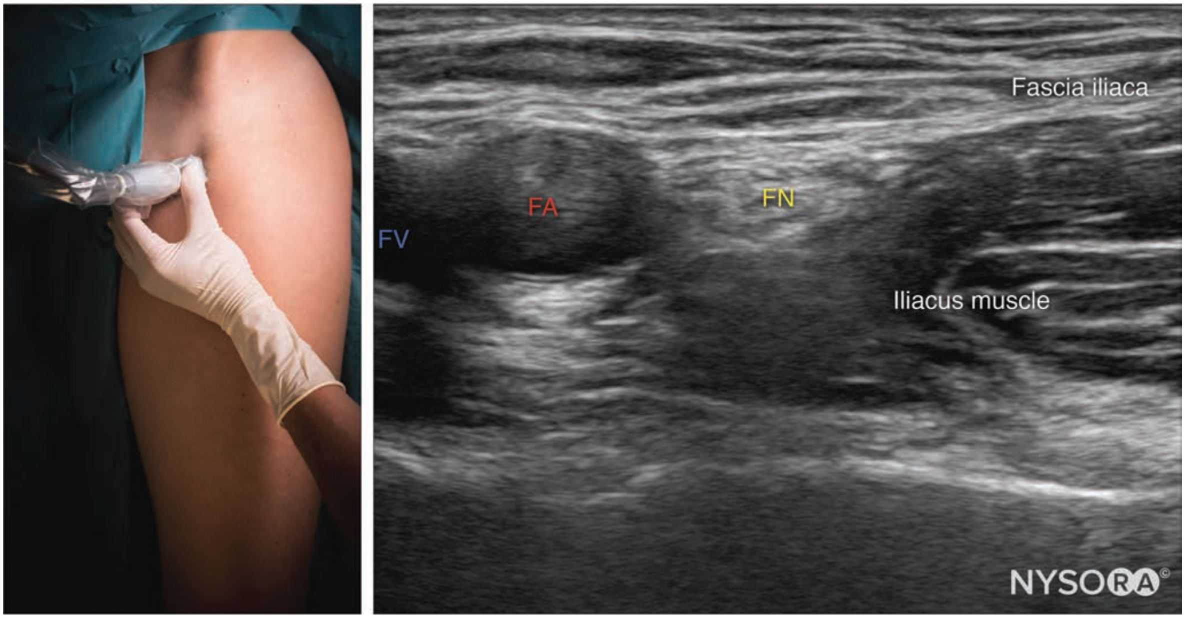


FIGURE 24-7. Transducer position and sonoanatomy of the femoral nerve (FN) at the femoral crease. FV, femoral vein; FA, femoral artery.

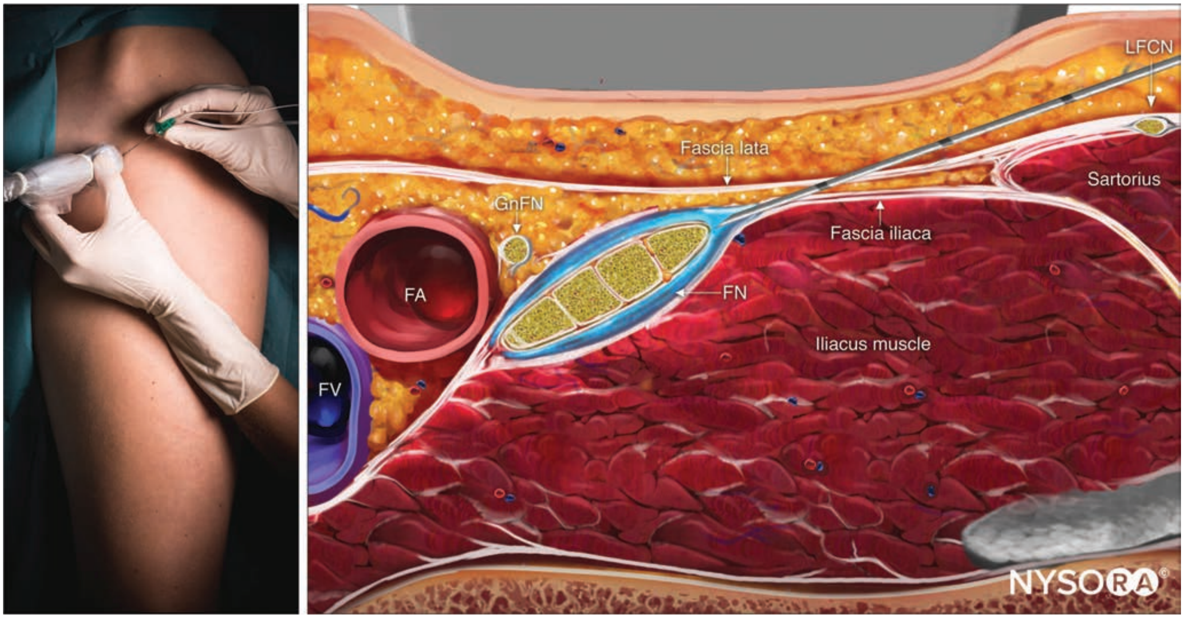


FIGURE 24-8. Reverse ultrasound anatomy of a femoral nerve (FN) block showing needle insertion in-plane. FV, femoral vein; FA, femoral artery; GnFN, genitofemoral nerve.

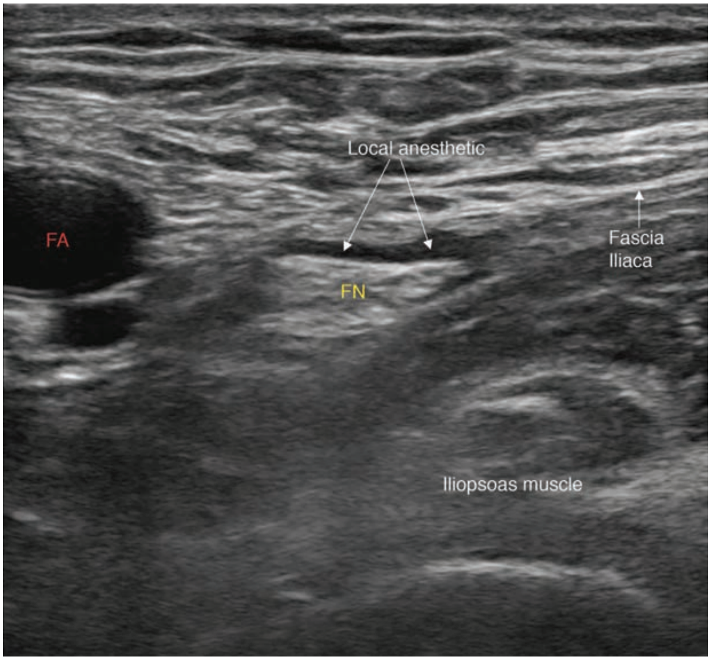


FIGURE 24-9. Ultrasound image after a femoral nerve (FN) block that shows an ideal spread of the local anesthetic. FA, femoral artery.

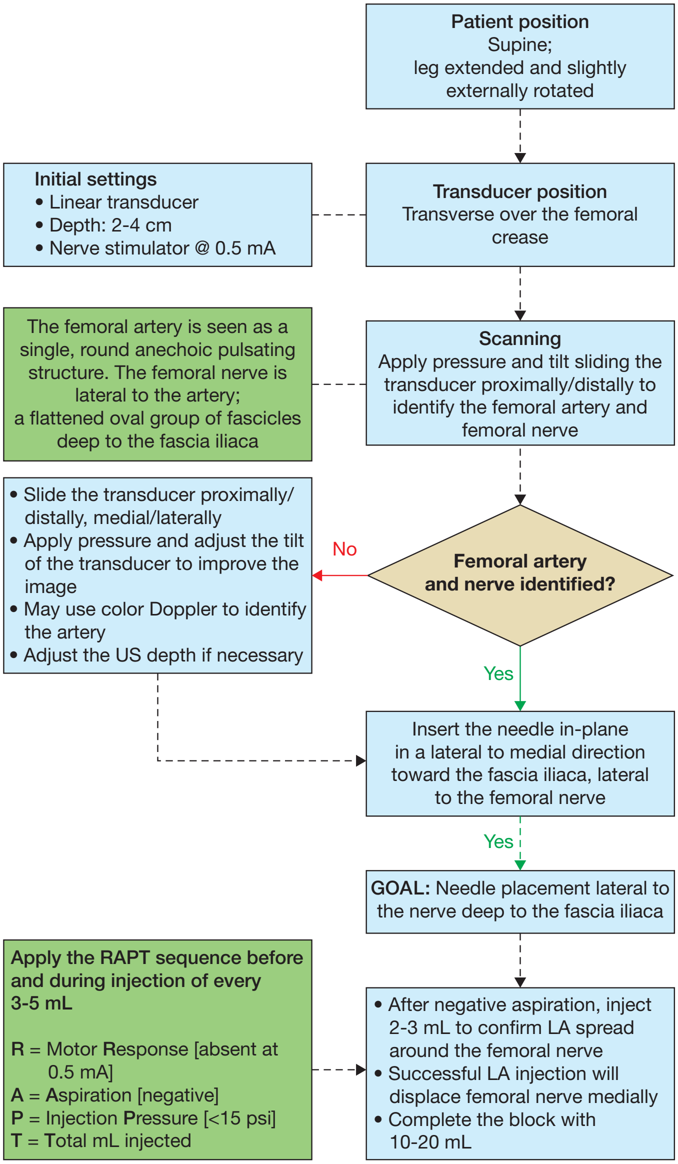
around the FN while monitoring the injection pressure; injection into the proper space will result in the displacement of the FN from the adjacent fascia and muscle (Figure 24-9).

Problem-Solving Tips

- Tilt the transducer craneo-caudally to optimize the image of the nerve.
- Pierce the fascia iliaca lateral to the edge of the FN.
- If nerve stimulation is used (0.5 mA, 0.1 msec), the contact of the needle tip with the FN is associated with a motor response of the quadriceps muscle group.
- Beware of the motor weakness of the quadriceps—risk of falls.
- Circumferential spread of LA around the nerve is not necessary for this block.

Flowchart

Femoral Nerve Block Technique Algorithm



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25 Subsartorial Blocks: Saphenous Nerve, Adductor Canal, and Femoral Triangle Blocks

BLOCK AT A GLANCE

Block of the saphenous nerve under the sartorius muscle at the medial aspect of the mid-third thigh. Depending on the injection level and injected volume, it may also block branches of the femoral and obturator nerves.

- **Indications:** Anesthesia for foot and ankle surgery in combination with a sciatic nerve block, analgesia for knee surgery in combination with multimodal analgesia, and saphenous vein stripping, or harvesting
- **Goal:** Spread of LA around the femoral artery in the fascial compartment between the sartorius, vastus medialis, and adductor muscles
- **Local anesthetic volume:** 10 to 20 mL

General Considerations

Under "subsartorial blocks," we describe three related, but distinct blocks: subsartorial saphenous nerve, adductor canal, and femoral triangle blocks.

The **subsartorial saphenous nerve block** is a well-established technique to anesthetize the medial aspect of the leg, ankle, and midfoot. It is commonly performed as an adjunct to the sciatic nerve block for lower leg surgery. The use of ultrasound (US) guidance improves its success rate, by allowing determination of the optimal injection site and monitoring of the LA spread.

The **adductor canal block** is similar to the subsartorial saphenous nerve block, except that larger volumes of LA are used. It was introduced as an alternative to the femoral nerve block to avoid quadriceps paresis after knee surgery. The adductor canal block is commonly used in the multimodal analgesic regimen of the enhanced recovery after surgery (ERAS) protocols for knee arthroplasty.

The **femoral triangle block** is an injection of LA proximal to the adductor canal to anesthetize additional terminal branches of the femoral nerve. This results in better analgesia, but also in more motor weakness of the quadriceps muscle.

While the analgesic efficacy of the adductor canal is well-documented, the ideal level at which LA should be injected remains unanswered. Recent anatomical studies suggested that in addition to the saphenous nerve, the medial femoral cutaneous nerve, branches from the nerve to the vastus medialis, and articular branches from the obturator nerve are often present in the adductor canal and contribute to the innervation of the anteromedial aspect of the knee. The level of the injection (proximal-distal) and volume of injectate are factors that determine the block outcomes. For instance, the femoral triangle block with a large volume of LA results in proximal spread to the femoral nerve, and quadriceps weakness. However, a proximal block also confers better analgesia to the anterior knee capsule. While the adductor canal injection does not result in a complete femoral nerve block, recent studies suggest that the LA may spread through the Hunter hiatus into the popliteal fossa. This, in turn, may result in a block of the articular branches to the posterior capsule from the sciatic nerve and obturator nerve (popliteal plexus).

Limitations

The saphenous nerve travels with the femoral artery and vein at the midthigh. Although easy to localize, there is a risk of femoral vascular puncture when performing the block, particularly in larger patients, or when the transducer pressure collapses the vein. Dissection of the femoral artery after an adductor canal block has also been reported.

The quality and extent of analgesia provided by the subsartorial block depend on the injection level and the volume of LA used. However, none of the techniques will cover all articular branches that supply the knee, so a multimodal analgesia approach is a must. An adductor canal block is not completely devoid of quadriceps weakness risk. Consequently, implementing protocols for postoperative fall prevention is mandatory when using lower extremity blocks.

Anatomy

The saphenous nerve is the longest sensory branch from the femoral nerve. It travels with the femoral artery and vein on the medial side of the thigh. At the level of the knee, the saphenous nerve pierces the fascia lata between the tendons of the sartorius and gracilis muscles to become subcutaneous. From there on, it descends to the medial side of the leg down to the midfoot, innervating the skin on its trajectory (Figure 25-1).

The sartorius muscle originates from the anterior superior iliac spine and descends obliquely across the anterior thigh in a lateral-to-medial direction. The intersection of the medial border of the sartorius muscle with the medial border of the adductor longus muscle defines the apex of the femoral triangle and proximal limit of the adductor canal (Figure 25-2). At the midthigh, the sartorius muscle covers the adductor canal.

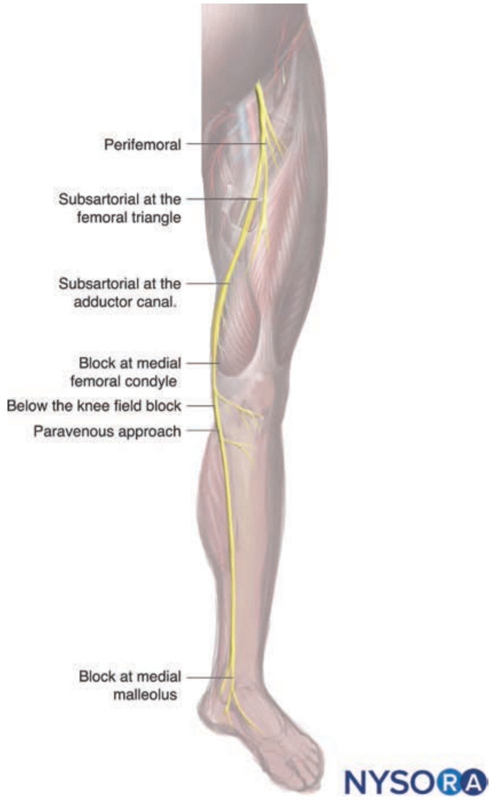


FIGURE 25-1. The saphenous nerve and the levels where it can be blocked.

The canal is sort of a triangular tunnel delimited anteriorly by the vastus medialis, posteriorly by the adductor muscles, and roofed by a thick aponeurosis connecting these muscles (i.e., vasto-adductor membrane) (Figure 25-2). The distal limit of the canal is the adductor hiatus through which the femoral vessels enter the popliteal fossa.

Cross-Sectional Anatomy and Ultrasound View

In a cross-sectional plane, the adductor canal appears as a triangular-shaped space, limited by the sartorius muscle and vastoadductor membrane (superficially), vastus medialis muscle (anterolaterally), and adductor longus and adductor magnus muscle (posteromedially). This interfascial space contains the femoral artery and vein, the saphenous nerve, the medial femoral cutaneous nerve, and branches from the nerve to the vastus medialis (Figure 25-3). Branches of the obturator nerve may also travel through the adductor canal, but this is not consistent.

Distribution of Anesthesia and Analgesia

A subsartorial block results in cutaneous anesthesia of the medial aspect of the leg below the knee, ankle, and midfoot. Proximal injections of large volumes of LA may result in a partial motor block of the quadriceps. The extent of analgesia of the knee joint would depend on the site of injection (Figure 25-4).

Block Preparation

Equipment

- Transducer: High-frequency linear transducer
- Needle: 50-mm, 22-gauge, insulated, stimulating needle

Local Anesthetic

Bupivacaine or ropivacaine 0.25% to 0.5% are best suited for this block. Although 5 to 10 mL is sufficient for saphenous nerve block, typically, 10 to 20 mL is used in adductor canal blocks for analgesia after knee surgery. A higher volume (e.g., 30 mL) has been associated with a risk of quadriceps paresis. The data indicate that a continuous adductor canal block prolongs analgesia without impairing the quadriceps function. Liposome bupivacaine can also be used to prolong the duration of the block without the catheter.

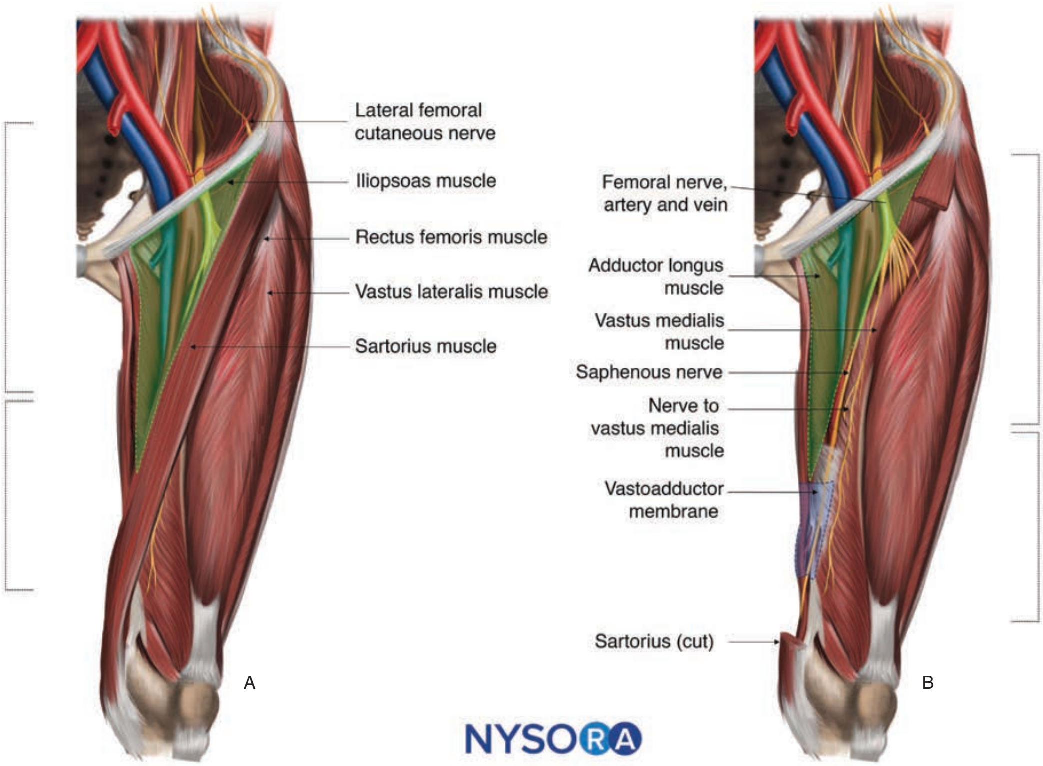


FIGURE 25-2. Anatomical limits of the femoral triangle (in green) and the adductor canal (in blue).

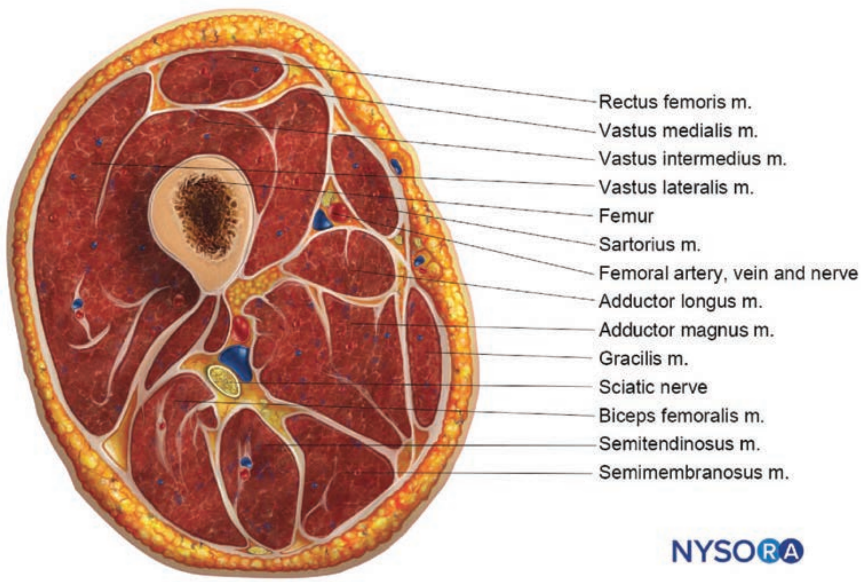


FIGURE 25-3. Cross-section anatomy of the midthigh.

FIGURE 25-4. Anesthesia distribution of the subsartorial blocks. From right to left, osteotomes, myotomes, and dermatomes.

Patient Positioning

The patient is positioned supine, with the knee slightly flexed and rotated externally to better expose the medial side of the thigh (Figure 25-5). The US machine is placed next to the patient on the contralateral side, facing the practitioner.

Technique

Landmarks and Transducer Position

The transducer is placed in a transverse orientation over the medial aspect of the midthigh. The femoral artery is visualized as a round anechoic pulsating structure deep to the sartorius muscle.

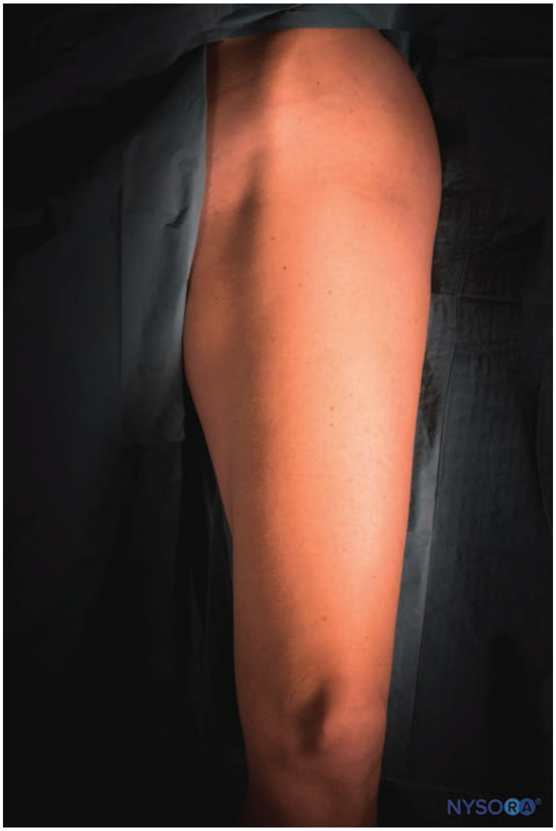


FIGURE 25-5. Patient position.

Scanning Technique

To find the injection site more precisely, the sartorius muscle is traced proximally-distally to identify the internal sonographic anatomy landmarks that define the femoral triangle and adductor canal. The apex of the femoral triangle is identified by the intersection between the medial border of the sartorius muscle and the medial border of the adductor longus muscle (Figure 25-6A). An injection distal to this limit will occur in the adductor canal (Figure 25-6B).

The femoral artery is traced proximally and distally until it is located below the midpoint of the sartorius muscle. At this level (adductor canal), the saphenous nerve is lateral to the artery and can be consistently blocked (Figure 25-7).

Needle Approach and Trajectory

The needle is advanced in-plane from lateral to medial toward the deep fascia of the sartorius muscle, lateral to the femoral artery. The pressure of the transducer should be released to identify the position of the femoral vein before injection (Figure 25-8).

Local Anesthetic Distribution

After negative aspiration, 1 to 2 mL of LA is injected to confirm the correct injection site. The block is completed with 10 to 15 mL of LA while observing the spread between the sartorius muscle, vastus medialis, and femoral artery. The injection usually facilitates imaging of the saphenous nerve (Figure 25-9).

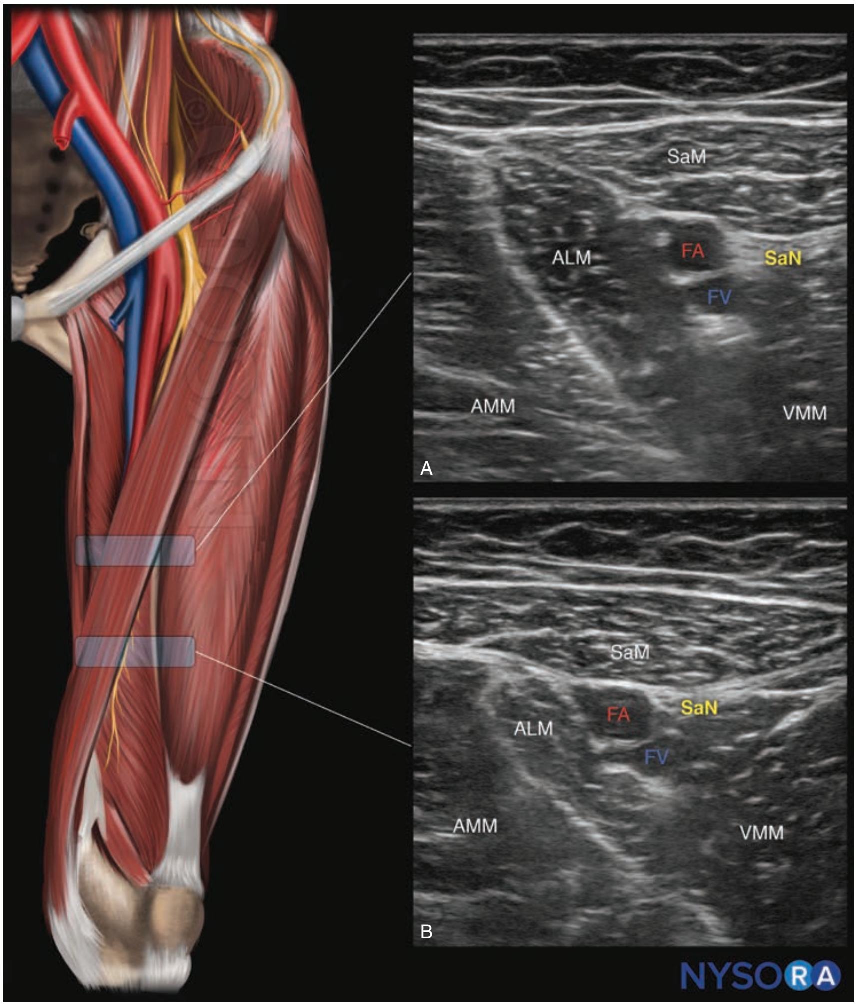


FIGURE 25-6. Ultrasonographic landmarks defining the distal limit of (A) the femoral triangle and (B) the adductor canal. SaM, sartorius muscle; SaN, saphenous nerve; FA, femoral artery; FV, femoral vein; VMM, vastus medialis muscle; ALM, adductor longus muscle; AMM, adductor magnus muscle.

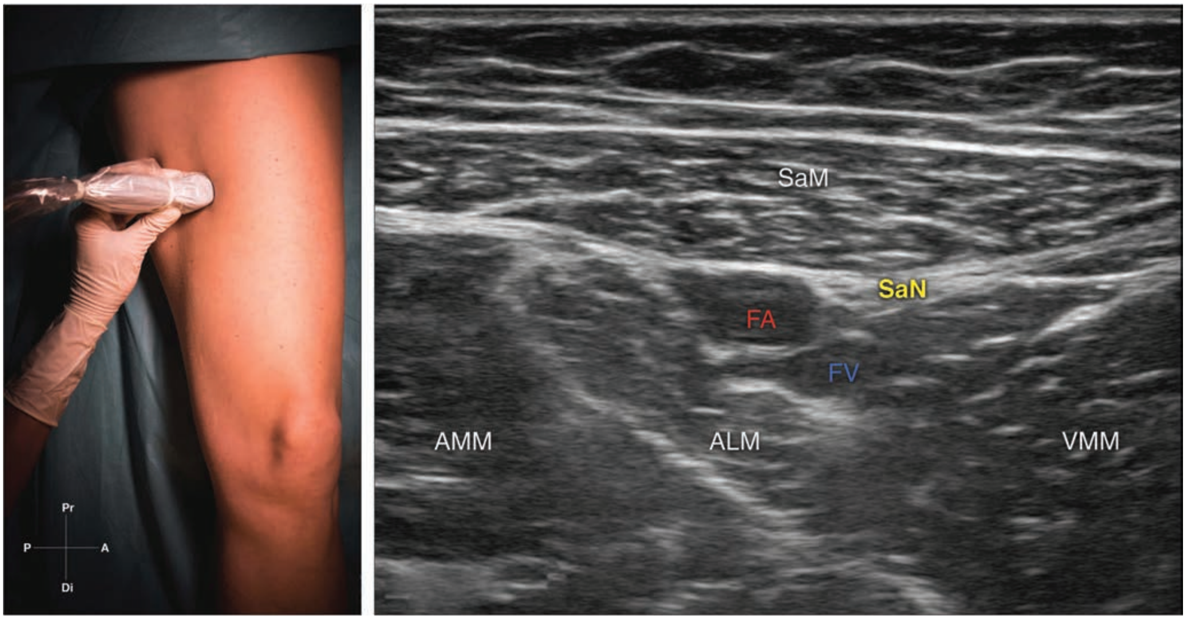


FIGURE 25-7. Transducer position and sonoanatomy of the adductor canal. SaM, sartorius muscle; SaN, saphenous nerve; FA, femoral artery; FV, femoral vein; VMM, vastus medialis muscle; ALM, adductor longus muscle; AMM, adductor magnus muscle.

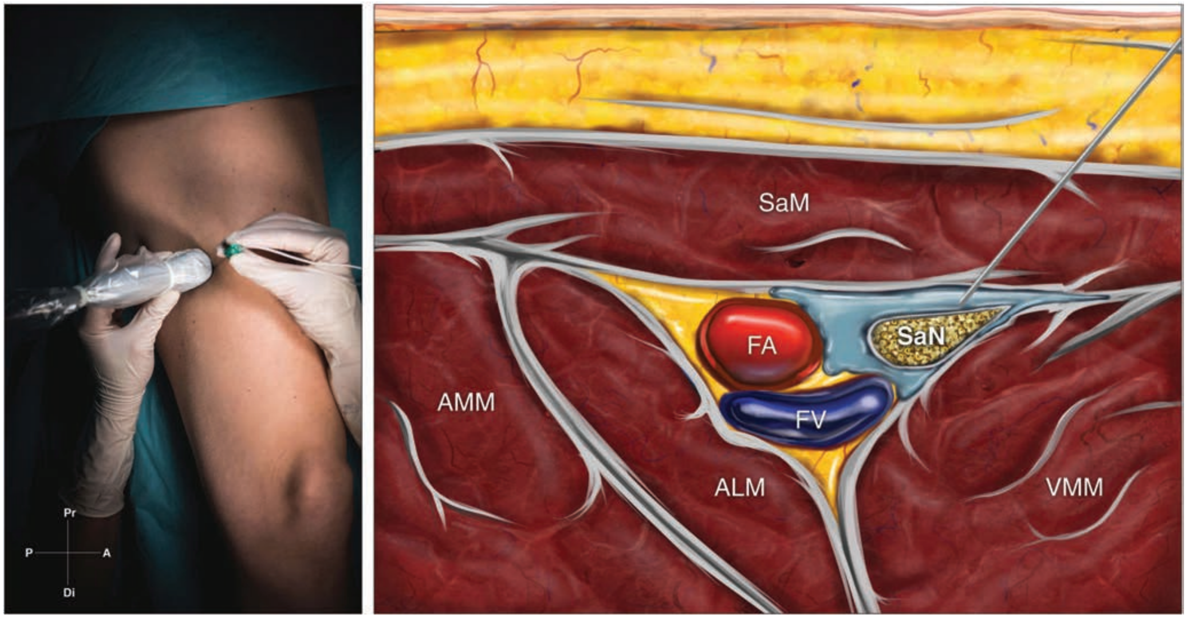


FIGURE 25-8. Reverse ultrasound anatomy of an adductor canal block with needle insertion in-plane. SaM, sartorius muscle; SaN, saphenous nerve; FA, femoral artery; FV, femoral vein; VMM, vastus medialis muscle; ALM, adductor longus muscle; AMM, adductor magnus muscle.

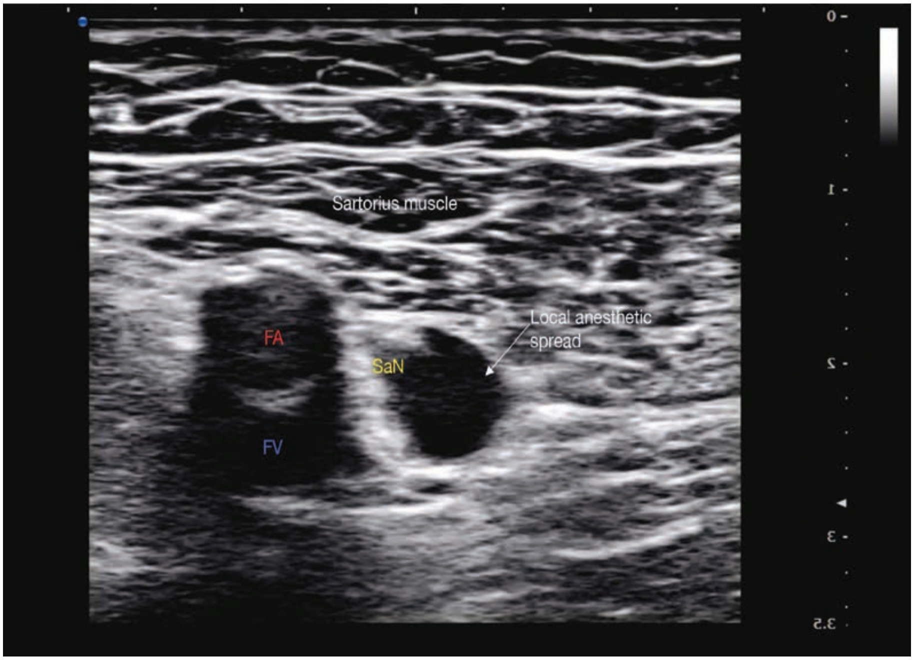


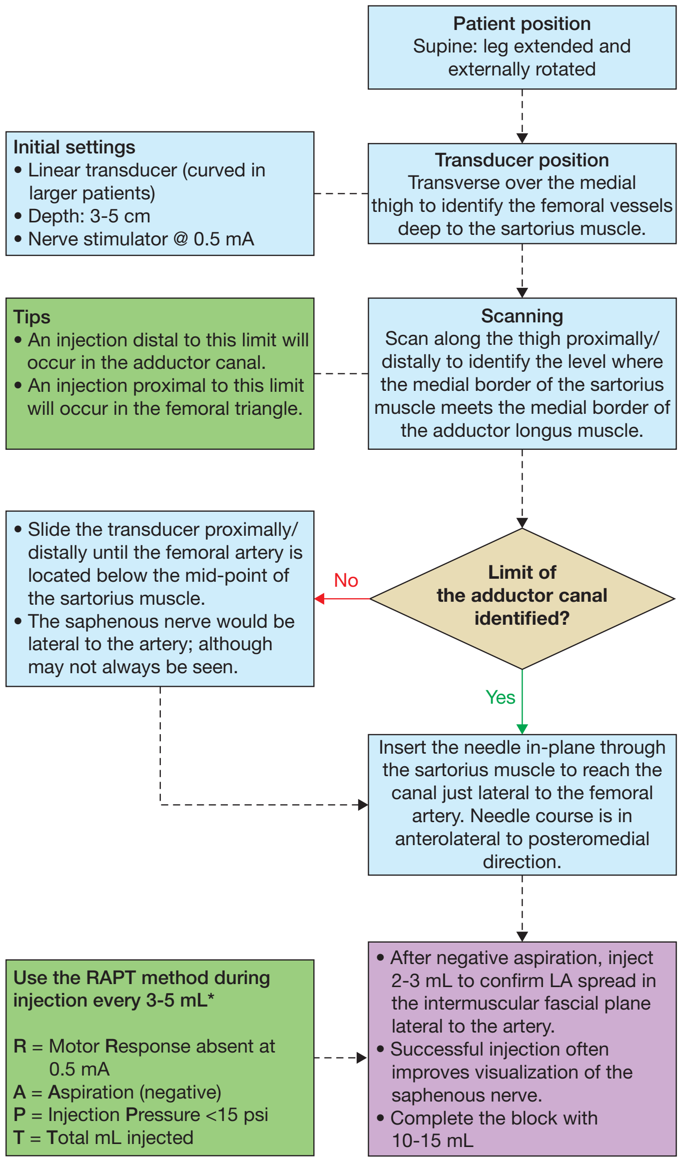
FIGURE 25-9. Local anesthetic distribution after injection into the adductor canal. FA, femoral artery; FV, femoral vein; SaN, saphenous nerve.

Problem-Solving Tips

- Tilt and slide the transducer cranial and caudal to optimize the image of the fascial planes.
- Color Doppler: If the artery cannot be visualized: (1) Use color Doppler or power Doppler mode and/or (2) Image the femoral artery at the femoral crease and follow the artery by scanning distally.
- Local anesthetic volume: Do not use more than 10 mL of LA. Bigger volumes may result in a motor block of the quadriceps muscle.
- The sonographic appearance of the saphenous nerve is hyperechoic; the nerve may not always be visualized (e.g., larger patients). The saphenous nerve often becomes better visualized after the injection lateral to the femoral artery as the landmark.
- An out-of-plane approach may be easier in larger patients.

Flowchart

Saphenous Nerve Block: Adductor Canal Technique Algorithm



*Local motor response may indicate wrong (intramuscular) needle placement. More distal motor response may indicate needle-nerve contact with the saphenous nerve, which requires caution to avoid its injury by the needle or injection.

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26 Lateral Femoral Cutaneous Nerve Block

BLOCK AT A GLANCE

Block of the lateral femoral cutaneous nerve distal to the anterior superior iliac spine.

- **Indications:** Analgesia for surgery on the anterolateral thigh; skin grafting, muscle biopsy, meralgia paresthetica
- **Goal:** Local anesthetic spread around the nerve superficial or lateral to the sartorius muscle
- **Local anesthetic volume:** 3 to 10 mL

General Considerations

The lateral femoral cutaneous nerve (LFCN) block is a commonly performed technique to provide cutaneous anesthesia or analgesia to the anterolateral aspect of the thigh. The block also can help diagnose and treat meralgia paresthetica. This mononeuropathy of the LFCN is manifested by pain, dysesthesia, or numbness in the area supplied by the LFCN. Ultrasound (US) facilitates clear identification of the nerve and ensures needle placement in the correct fascial plane.

Anatomy

The LFCN is a small sensory nerve arising from the dorsal divisions of L2-L3. After emerging from the lateral border of the psoas major muscle, it courses under the fascia iliaca laterally toward the anterior superior iliac spine (ASIS). The nerve then passes under the inguinal ligament and travels distally over the sartorius muscle into the thigh, where it divides into two branches (i.e., anterior and posterior) to provide innervation to the anterolateral aspect of the thigh (Figure 26-1). There are many anatomical variations of the nerve with regards to its entrance into the thigh.

Cross-Sectional Anatomy and Ultrasound View

At the level of the ASIS, the LFCN is located just medial to the insertion of the sartorius muscle. As the sartorius muscle descends in a lateral to a medial direction across the anterior thigh, the LFCN travels superficially from its medial to its lateral border. A few centimeters distally, the LFCN is located between the sartorius and tensor fasciae latae muscles. On US, the nerve appears as a small hyperechoic neural structure 0.5 to 2 cm below the skin surface between the fascia lata and superficial fascia of the sartorius, or within a fat-filled hypoechoic space between the sartorius and tensor fascia latae muscles (Figure 26-2).

Distribution of Anesthesia and Analgesia

The LFCN is a purely sensory nerve that provides cutaneous innervation to the anterolateral thigh (Figure 26-3). The innervation territory of the LFCN is highly variable.

Block Preparation

Equipment

- Transducer: High-frequency linear transducer
- Needle: 25- to 40-mm, 25-gauge needle

Local Anesthetic

For cutaneous anesthesia, lidocaine 2% or ropivacaine 0.2% are commonly used. For meralgia paresthetica, long-lasting local anesthetics (LAs) with steroids are used.

Patient Positioning

The patient is placed in a supine position with the lower extremity extended to maximize the exposure to the proximal thigh (Figure 26-4).

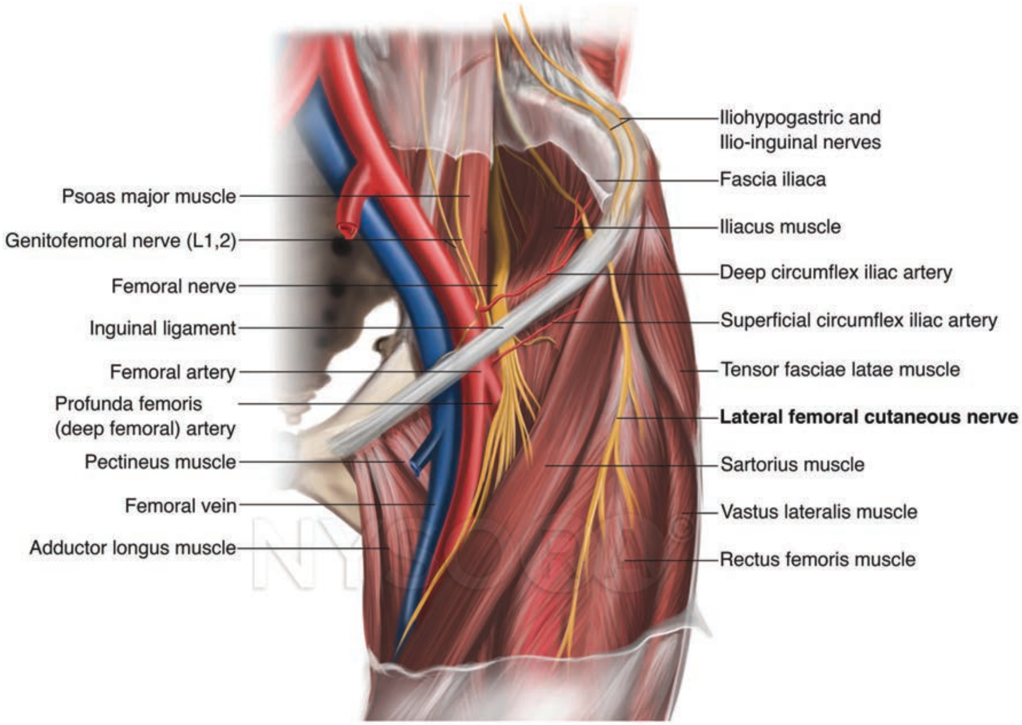


FIGURE 26-1. Anatomy of the lateral femoral cutaneous nerve.

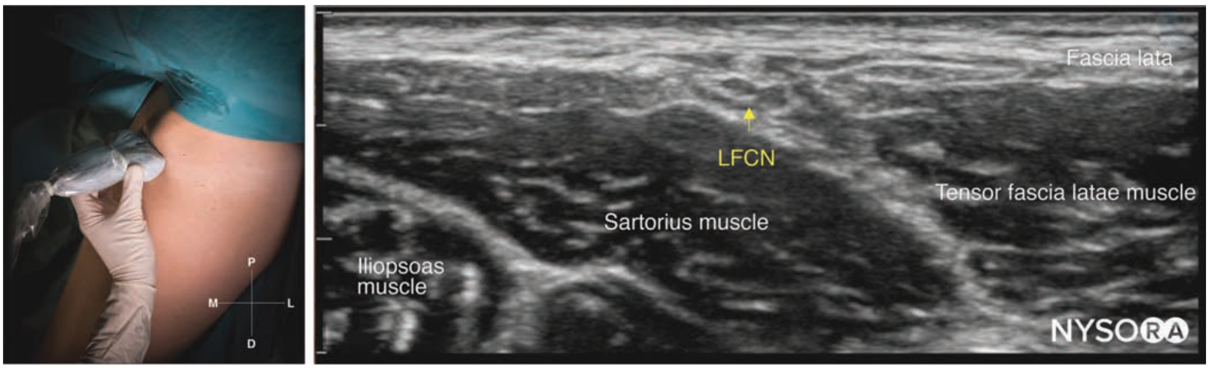


FIGURE 26-2. Transducer position and sonoanatomy of the lateral femoral cutaneous nerve.

FIGURE 26-3. Expected sensory distribution of the lateral femoral cutaneous nerve (highlighted in red).

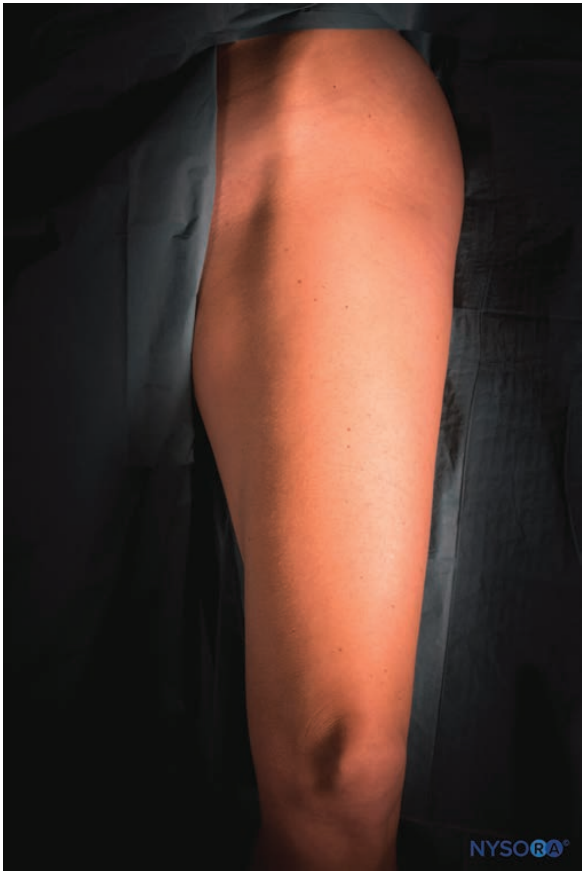


FIGURE 26-4. Patient position to perform an ultrasound-guided lateral femoral cutaneous nerve block.

Technique

Landmarks and Initial Transducer Position

After identification of the ASIS, the transducer is placed in a transverse orientation just distal to it to identify the sartorius muscle as a hypoechoic triangular structure.

Scanning Technique

The transducer is slid distally over the sartorius muscle, adjusting the tilt and pressure, to see the rather small-appearing LFCN. The LFCN is identified as a hyperechogenic structure moving superficial to the muscle toward a tiny space between the sartorius and tensor fascia latae muscles. The nerve is accessed where it is best visible (see Figure 26-2).

Needle Approach and Trajectory

The needle is advanced either in-plane or out-of-plane deep to the fascia lata next to the nerve. After negative aspiration, 1 mL of LA is injected to confirm the correct needle position (Figure 26-5).

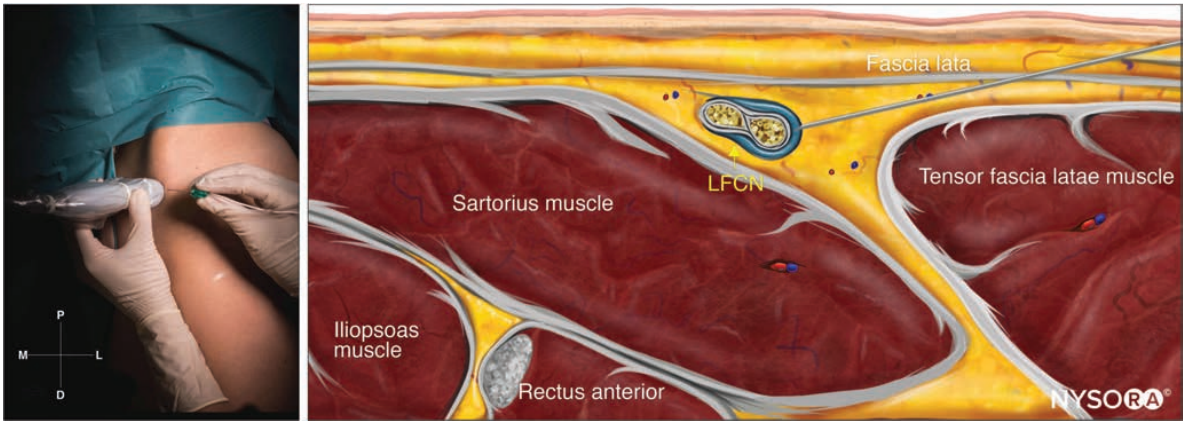


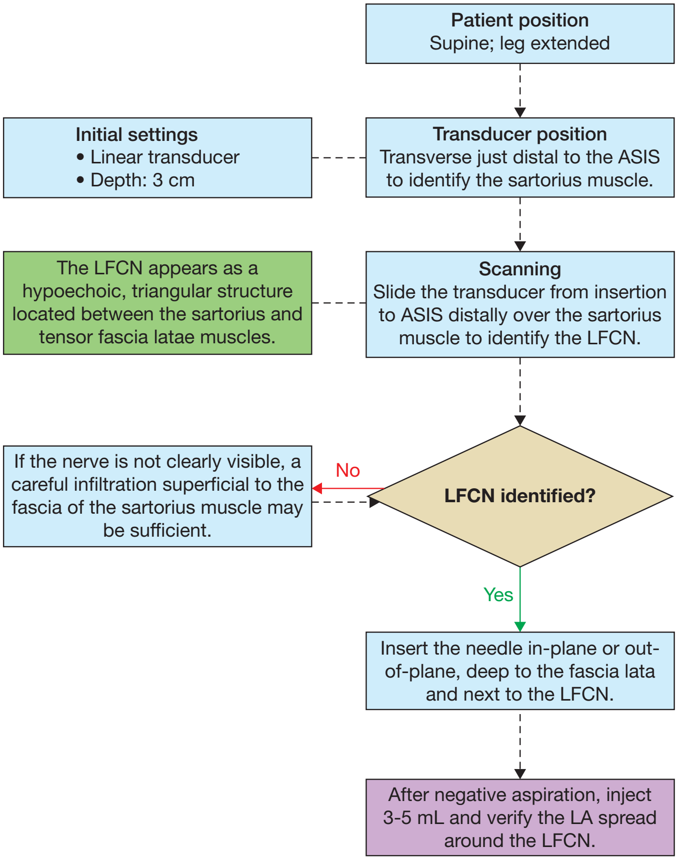
FIGURE 26-5. Reverse ultrasound anatomy with needle insertion in-plane to block the lateral femoral cutaneous nerve.

Local Anesthetic Distribution

The LA spread surrounding the LFCN ensures a successful block. If the nerve is not clearly visible, a careful infiltration superficial to the fascia of the sartorius muscle is sufficient for a successful block.

Flowchart

Lateral Femoral Cutaneous Nerve (LFCN) Block Technique Algorithm



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27 Obturator Nerve Block

BLOCK AT A GLANCE

Block of the obturator nerve at the inguinal crease.

- **Indications:** Supplemental analgesia for hip and knee surgeries (considered as rescue block for knee surgery), prevention of thigh adduction response during transurethral bladder surgery, relief of painful or permanent hip adductor spasticity
- **Goal:** Local anesthetic (LA) spread in the fascial planes containing the branches of the obturator nerve
- **Local anesthetic volume:** 5 to 10 mL in each interfascial space or around each branch of the obturator nerve. For the proximal approach, use 10 to 15 mL.

General Considerations

The obturator nerve block is a well-established technique for hip and knee surgeries, traditionally performed based on landmarks and nerve stimulation. However, the anatomical variability and deep location of the structures make it difficult to achieve consistent results. The widespread availability of point-of-care ultrasound (US) led to a renewed interest in this technique because US allows visualization of the nerves and precise injection of LAs into the fascial planes through which they travel. Modifications of the technique have been proposed to optimize the spread of the injectate around the obturator nerve and along the obturator canal, proximal to the bifurcation of the nerve. The obturator nerve block may add to the quality of analgesia after hip and knee surgeries; however, its analgesic value in the context of a multimodal analgesia regime is yet to be determined.

Limitations and Specific Risks

A limitation of this technique includes the difficulty in obtaining good US images of the structures in the inguinal area. Likewise, the insufficient cranial spread of the LA and anatomical variability may result in an inconsistent block extent and limit the analgesic value to treat hip pain.

The risk of vascular puncture is a common complication related to this block because the obturator artery anastomoses with a branch of the medial circumflex femoral artery in the vicinity of the obturator nerve.

Anatomy

The obturator nerve arises from the ventral rami of the L2 to L4 lumbar nerves. It descends to the pelvis through the psoas major muscle emerging from its medial border, then travels posteriorly with the common iliac arteries and laterally along the pelvic wall toward the obturator foramen, through where it enters the thigh (Figure 27-1). In most individuals, the nerve divides before exiting the pelvis into an anterior and posterior branch, which are separated at first by fibers of the external obturator, and more distally by the adductor brevis muscles. The articular branches supplying the hip joint are usually derived from the common obturator nerve proximal to its division and only occasionally from the individual branches.

The **anterior branch** of the obturator nerve initially travels through the interfascial plane between the pectineus and adductor brevis muscles. It runs further caudad between the adductor longus and adductor brevis muscles, innervating the adductor longus, adductor brevis, and gracilis muscles. The **posterior branch** travels in the fascia between the adductor brevis and adductor magnus muscles (Figure 27-1). The nerve supplies multiple branches to the adductor magnus and adductor brevis muscles and occasionally innervates the external obturator and adductor longus muscles as well. The posterior branch also provides articular branches to the medial aspect of the knee joint.

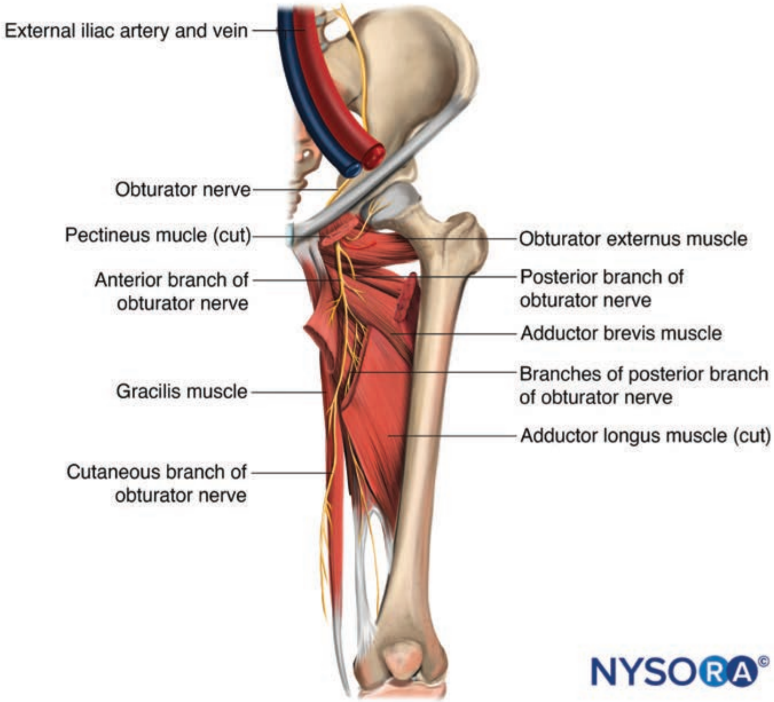


FIGURE 27-1. Anatomy of the obturator nerve in the thigh.

Cross-Sectional Anatomy and Ultrasound View

At the level of the inguinal ligament, just distally to the obturator foramen, the branches of the obturator nerve run superficially to the external obturator muscle and deep to the pectineus muscle (Figure 27-2A).

Slightly distally, the branches of obturator nerve diverge as they reach the adductor brevis muscle (Figure 27-2B).

Further distally, the anterior branch lies between the adductor longus and brevis, while the posterior branch runs between the adductor brevis and magnus. The identification of the adductor fascial planes, just medial to the pectineus muscle, is easy with a linear US transducer, although the branches of the obturator nerve may not always be visualized (Figure 27-2C).

Distribution of Anesthesia and Analgesia

The obturator nerve provides motor innervation to the gracilis and adductor longus brevis and magnus muscles. The pectineus and adductor magnus muscles receive co-innervation from the femoral nerve and the sciatic nerves, respectively. Consequently, a decrease in adductor muscle strength of more than 40% to 50% is often used as a definition of a successful obturator nerve block.

The obturator nerve also contributes to the sensory innervation of the hip and knee joints. The branch to the hip joint might not be blocked by the described distal block approaches. The cutaneous anesthesia of the medial aspect of the thigh is inconsistent and variable in extension (Figure 27-3).

Block Preparation

Equipment

- Transducer: Linear high-frequency or curved transducer
- Needle: 50- or 100-mm, 21- or 22-gauge, short-bevel, insulated, stimulating needle

Choice of Local Anesthetic

To avoid contractions of the adductor muscles during endoscopic bladder surgery, short- or intermediate-acting LAs, such as lidocaine 2%, are indicated. For analgesia after hip or knee surgery, long-lasting LAs (e.g., bupivacaine 0.5% or ropivacaine 0.5%) are recommended. Like most fascial plane blocks, the success of the block relies on the volume injected. Therefore, 10 to 15 mL is commonly injected to obtain an adequate spread pattern.

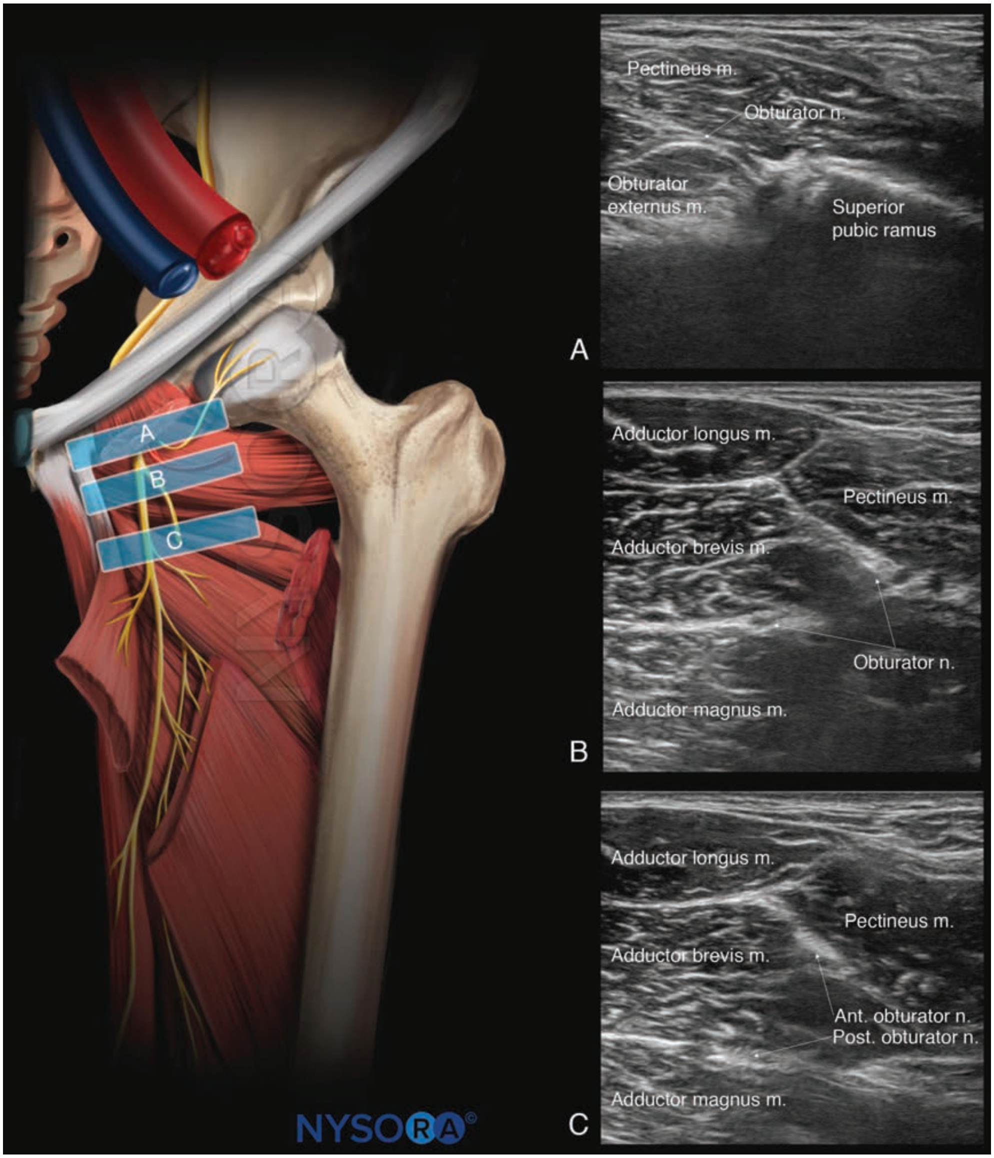


FIGURE 27-2. Cross-sectional anatomy of the obturator nerve (A) exiting the obturator foramen, (B) approaching the adductor brevis muscle, and (C) at the level of the adductor brevis muscle.

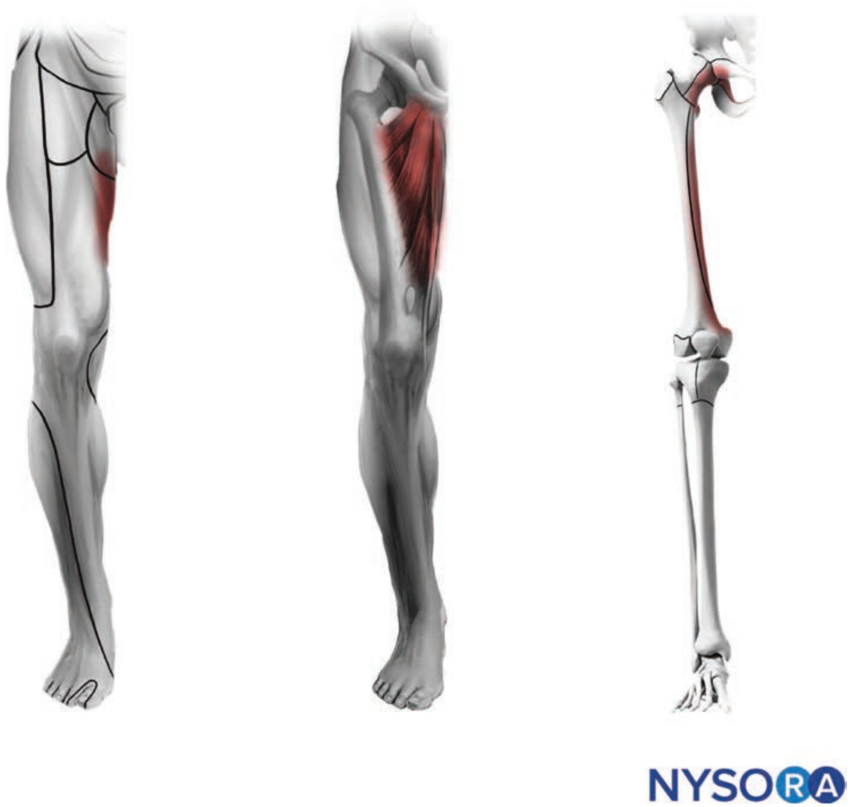


FIGURE 27-3. Obturator nerve block: sensory and motor distribution (highlighted in red).

Patient Positioning

Patients are placed in the supine position with the thigh slightly abducted and externally rotated to facilitate access to the medial aspect of the inguinal crease (Figure 27-4).

Technique

Landmarks and Initial Transducer Position

The US transducer is placed in a transverse orientation perpendicular to the inguinal crease to identify the femoral vessels. The transducer is moved medially along the crease to identify the pectineus, and further medially, the adductor longus, adductor brevis, and adductor magnus muscles.

Scanning Technique

The anterior and posterior branches of the obturator nerve can be seen running along the fascial planes superficial and deep to the adductor brevis muscles (Figure 27-2).

Scanning as much proximally as possible and tilting the transducer about 45° cranially, the two branches are seen

FIGURE 27-4. Patient position for an obturator nerve block.

converging in the fascial plane between the pectineus and the external obturator muscles (Figure 27-2).

Needle Approach and Trajectory

The block can be performed proximal or distal to the bifurcation of the nerve.

- **Distal approach:** The needle can be advanced in-plane or out-of-plane; two aliquots of LA are injected into the fascial planes between the adductor longus and adductor brevis muscles (anterior branch) and between the adductor brevis and adductor magnus muscles (posterior branch). Nerve stimulation may elicit contraction of the adductor muscles. When necessary, the needle is adjusted to optimize the spread of the LA solution in the interfascial space (Figures 27-5 and 27-6).
- **Proximal approach:** The needle is inserted in-plane from lateral to medial toward the hyperechoic fascial plane between the pectineus and external obturator muscles. The obturator nerve may be seen as a hyperechoic thick structure, although it may be difficult to distinguish from the interfascial plane (Figures 27-7 and 27-8). Due to the pronounced tilt of the transducer, it can be difficult to align the needle with the transducer in order to visualize the needle and target simultaneously when in-plane needle insertion is used.

Local Anesthetic Distribution

With the distal and proximal techniques, the spread of the LA occurs along the corresponding intermuscular fascial planes. Moreover, in the proximal technique, a retrograde spread of LA through the obturator canal is to be expected, resulting in blockade of the branches diverging cranially to the inguinal ligament. The proximal approach is better suited to avoid the contraction of the adductor muscles during endoscopic bladder surgery.

Problem-Solving Tips

- Weakness or inability to adduct the leg indicates a successful obturator nerve block. A simple method of assessing adductor muscle strength (motor block) is to instruct the patient to adduct the leg from an abducted position against resistance.
- Caution should be exercised to prevent intravascular injection in a highly vascular area. Always use color Doppler, appropiate monitoring, and frequent aspiration, and fractionate the dose and maintain verbal contact with the patient.
- When nerve stimulation is used, adduction of the thigh can occur even without proper nerve identification. This is due to direct muscle or muscle branch stimulation with currents >1.0 mA. Decreasing the current intensity helps distinguish between nerve versus direct muscle stimulation.

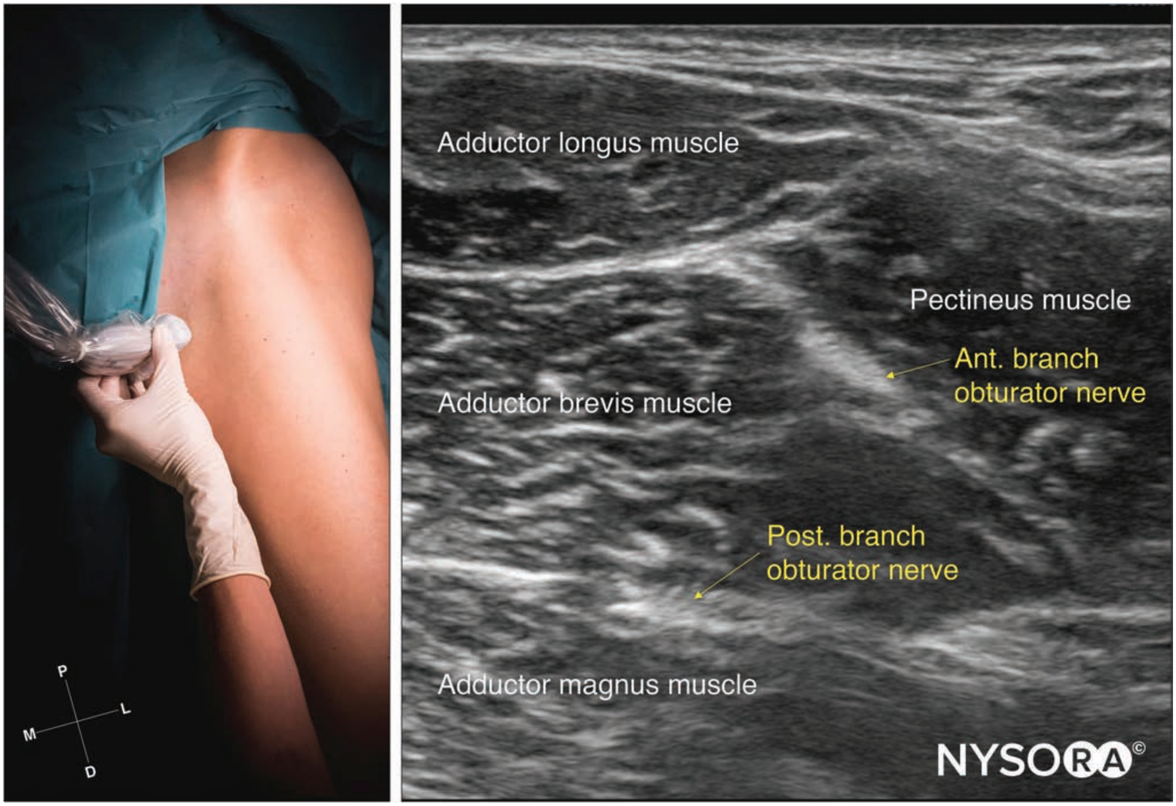


FIGURE 27-5. Distal approach to block the obturator nerve; transducer position and sonoanatomy.

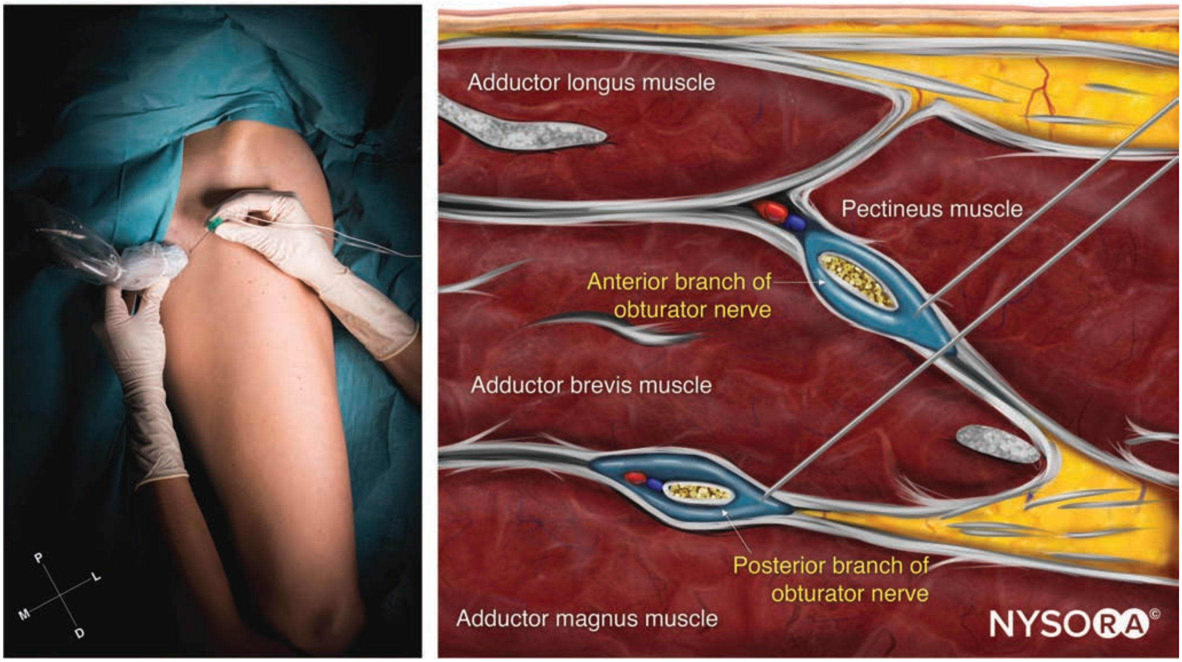


FIGURE 27-6. Distal approach to block the obturator nerve; reverse ultrasound anatomy with needle insertion in-plane.

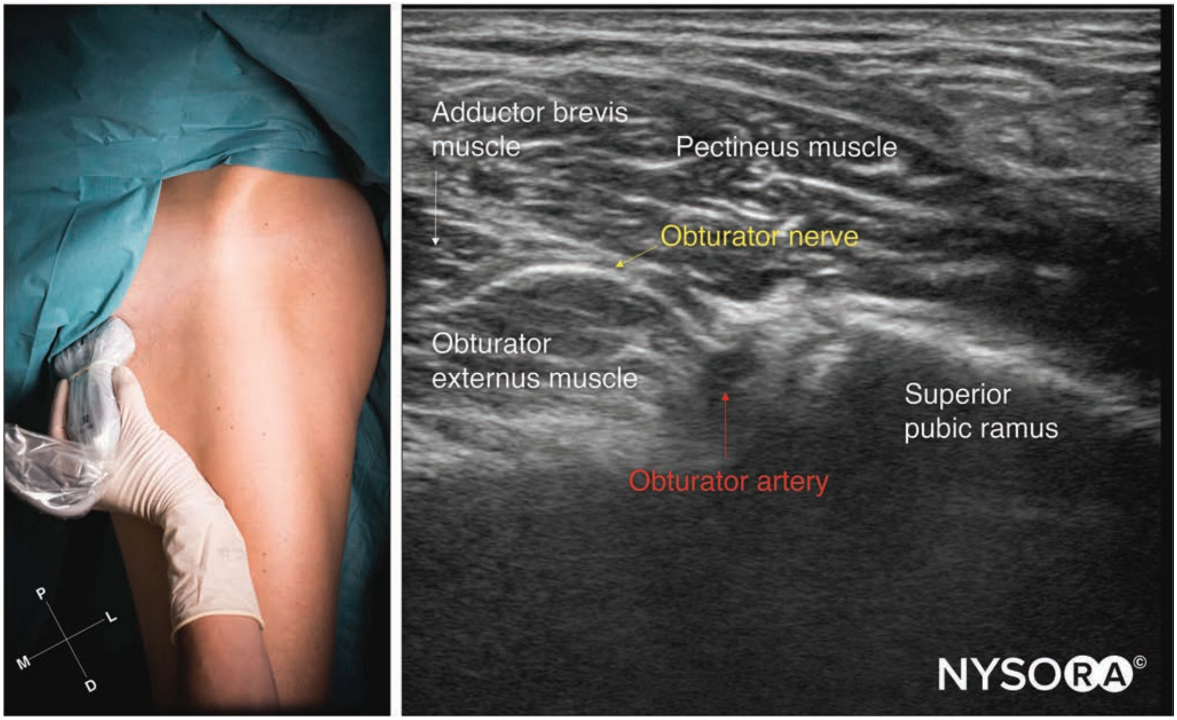


FIGURE 27-7. Proximal approach to block the obturator nerve; transducer position and sonoanatomy.

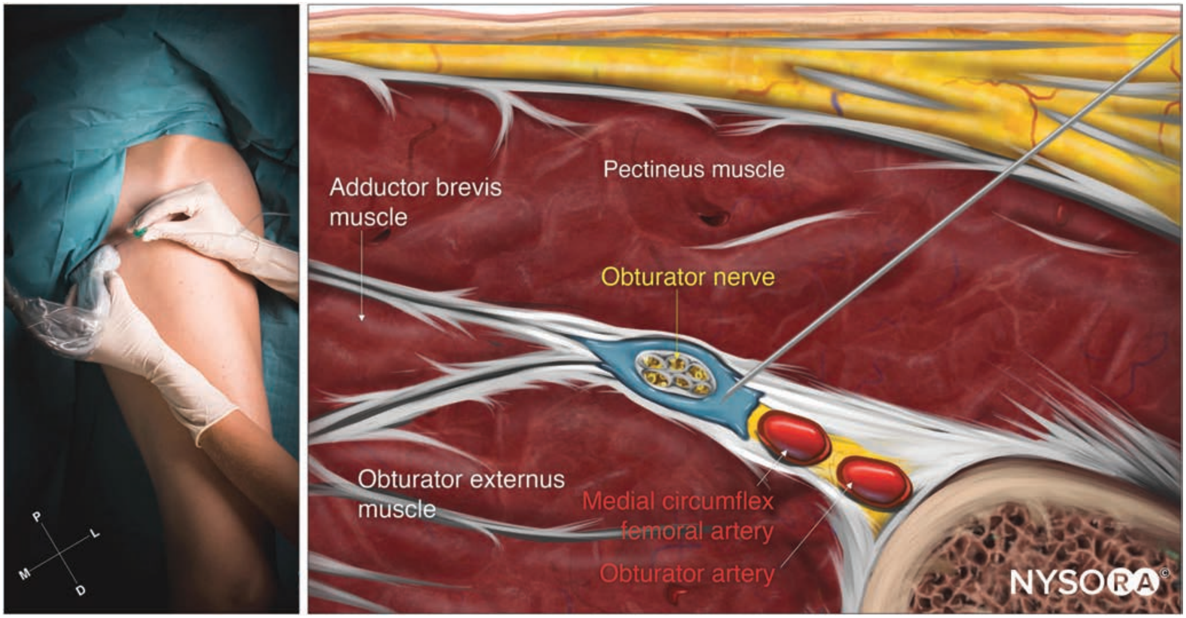
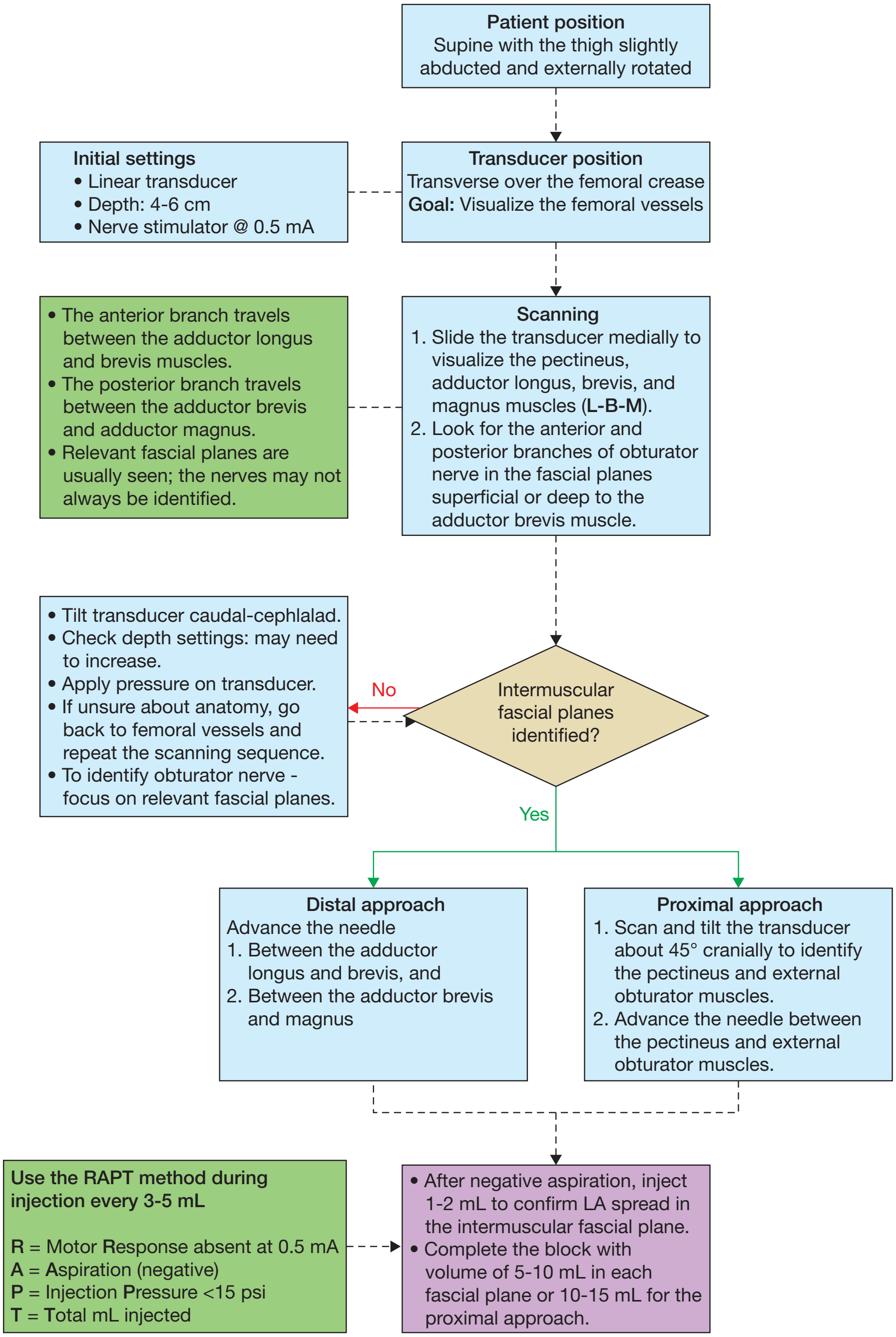


FIGURE 27-8. Proximal approach to block the obturator nerve; reverse ultrasound anatomy with needle insertion in-plane.

Flowchart

Obturator Nerve Block Technique Algorithm



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28 Proximal Sciatic Nerve Block

BLOCK AT A GLANCE

Block of the sciatic nerve at the gluteal, subgluteal, or proximal thigh level.

- **Indications:** Anesthesia and analgesia for foot and ankle surgery, procedures involving the posterior aspect of the thigh and knee, and for above-knee amputation
- **Goal:** Local anesthetic spread within the sheath containing the sciatic nerve
- **Local anesthetic volume:** 10 to 20 mL

General Considerations

The sciatic nerve block is a well-established regional anesthesia technique for lower extremity surgery, both with or without combination of the saphenous nerve block. It is sometimes performed as an optional component of multimodal analgesia strategies for knee surgery. The development of ultrasound (US) guidance in regional anesthesia has increased the success rate while reducing the required local anesthetic (LA) volume for a successful block. The sciatic nerve can be accessed at several levels along its proximal course (parasacral, gluteal, subgluteal) and through different needle approaches (posterior, lateral, or anterior). However, the popularity of these techniques appears to be declining in favor of more distal approaches or motor sparing blocks of the sensory branches of the sciatic nerve components. For instance, popliteal or ankle blocks are preferred for ambulatory foot surgery (see Chapters 29 and 32) as they interfere less with early ambulation. Similarly, interventional analgesia for knee surgery is evolving toward more selective blocks targeting the terminal sensory branches of the posterior knee capsule (see Chapter 31).

Limitations

Obtaining an optimal image of the sciatic nerve at the gluteal level may be challenging due to its deep location, particularly in obese patients. The distribution of anesthesia below the knee resulting from a proximal block is equivalent to that of a popliteal approach, but the resulting motor block of the posterior compartment of the thigh limits the patient autonomy. The deeper needle path toward the sciatic nerve is less tolerated requiring higher degree of sedation.

Anatomy

The sciatic nerve is a large nerve, originating from the lumbosacral plexus (L4-L5 and S1-S3). The nerve exits the pelvis through the greater sciatic foramen below the piriformis muscle. It courses distally along the fascial planes between the gluteus maximus muscle (posterior) and the inner group of muscles (i.e., superior and inferior gemellus, obturator internus, and quadratus femoris muscles). The nerve descends into the posterior thigh between the greater trochanter of the femur and ischial tuberosity and continues down to the popliteal fossa between the biceps femoris and adductor magnus. The posterior femoral cutaneous nerve runs along the sciatic nerve at the gluteal level until they are separated by the insertion of the biceps femoris muscle at the ischial tuberosity (Figure 28-1).

Cross-Sectional Anatomy and Ultrasound Anatomy

At the **gluteal level**, the nerve is located between the gluteus maximus (superficial) and deep muscles (i.e., obturator internus, inferior gemellus, or quadratus femoris muscles). Using a curvilinear transducer between the greater trochanter (lateral) and ischial tuberosity (medial), the gluteus maximus muscle is seen as the most superficial muscular layer, typically several centimeters thick and the quadratus femoris muscle deep to it. The intermuscular fascial plane bridges the two bony structures. The sciatic nerve is seen as a triangular hyperechoic structure in this fascial plane, slightly closer to the ischial tuberosity than to the greater trochanter (Figure 28-2A).

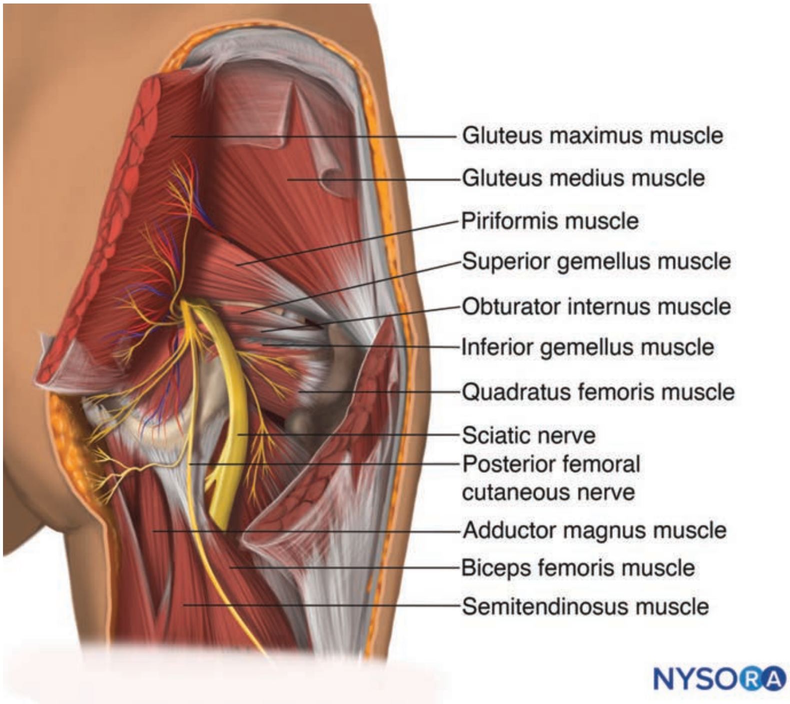


FIGURE 28-1. Anatomy of the sciatic nerve in the posterior thigh.

More distally, at the **gluteal crease**, the sciatic nerve is more superficial and easier to block as the gluteus maximus muscle tapers off. The nerve is located between the gluteus maximus (posterior) and adductor magnus (anterior). The long head of the biceps femoris and ischiotibialis muscles originate at the ischial tuberosity, just medially to the sciatic nerve at this level. Placing a linear (or curvilinear) transducer at the gluteal crease visualizes the sciatic nerve as a triangular or oval hyperechoic structure in the intermuscular fascial plane (Figure 28-2B).

At the **proximal thigh**, the sciatic nerve can also be blocked through the **lateral** or **anterior approach**. However, these techniques are more challenging because of the deep location of the nerve. The femoral artery and its profunda femoris branch can be identified with color Doppler US medially to the nerve. The femur is readily seen as a hyperechoic rim with the corresponding shadow lateral to the nerve. The sciatic nerve is visualized as a hyperechoic structure at a depth of 6 to 8 cm, in the fascial plane between the adductor magnus and biceps femoris muscle (Figure 28-3).

Distribution of Anesthesia and Analgesia

The proximal sciatic nerve block results in a sensory and motor block of the posterior aspect of the thigh and leg below the knee. In the thigh, the motor block involves all the posterior compartment muscles (i.e., biceps femoris, semimembranosus, and semitendinosus), and partially of the adductor magnus muscles. The sensory block includes the posterior capsules of the hip and knee. The posterior femoral cutaneous nerve is usually spared by the subgluteal and anterior approaches. Unless the surgical incision involves the posterior thigh, the lack of cutaneous anesthesia in this area is of little clinical relevance. Below the knee, a sciatic block results

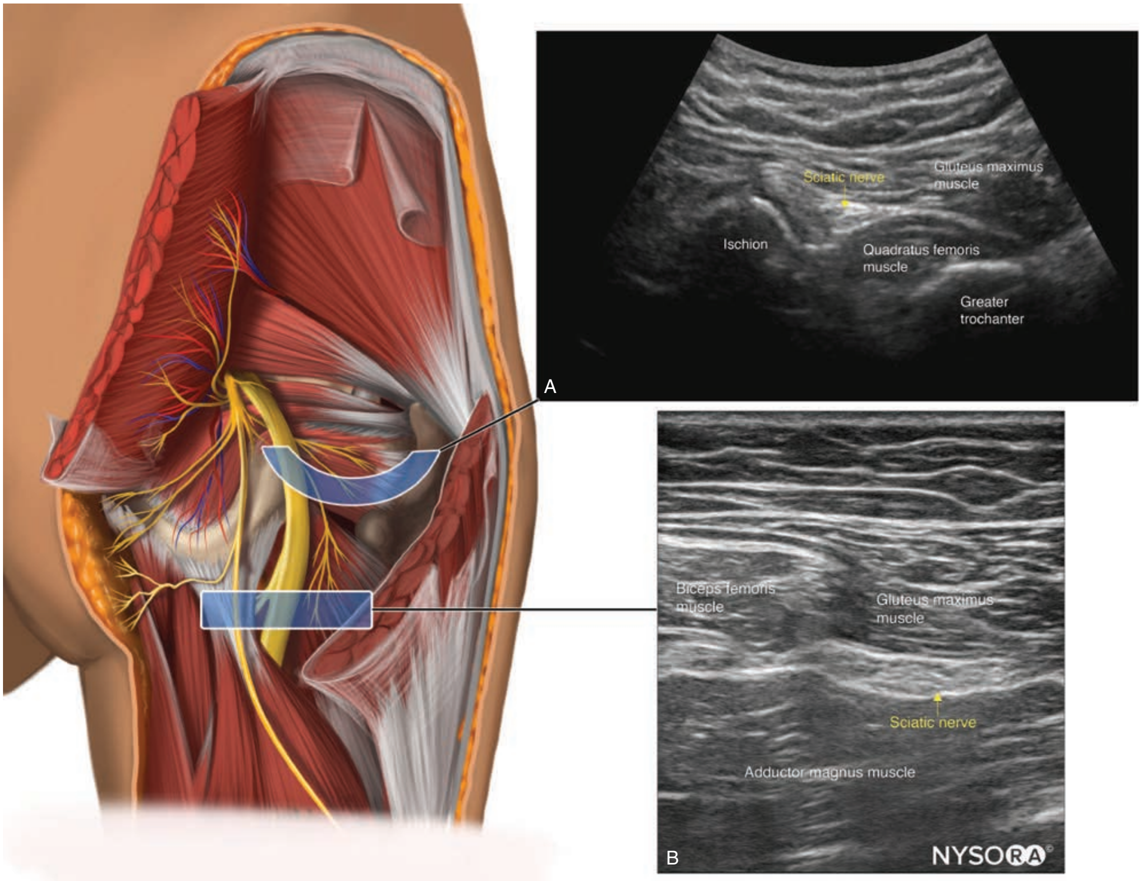


FIGURE 28-2. Sonoanatomy of the sciatic nerve (A) at the gluteal level with a curvilinear transducer and (B) at the gluteal crease (subgluteal) with a linear transducer.

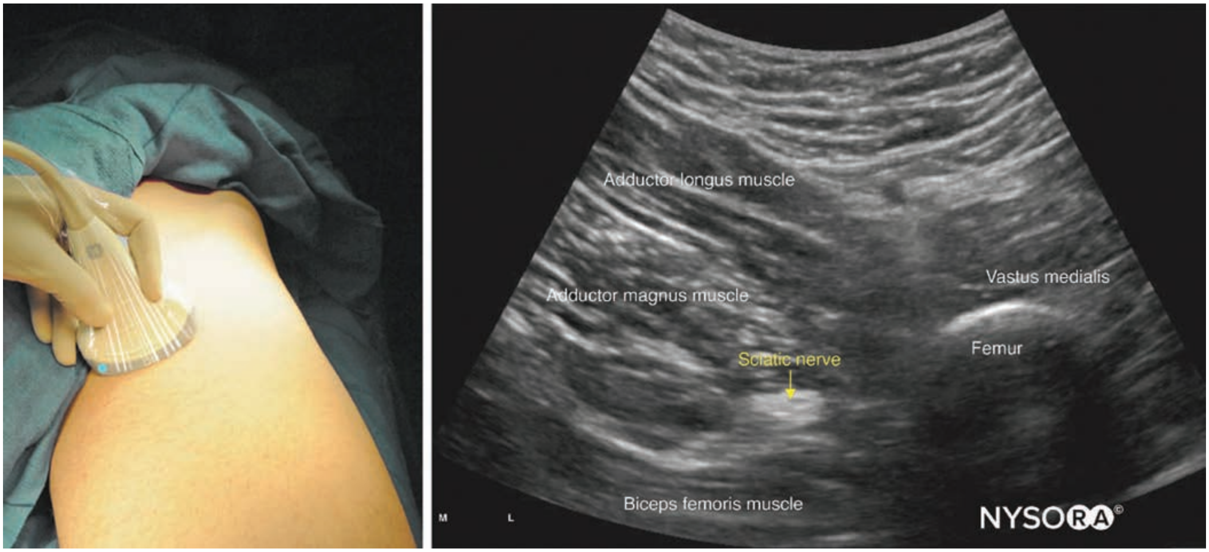


FIGURE 28-3. Sonoanatomy of the sciatic nerve when imaged via an anterior approach.

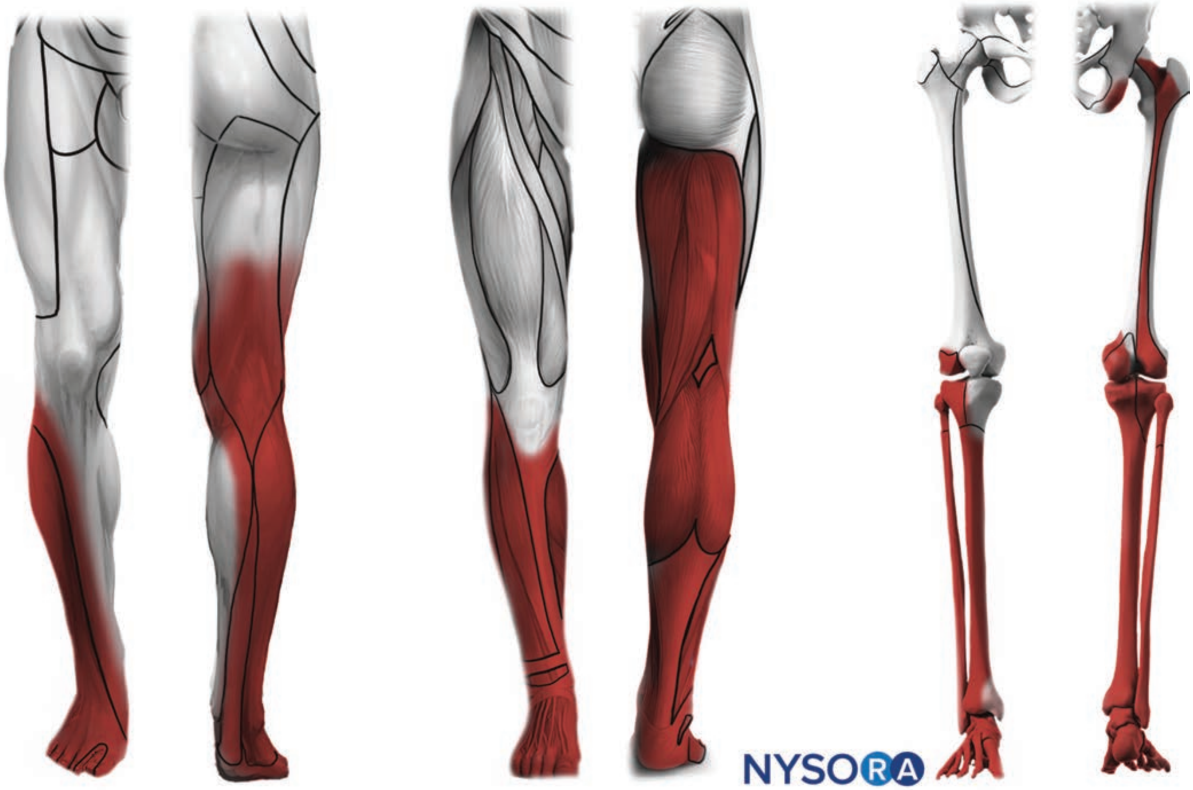


FIGURE 28-4. Sensory and motor distribution after a sciatic nerve block at a gluteal or subgluteal level.

in complete anesthesia, except for the territory of the saphenous nerve on the medial leg, ankle, and foot (Figure 28-4).

Block Preparation

Equipment

- Transducer: Low-frequency curvilinear transducer (or high-frequency linear transducer for subgluteal approach)
- Needle: 80- to 100-mm, 22-gauge, insulated, stimulating needle

Local Anesthetic

Bupivacaine or ropivacaine 0.5% are used for anesthesia and analgesia for foot and ankle surgeries. Diluted mixtures of these LAs (e.g., 0.125-0.25%) may be used to provide analgesia after knee surgery. Short-acting LAs, such as lidocaine 2%, are commonly used for short, less painful procedures. A volume of 10 to 20 mL is usually sufficient for an effective block. Increasing the volume up to 30 mL may not significantly prolong the block duration.

Patient Positioning

For the gluteal or subgluteal approach, the patient can be placed in a lateral decubitus position (Sim's position) with the limb to be blocked flexed at the hip and knee, or in a prone position (Figure 28-5). Exposures of the thigh, calf, and foot are required to detect a motor response when using nerve stimulation.

For the anterior and lateral approaches, the patient is placed in a supine position with the hip abducted and externally rotated to facilitate transducer and needle placement. A supine position has also been described for the lateral approach.

FIGURE 28-5. Patient position to perform a proximal sciatic nerve block.

Techniques

Gluteal Approach

The transducer is positioned in a transverse orientation over the gluteal region between the greater trochanter and ischial tuberosity to identify the deep fascia of the gluteus maximus muscle connecting the two landmarks. By applying pressure and adjusting the tilt, the sciatic nerve is identified as the triangular hyperechoic image in the fascial plane (Figure 28-6).

The needle is advanced in-plane, from lateral to medial toward the lateral edge of the sciatic nerve within the fascial plane and 1-2 mL of LA is injecte to confim the injection site. (Figure 28-7) Note that this approach is also termed "subgluteal" in the literature, referring to an injection deep to the gluteus muscle.

Subgluteal Approach

The transducer is placed over the gluteal crease to identify the fascial planes between the gluteus maximus (posterior), biceps femoris (medial), and adductor magnus muscles (anterior). The sciatic nerve is seen as a hyperechoic oval structure within this fascial plane. Scanning distally while adjusting the tilt helps to distinguish the sciatic nerve in continuity from the tendinous structures attached to the ischial tuberosity at this level (Figure 28-8). The needle is advanced in-plane, from lateral to medial toward the lateral edge of the sciatic nerve within the fascial plane (Figure 28-9). This approach is also known as "infra-gluteal" referring to an injection distal to the gluteus muscles.

Anterior Approach

The curved transducer is placed in a transverse orientation over the anteromedial aspect of the proximal thigh. The femoral artery and nerve are seen superficially on the medial side, with the lesser trochanter appearing on the lateral side. The sciatic nerve is visualized as a hyperechoic oval structure in the deep fascial plane between the adductor magnus muscle and biceps femoris. (Figure 28-3) Sliding and tilting the transducer usually help to improve the visualization. If the patient is able to dorsiflex and/or plantarflex the ankle, this maneuver can be used to rotate the nerve or move it within the muscular planes, facilitating identification.

The needle is inserted in-plane or out-of-plane and advanced toward the fascial plane where the sciatic nerve is located. It is important to identify the femoral vessels (color Doppler) and femoral nerve before inserting the needle to avoid inadvertent puncture.

Due to the steep angle, visualization of the needle tip may be difficult.

Local Anesthetic Distribution

Once the needle tip is positioned within the fascial plane next to the sciatic nerve sheath, 1 to 2 mL of LA is injected to confirm the proper injection site. Repositioning the needle is often necessary to accomplish the desired LA spread around the sciatic nerve to increase the block speed and success.

Problem-Solving Tips

- A linear transducer can also be used in smaller patients and for the subgluteal approach. However, the wider sector of the curved transducer is usually better for a proximal sciatic nerve block as it allows visualization of the osseous landmarks.
- The ability to visualize the sciatic nerve proximally depends on the identification of the correct fascial planes. Tracing the muscular planes proximally and distally, or from their insertion sites, often helps to find the sciatic nerve.
- The depth of the sciatic nerve changes along its course depending on the thickness of the surrounding muscles. Consequently, the sciatic nerve exhibits a high degree of anisotropy. Adjusting the tilt along the way is essential to obtain an optimal view of the sciatic nerve.

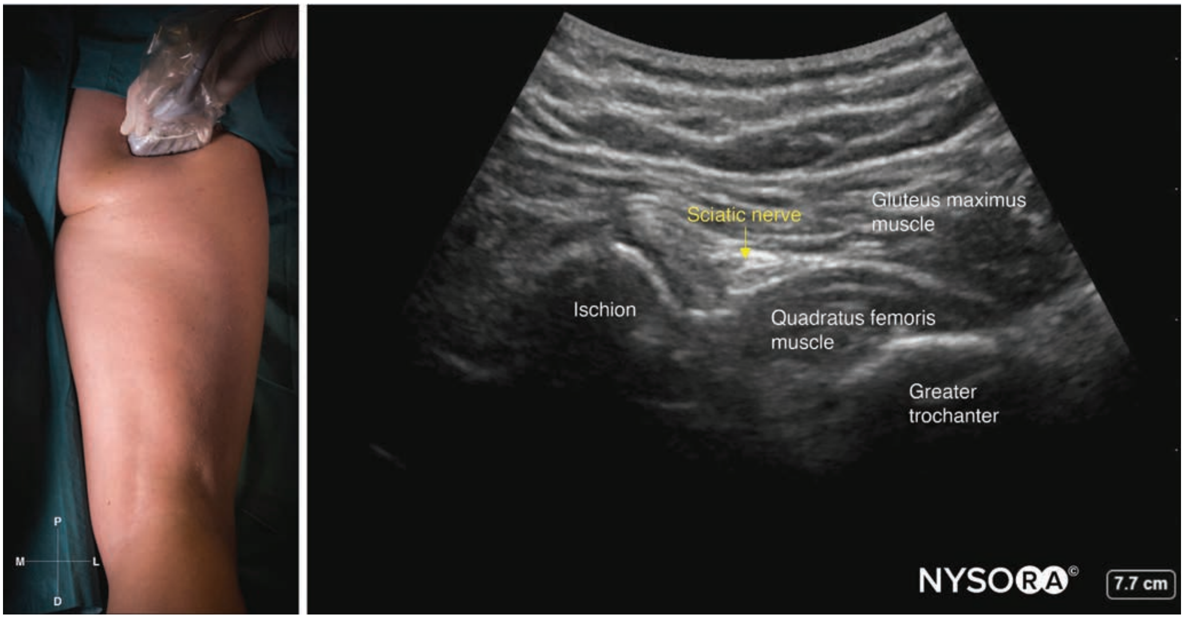


FIGURE 28-6. Transducer position and sonoanatomy of the sciatic nerve at the gluteal level.

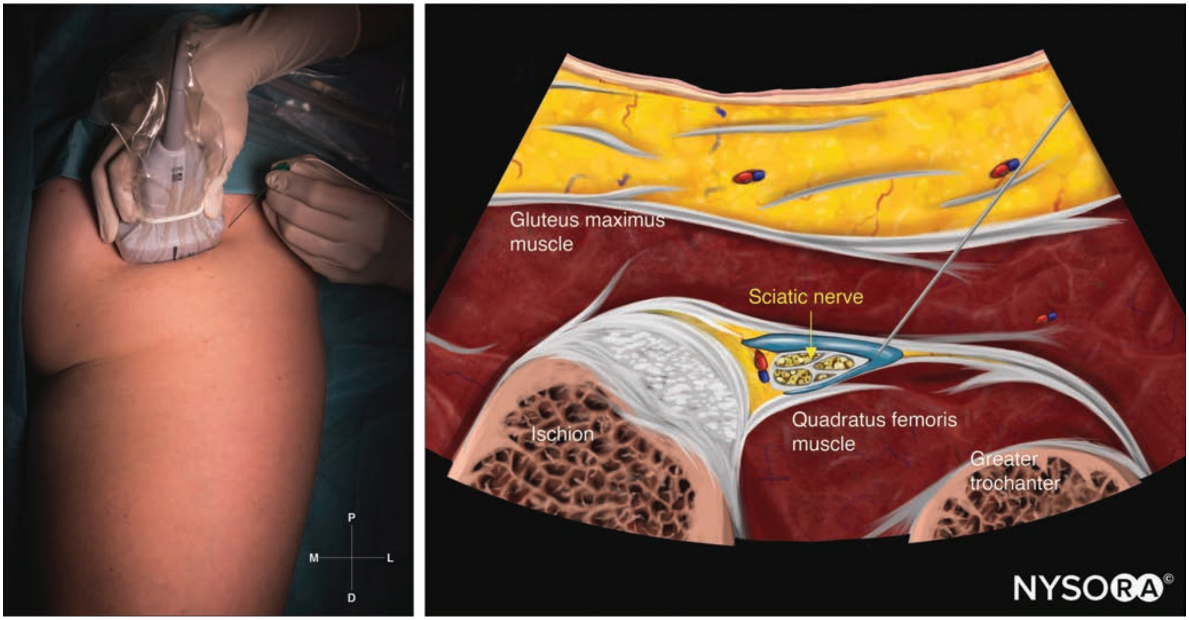


FIGURE 28-7. Reverse ultrasound anatomy of a proximal sciatic nerve block at the gluteal level with needle insertion in-plane.

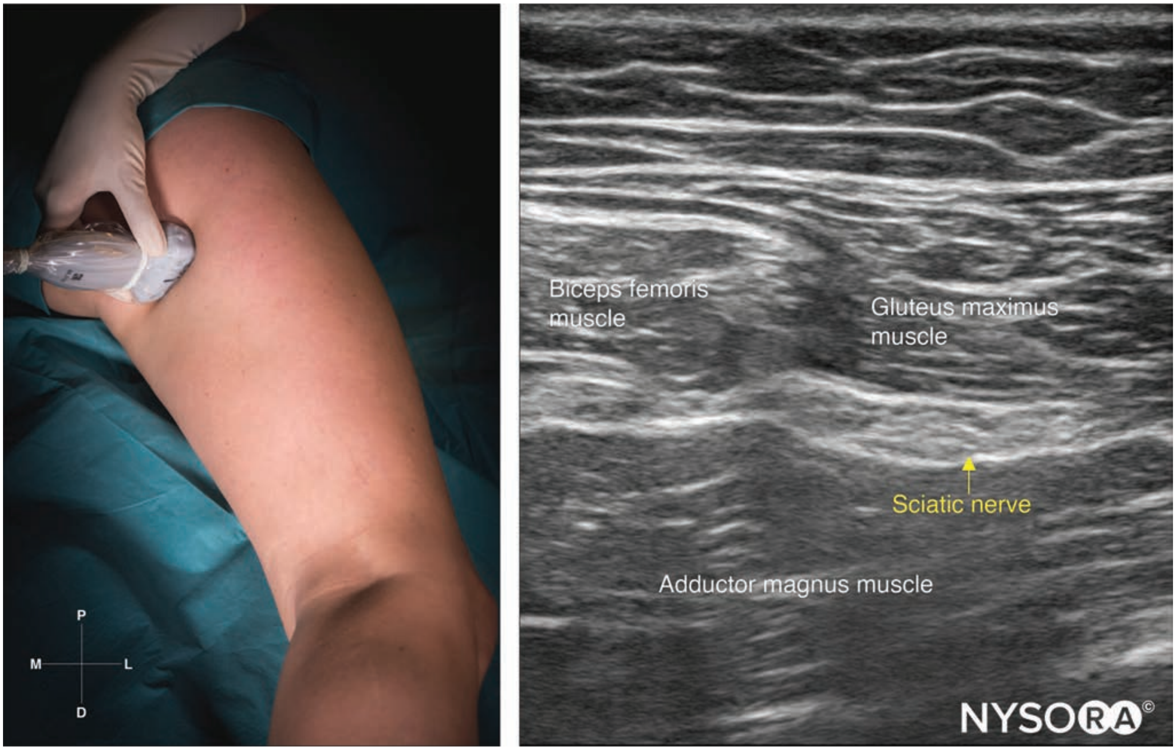


FIGURE 28-8. Transducer position and sonoanatomy of the sciatic nerve at the subgluteal level.

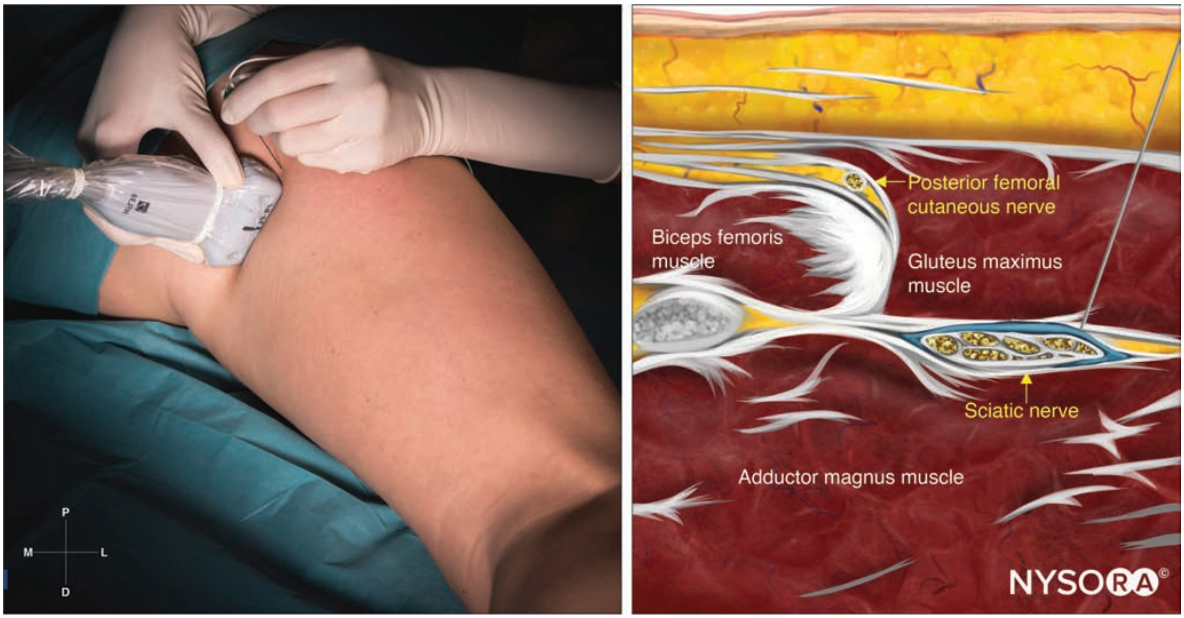
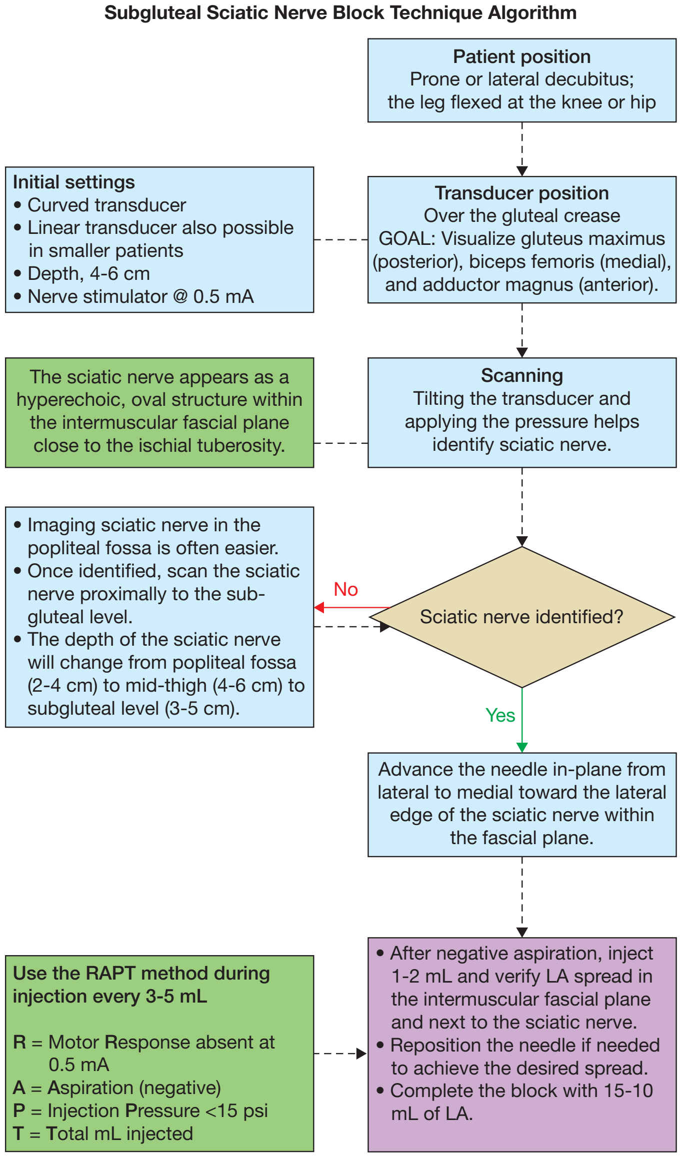


FIGURE 28-9. Reverse ultrasound anatomy of a proximal sciatic nerve block at the subgluteal level with needle insertion in-plane.

Flowchart



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29 Popliteal Sciatic Block

BLOCK AT A GLANCE

Block of the sciatic nerve at the popliteal fossa.

- **Indications:** Foot and ankle surgery; analgesia after major knee surgery
- **Goal:** Local anesthetic (LA) spread within the sciatic nerve sheath (Vloka's sheath) between tibial and common peroneal nerves
- **Local anesthetic volume:** 15 to 20 mL

General Considerations

The popliteal block is a commonly used anesthesia technique for foot and ankle procedures, particularly in the setting of ambulatory surgery. It provides a sensory-motor block of the lower extremity below the knee. The anesthetic effect is similar to that of the proximal sciatic nerve block but spares the hamstring muscles.

The introduction of ultrasound (US) and research on the functional anesthesia anatomy of the popliteal space resulted in substantial refinement and standardization of popliteal block techniques. In particular, US allows monitoring of the LA spread proximally/distally, and determination of the level where the sciatic nerve divides, as the optimal injection site. Monitoring of the spread of the injectate also allows for a reduction of the LA volume and dose required for a successful block. The popliteal block can be performed in different patient positions and with different needle insertion techniques to obtain consistent results.

Limitations

The popliteal block results in complete motor block below the knee limiting the ability to ambulate without assistive devices.

Anatomy

The sciatic nerve descends through the posterior compartment of the thigh into the popliteal fossa where its main components, the tibial nerve (TN) and the common peroneal nerve (CPN), diverge. The level at which the TN and CPN divergence occurs varies being approximately 2 to 4 cm proximal to the popliteal crease. From their origin in the pelvis, the TN and CPN are enveloped by a common connective tissue sheath that continues along the nerves individually after their separation (Figure 29-1). The nomenclature, consistency, and function of the connective tissue sheath around the sciatic nerve have been the subject of considerable debate. In this text, we opt to call it the *Vloka sheath* in recognition of Dr. Jerry Vloka's contribution to the understanding of the sciatic sheath and its role in sciatic popliteal block.

In the popliteal fossa, the nerve becomes relatively superficial as the biceps femoris tapers into a tendon. The TN continues its course along the posterior aspect of the popliteal vein and artery while the CPN courses laterally deep to the tendon of the biceps femoris muscle and descends around the head and neck of the fibula. The semimembranosus muscle and the tendon of the semitendinosus muscle are located at the medial side of the popliteal fossa.

Cross-Sectional Anatomy and Ultrasound View

At the popliteal crease, the popliteal artery is located at a depth of approximately 2 to 4 cm in between the condyles of the femur. The popliteal vein runs posterior to the artery and the TN is seen posterior (superficial) to the vein and slightly lateral. The CPN is located anterior (deep) to the tendon of the biceps femoris muscle (Figure 29-2A).

At the level of division of the sciatic nerve, the TN and the CPN are clearly seen as individual structures enclosed in the Vloka's sheath. The popliteal vessels are distanced from the sciatic nerve by the popliteal fat, the amount of which substantially varies among individuals (Figure 29-2B).

Proximal to the division of the sciatic nerve, the popliteal vessels lie deeper (anterior) and become more challenging to image. The sciatic nerve is deep (anterior) to the long head of the biceps femoris between the short head of the biceps on the lateral side and the semimembranosus muscle on the medial side (Figure 29-2C).

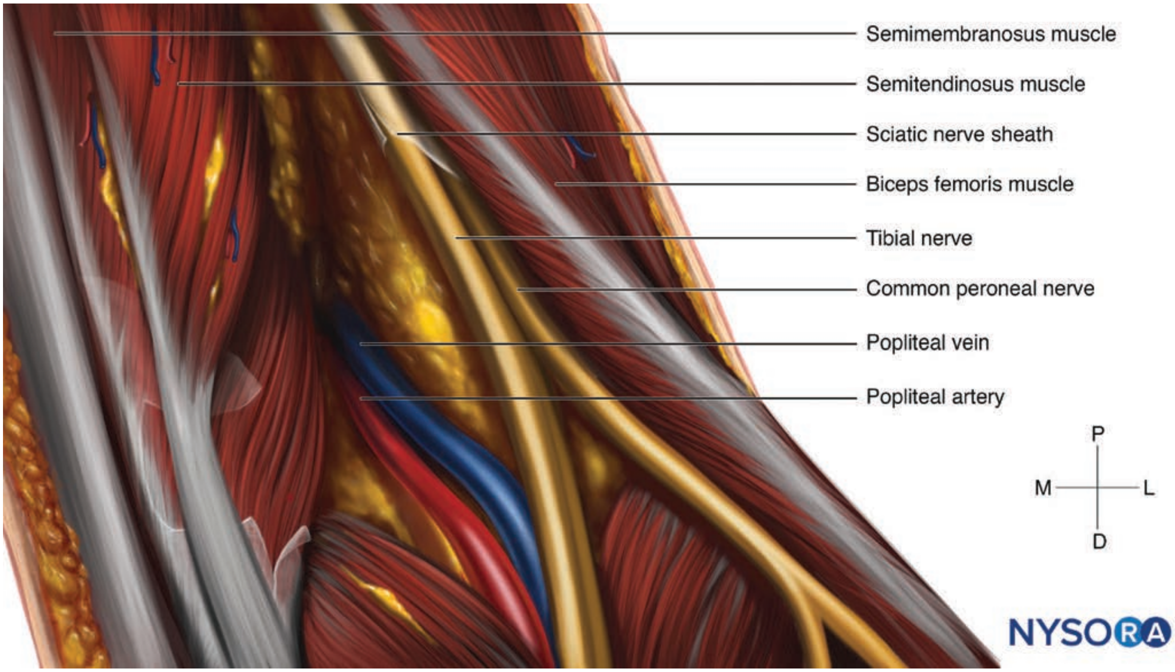


FIGURE 29-1. Anatomy of the sciatic nerve in the popliteal fossa.

Distribution of Anesthesia and Analgesia

The popliteal sciatic nerve block results in anesthesia of the lower extremity below the knee, except for the skin on the medial aspect of the leg down to the midfoot (supplied by the saphenous nerve, a branch of the femoral nerve). The motor block includes flexion and extension of the ankle and toes, thus foot drop is expected. The sensory fibers reaching the posterior aspect of the knee capsule are also anesthetized, but not the hamstring muscles, which are responsible for knee flexion. In combination with a saphenous nerve block, the popliteal block results in complete anesthesia of the leg and ankle (Figure 29-3).

Block Preparation

Equipment

- Transducer: High-frequency, linear transducer
- Needle: 50-mm, 22-gauge, short-bevel, stimulating needle (in most patients)

Local Anesthetic

Bupivacaine or ropivacaine 0.5% are used for anesthesia and analgesia for foot and ankle surgeries. Short-acting LAs, such as lidocaine 2%, are commonly used for short, less painful procedures. A volume of 10 to 20 mL is usually sufficient for an effective block.

Patient Positioning

The popliteal block can be performed with the patient in the lateral (oblique), prone, or supine position. In all positions, exposure of the calf and foot is required to be able to observe motor responses to nerve stimulation (Figure 29-4).

With the patient in the *lateral position*, the underlying, nonoperating leg is flexed, the upper leg is extended, and a footrest is placed underneath the ankle.

In the *prone position*, the patient's legs are almost fully extended and slightly abducted, with the foot resting on a small footrest. This way the hamstring tendons are relaxed, making transducer placement and manipulation easier.

Finally, if the procedure is to be performed supine, it must be ensured that there is sufficient space to accommodate the transducer below the knee and thigh. This can be accomplished by using an elevated footrest.

Technique

Initial Transducer Position

The transducer is placed in a transverse orientation 2 to 3 cm proximal to the crease over the medial border of the biceps femoris muscle. Alternatively, it can be positioned at the popliteal crease to identify the popliteal vessels and the TN posterior to them. In the latter case, the TN is traced proximally until it unites with the CPN into the common sciatic (Vloka) nerve sheath (Figure 29-5).

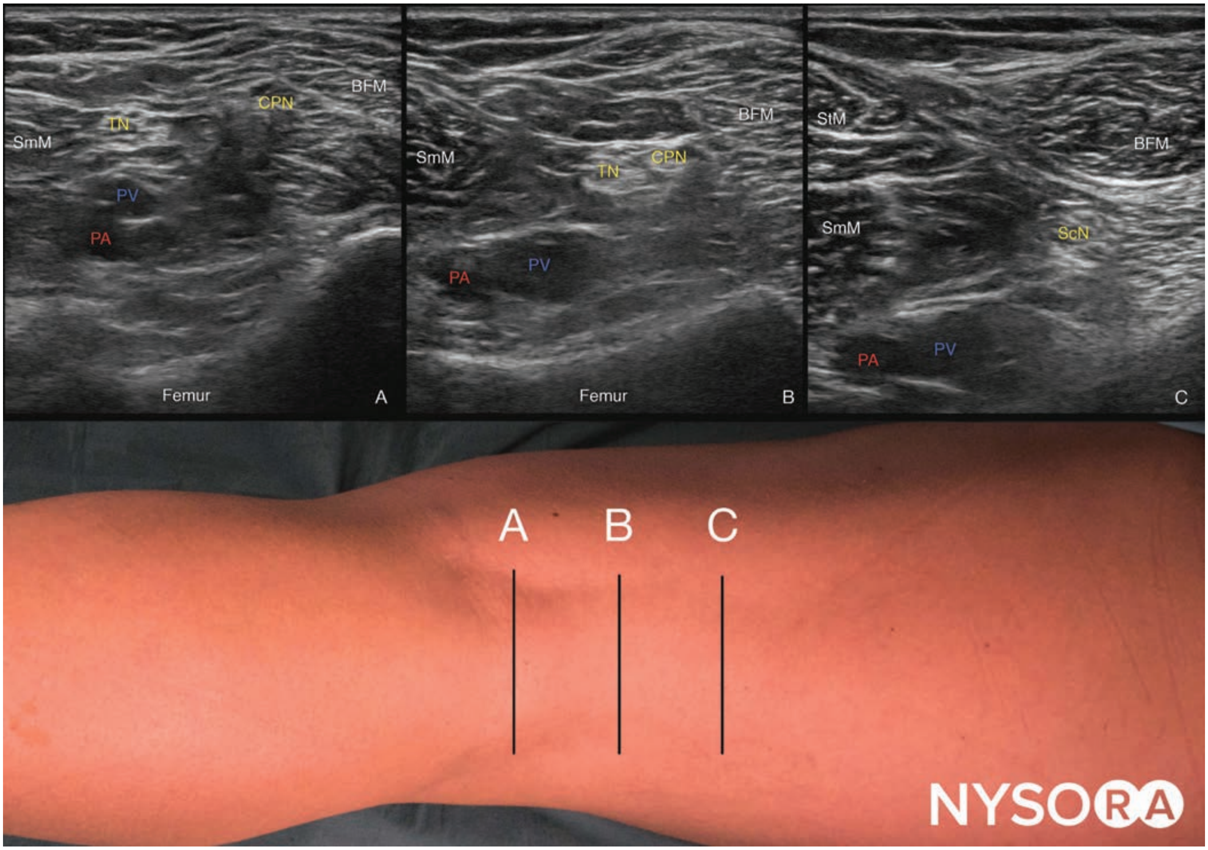


FIGURE 29-2. Transducer position and sonoanatomy of the sciatic nerve. (A) At the popliteal crease were tibial nerves (TNs) and common peroneal nerve (CPNs) are separated; (B) at the level of the division, and (C) proximal to the division. BFM, biceps femoris muscle; ScN, sciatic nerve; TN, tibial nerve; CPN, common peroneal nerve; PV, popliteal vein; PA, popliteal artery; SmM, semimembranosus muscle; StM, semitendinosus muscle

Scanning Technique

The stock maneuvers to visualize the sciatic nerve are transducer pressure and tilt caudally to pick up the hyperechoic round shape of the nerve(s). The level of bifurcation can then be found by sliding the transducer proximally and distally while adjusting the tilt accordingly. The optimal site of injection is where the nerves just start diverging but are still together in the common Vloka's sheath. By adjusting the pressure on the medial or lateral side of the transducer (heeling maneuver), the relative position of the two nerves can be optimized from horizontal to oblique for the out-of-plane and in-plane approaches, respectively.

Needle Insertion

Using an in-plane or out-of-plane technique, insert the needle and advance the tip into the sciatic nerve sheath between the TN and CPN.

- **In-plane lateral approach:** The needle is inserted through the biceps femoris muscle and its fasciae toward the space between the TN and CPN (Figure 29-6). As the needle enters the sheath, a loss of resistance is felt and can be detected by the US as an indentation, followed by snapback.
- **Out-of-plane:** The needle is inserted from posterior and directed into the sheath, as described above. This approach is associated with less discomfort as the needle trajectory through the skin and adipose tissue, rather than through the muscle, is shorter (Figure 29-7).

Nerve stimulation may result in flexion or extension of the ankle or toes if the tip contacts the TN or CPN.

Local Anesthetic Distribution

Injection of 1 to 2 mL of LA should result in separation of the TN and CPN within Vloka's sheath. A correct injection is ensured when the spread of the LA extends within the sheath several centimeters proximally to the site of injection, as well as distally around both divisions of the nerve (Figure 29-8).

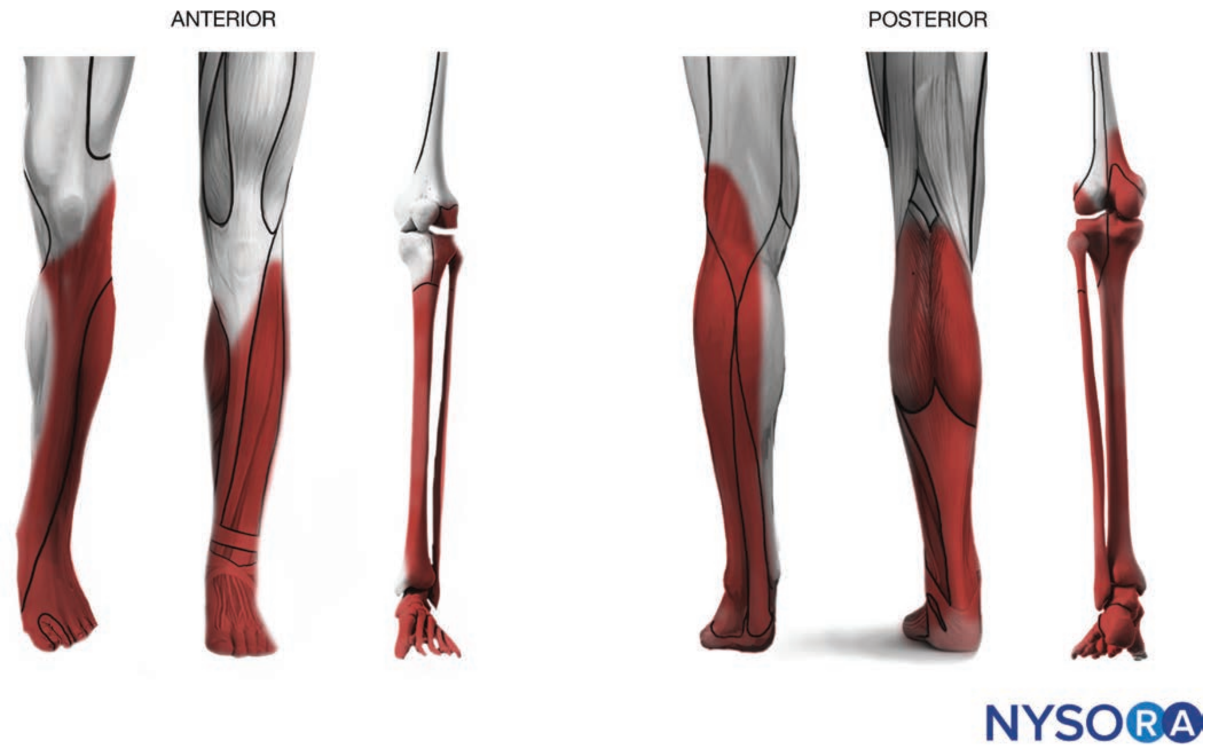


FIGURE 29-3. Distribution of anesthesia with a popliteal block. From left to right: dermatomes, myotomes, and osteotomes.

FIGURE 29-4. Patient positions for various approaches to popliteal block: (A) lateral, (B) prone, and (C) supine with an elevated footrest.

Continuous Ultrasound-Guided Popliteal Sciatic Block

The goal of the continuous popliteal sciatic block is to place the catheter into the sciatic nerve sheath in the popliteal fossa.

The needle is inserted in-plane (or out-of-plane) from lateral to medial and advanced to the space between the TN and CPN. The correct placement of the needle can be confirmed by injecting 4 to 5 mL of LA into the common nerve sheath. This LA injection distends the sheath and

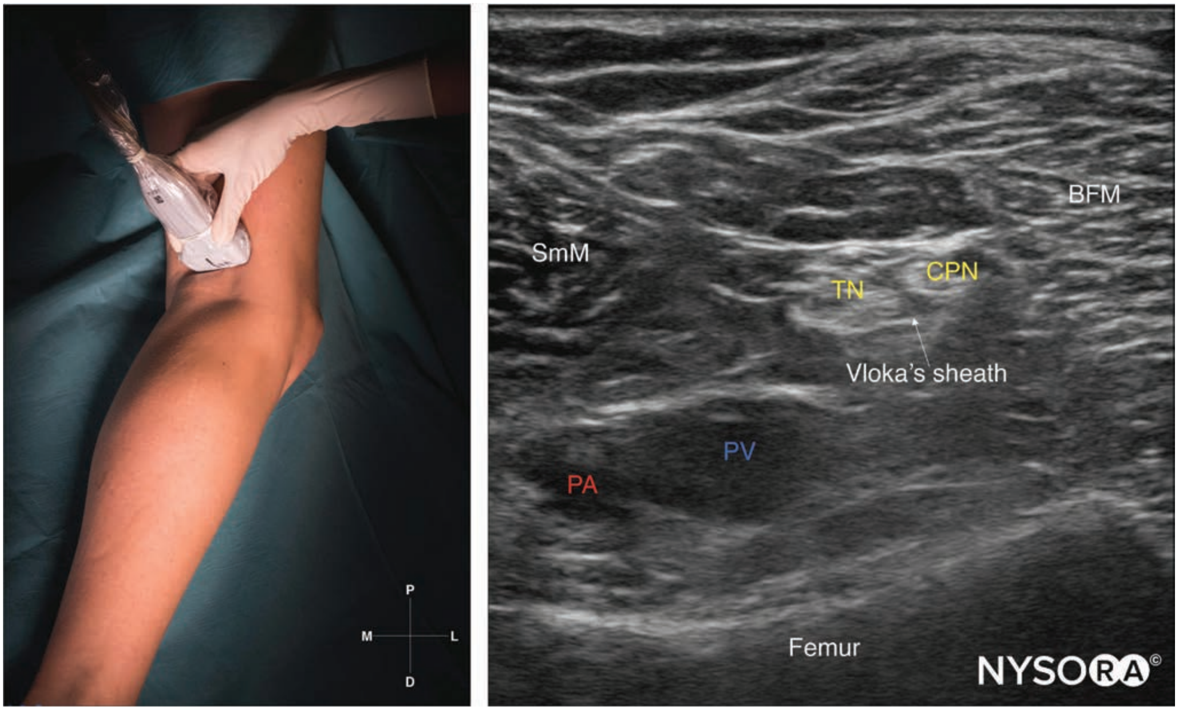


FIGURE 29-5. Transducer position and sonoanatomy of the sciatic nerve proximal to the popliteal fossa crease. TN, tibial nerve; CPN, common peroneal nerve; PA, popliteal artery; PV, popliteal vein; SmM, semimembranosus muscle; BFM, biceps femoris muscle.

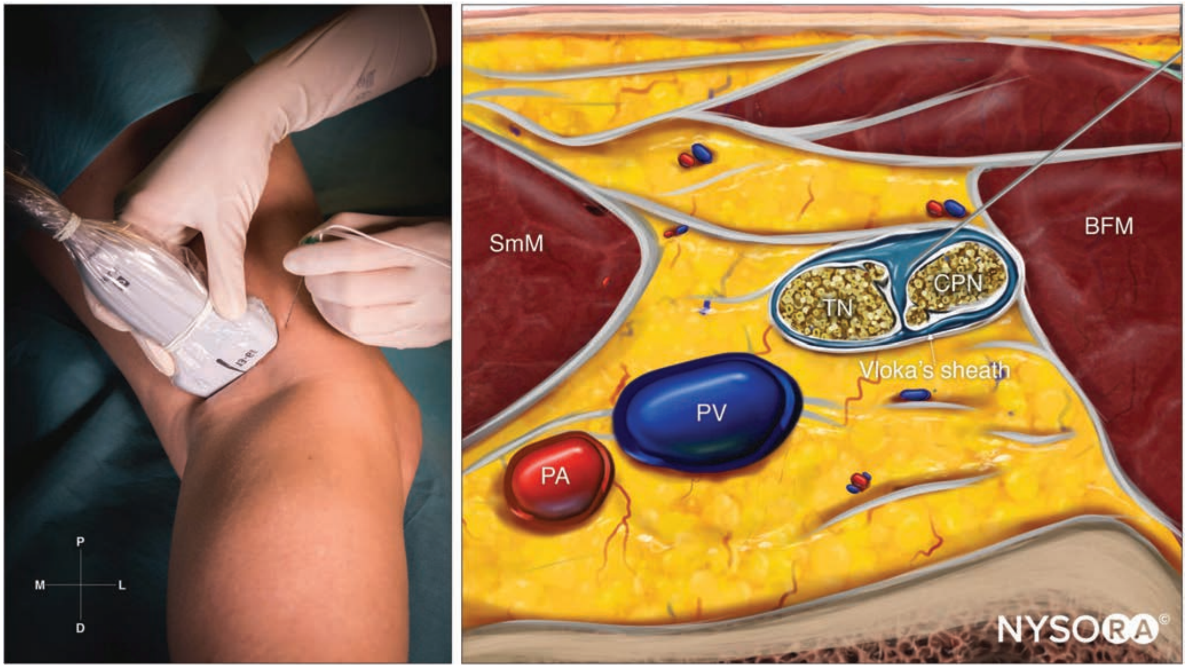


FIGURE 29-6. Reverse ultrasound anatomy of a popliteal block with needle insertion in-plane. TN, tibial nerve; CPN, common peroneal nerve; PA, popliteal artery; PV, popliteal vein; SmM, semimembranosus muscle; BFM, biceps femoris muscle.

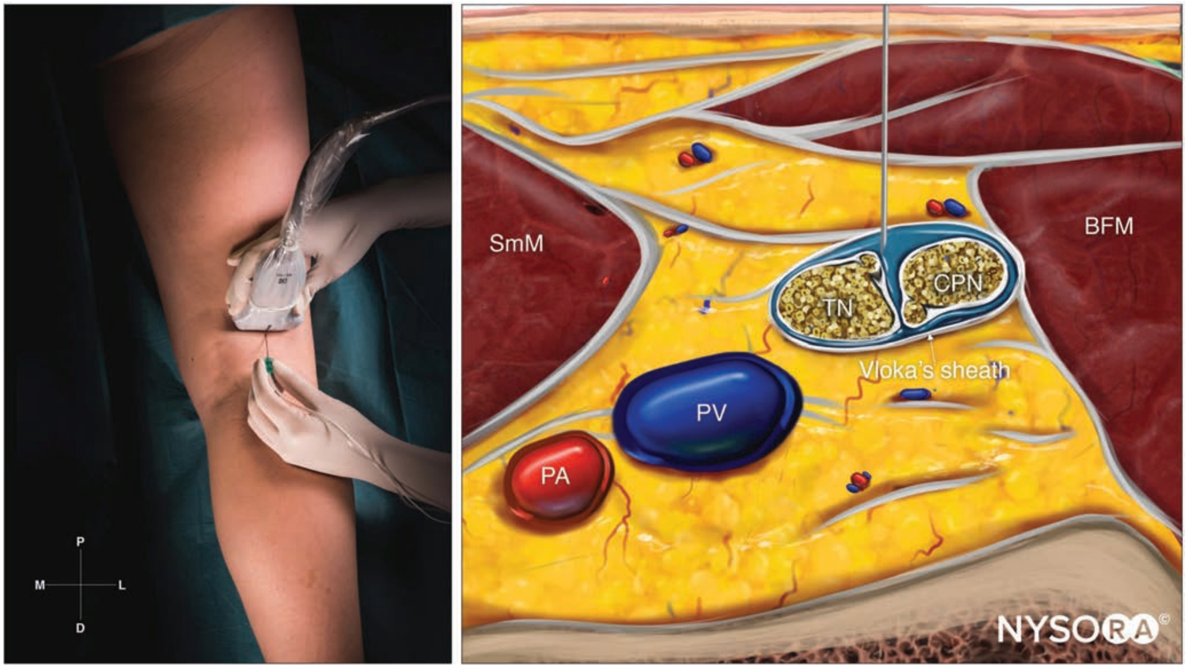


FIGURE 29-7. Reverse ultrasound anatomy of a popliteal block with needle insertion out-of-plane. TN, tibial nerve; CPN, common peroneal nerve; PA, popliteal artery; PV, popliteal vein; SmM, semimembranosus muscle; BFM, biceps femoris muscle.

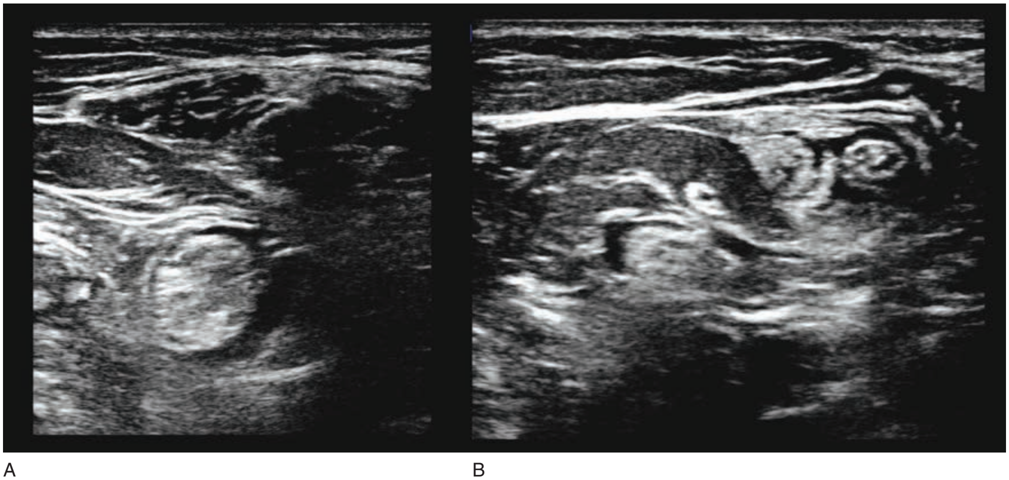


FIGURE 29-8. Adequate local anesthetic distribution after a popliteal block. (A) Proximally around the sciatic nerve. (B) Distally around both the TN and the CPN.

facilitates the advancement of the catheter. Maintaining the needle in a steady position inside the sheath, the catheter is advanced 3 to 5 cm and the needle is then withdrawn. Injection through the catheter should result in the extension of the spread into the space containing the two nerves proximally and distally.

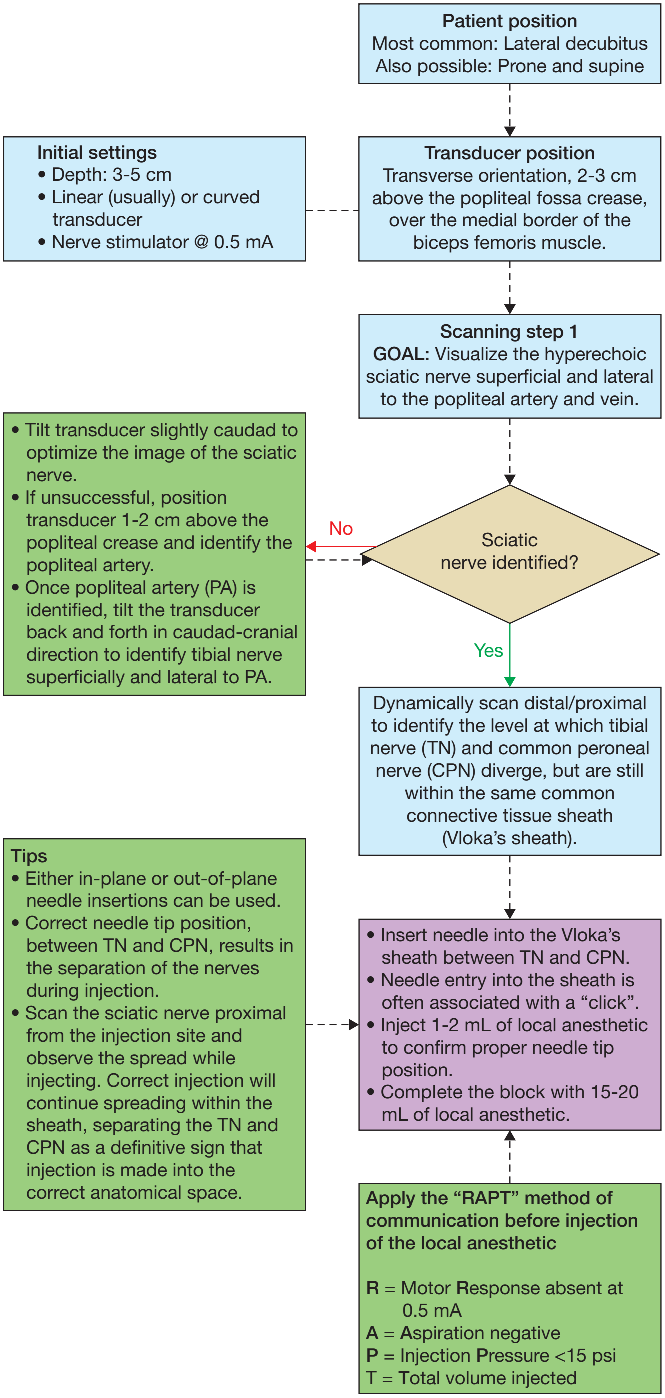
The lateral in-plane approach may have some advantages over the prone approach with regard to catheter placement. Insertion of the catheter through the biceps femoris muscle may stabilize the catheter and decrease the chance of dislodgement, compared with the subcutaneous tissue of the popliteal fossa in the prone approach. When the knee is flexed and extended, the side of the thigh is less mobile than the back of the knee. Finally, access to the catheter site is more convenient with the lateral approach compared with the prone approach. A common starting infusion regimen is to infuse ropivacaine 0.2% at 5 mL/hour with a patient-delivered bolus of 5 mL every 60 minutes.

Problem-Solving Tips

- To facilitate the visualization of the popliteal vessels, apply color Doppler and adjust the tilt of the transducer. The compression of the calf will also help to identify the popliteal vein by increasing the blood flow.
- Dorso-plantar flexion of the ankle may help as it makes the nerve rotate in relation to its surroundings.

Flowchart

Ultrasound-guided Popliteal Sciatic Block Technique Algorithm



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30 Genicular Nerves Block

BLOCK AT A GLANCE

Infiltration around the sensory branches that provide innervation to the knee joint (genicular nerves) before they enter the knee capsule.

- **Indications:** Chronic knee pain, total knee arthroplasty, or procedures associated with moderate to severe postoperative knee pain
- **Goal:** Local anesthetic spread next to the genicular arteries (if visible) or at the junction of the epiphysis and diaphysis of the femur and tibia
- **Local anesthetic volume:** 4 to 5 mL per nerve

General Considerations

The genicular nerve block and radiofrequency ablation therapy were initially described to treat severe chronic pain of the knee. An extended version of the block technique under ultrasound (US) guidance was recently introduced to provide analgesia after knee surgery. The infiltration targets only the sensory branches to the knee joint, preserving quadriceps muscle strength. Thus, this novel analgesic technique could be used as an alternative when the femoral nerve and adductor canal blocks are not indicated or not desirable.

The first reported block of genicular nerves under fluoroscopy guidance was based on bony landmarks. The introduction of US allows for easy recognition of the same landmarks and provides additional visualization of the soft tissues and vessels needed to identify the injection site. The available data is still limited; however, case series show promising results of genicular nerve block in the perioperative setting. Clinical trials are currently ongoing to determine the efficacy of this novel technique to treat acute pain after total knee replacement.

Limitations

The genicular nerves vary in number and trajectory and, because of their small size, they are not visualized with the available US technology. Genicular nerve blocks are based on US landmarks, which may result in inconsistent analgesia, particularly if a low volume of local anesthetic (LA) is used.

Specific Risks

The proximity of the inferolateral genicular nerve (ILGN) to the common peroneal nerve (CPN) is a risk factor for unintended CPN block resulting in foot drop. Thus this nerve is spared if denervation is planned to treat chronic pain. Vascular or intraarticular punctures are other potential risks.

Anatomy

The innervation of the knee is complex, with branches originating from femoral, obturator, and sciatic nerves (Figure 30-1). The interindividual variability explains the discrepancy in the literature over the nomenclature and the origin of the genicular nerves.

To facilitate understanding of knee innervation, most authors divide the knee into an anterior and posterior compartment, and then further divide the anterior compartment into four quadrants. For the purpose of the technique description, the genicular nerves are called the superolateral (SLGN), superomedial (SMGN), inferolateral (ILGN), and inferomedial (IMGN) genicular nerves, which innervate primarily each corresponding quadrant. Several cadaver studies also show a contribution from other branches such as the recurrent peroneal nerve, the nerve to the vastus medialis, intermediate, lateralis, and the infrapatellar branch.

- The SLGN courses around the femur shaft to pass between the vastus lateralis and the lateral epicondyle. It accompanies the superior lateral genicular artery.

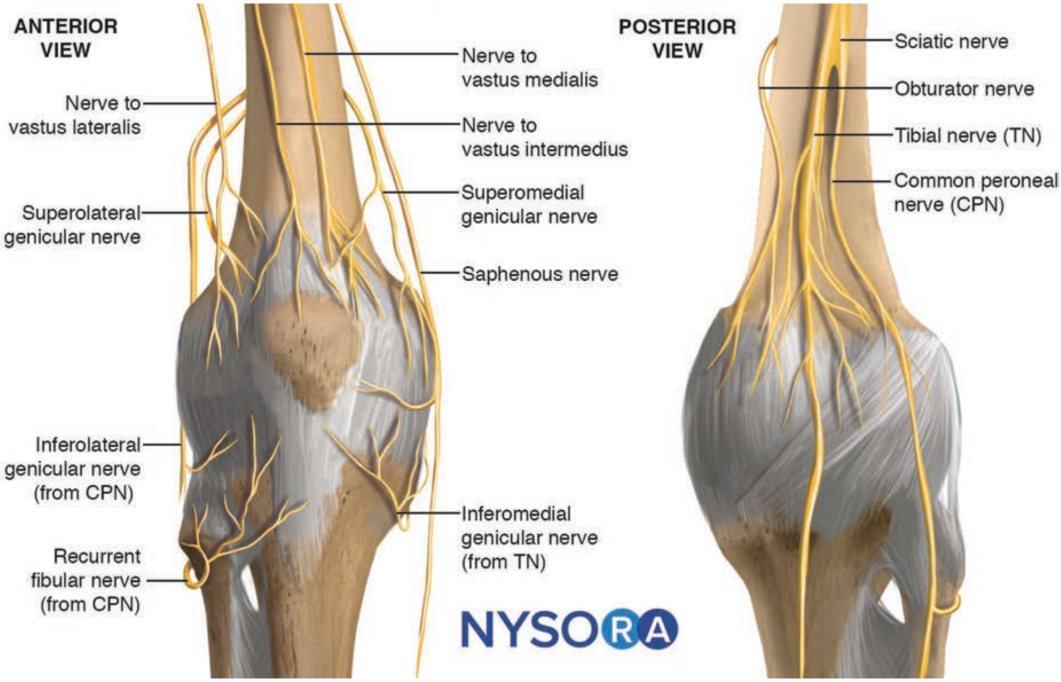


FIGURE 30-1. Innervation of the knee. The origin of the superomedial and superolateral genicular nerves (from the sciatic nerve or from the femoral nerve) is controversial.

- The SMGN courses around the femur shaft, following the superior medial genicular artery, to pass between the adductor magnus tendon and the medial epicondyle below the vastus medialis.
- The ILGN courses around the tibial lateral epicondyle deep to the lateral collateral ligament, following the inferior lateral genicular artery, superior of the fibula head.
- The IMGN courses horizontally below the medial collateral ligament between the tibial medial epicondyle and the insertion of the collateral ligament. It accompanies the inferior medial genicular artery.
- The recurrent peroneal nerve originates in the inferior popliteal region from the common peroneal nerve and courses horizontally around the fibula to pass just inferior of the fibula head and travel superior to the anterolateral tibial epicondyle. It accompanies the recurrent tibial artery.

Ultrasound View

The relative position of the genicular nerves to bony landmarks at the level of the knee seems to be consistent according to the studies performed in cadavers, providing a reliable anatomic basis for an ultrasound-guided block. The US landmarks are the osteo-muscular planes at the level of the metaphysis (the junction between the epiphysis and diaphysis) of the femur and tibia. Additional landmarks are the corresponding arteries, which follow the same path as the nerves and the collateral ligaments (Figure 30-2).

Distribution of Analgesia

The genicular nerve block is a motor-sparing technique that anesthetizes the sensory terminal branches innervating the knee joint, resulting in anesthesia of the anterior compartment of the knee. The distribution of anesthesia of each nerve is mostly in the corresponding quadrant.

Block Preparation

Equipment

- Transducer: High-frequency, linear transducer
- Needle: 50-mm, 22-gauge, short-bevel needle

Local Anesthetic

Long-lasting LAs such as bupivacaine or ropivacaine (0.25-0.5%) in a volume of 4 to 5 mL per nerve are suggested.

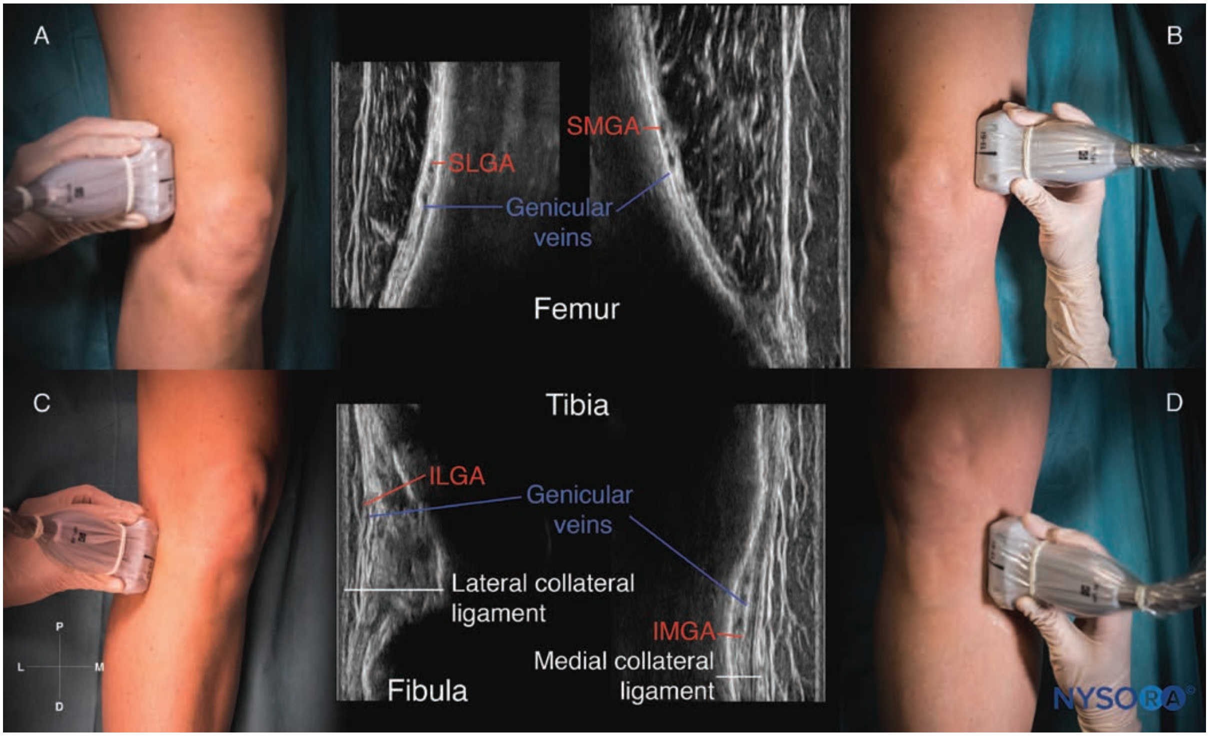


FIGURE 30-2. Sonoanatomy of the genicular nerves in a coronal plane. SLGA, superolateral genicular artery; SMGA, superomedial genicular artery; ILGA, inferolateral genicular artery; IMGA, inferomedial genicular artery. (A) Transducer position and sonoanatomy of the superomedial genicular nerve. (B) Transducer position and sonoanatomy of the inferomedial genicular nerve. (C) Transducer position and sonoanatomy of the superolateral genicular nerve. (D) Transducer position and sonoanatomy of the inferolateral genicular nerve.

Patient Positioning

The patient is placed in a supine position with the knee slightly flexed by placing a pillow in the popliteal fossa (Figure 30-3).

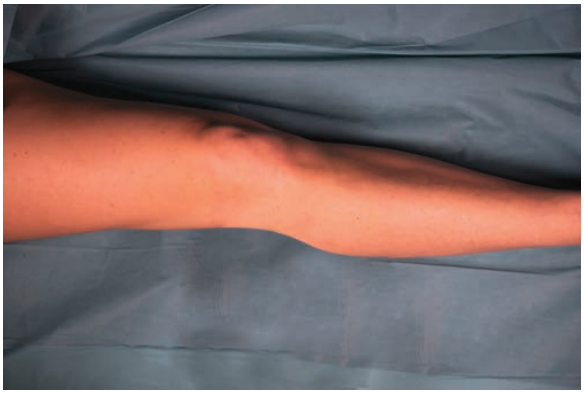


FIGURE 30-3. Patient position to perform a genicular nerve block.

Technique

Initial Transducer Position and Scanning Technique

- SLGN: The transducer is placed in a coronal orientation over the lateral epicondyle of the femur and then moved proximally to visualize the metaphysis of the bone. The superolateral genicular artery may be seen between the deep fascia of the vastus lateralis and the femur at this level (see Figure 30-2A).
- SMGN: The transducer is placed in a coronal orientation over the medial epicondyle of the femur (see Figure 30-2B). The transducer is moved slightly proximally to visualize the metaphysis of the bone just anterior to the adductor tubercle. The SMG artery may be seen at this level between the deep fascia of the vastus medialis and the femur.
- ILGN: The transducer is placed in a coronal orientation over the lateral side of the distal knee. After identifying the lateral epicondyle of the tibia, the transducer is moved distally to visualize the head of the fibula. The inferolateral genicular artery may be seen between

the collateral ligament and the lateral condyle of the tibia (see Figure 30-2C).

- IMGN: The transducer is placed in a coronal orientation over the medial condyle of the tibia and moved distally to visualize the metaphysis of the bone. At this level, the inferomedial genicular artery is seen beneath the medial collateral ligament (see Figure 30-2D).
- Additionally, the recurrent peroneal nerve can also be blocked: the transducer is placed in a coronal orientation over the anterolateral side of the distal knee to visualize the junction of the tibial lateral epiphysis and diaphysis, anterior of the fibula. The recurrent tibial artery is visualized superficial to the bone.

Needle Approach and Trajectory

Once the injection site has been identified, the needle tip is advanced next to the vessel (if seen) until bony contact is felt using an in-plane or out-of-plane approach. Alternatively, the transducer can be rotated in a transverse orientation and the needle tip redirected toward the bone surface. After confirming the correct position, the rest of the LA is injected (**Figure 30-4**).

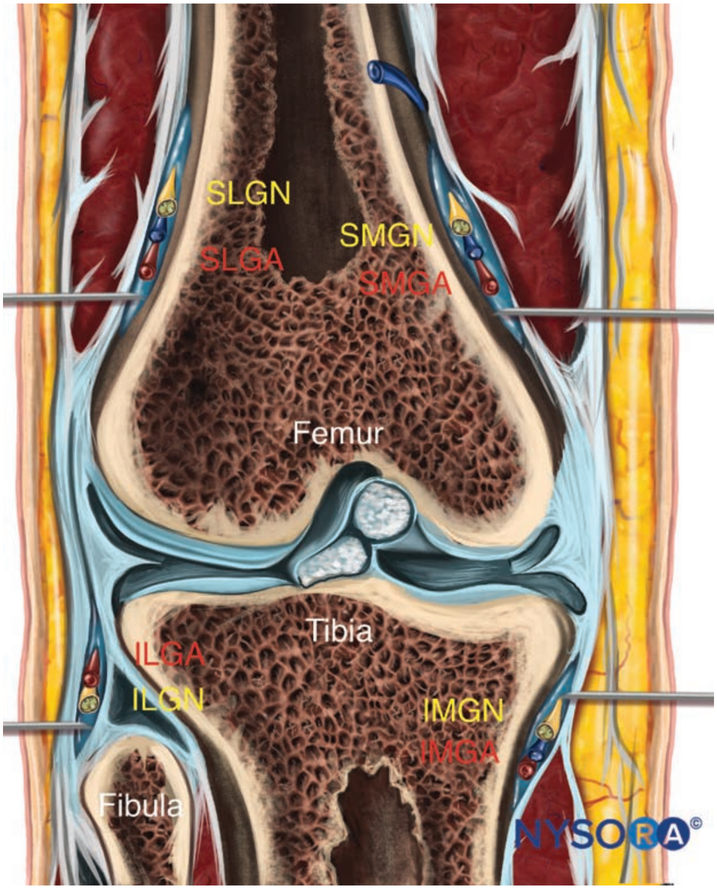
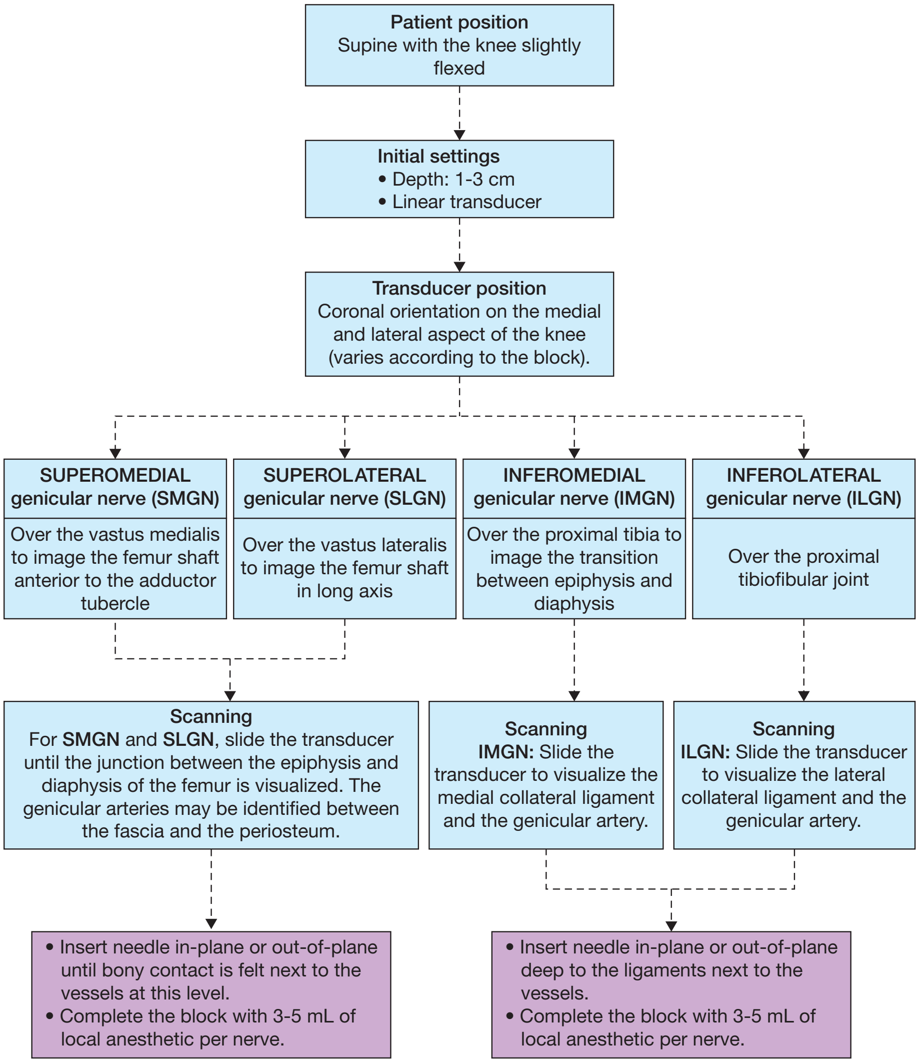


FIGURE 30-4. Reverse ultrasound anatomy of the genicular nerves showing needle insertion and distribution of the local anesthetic. SLGN, superolateral genicular nerve, and artery; SMGN, superomedial genicular nerve, and artery; ILGN, inferolateral genicular nerve, and artery; IMGN, inferomedial genicular nerve, and artery.

Flowchart

Genicular Nerves Blocks Technique Algorithm



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31 iPACK Block

BLOCK AT A GLANCE

Infiltration of the local anesthetic into the space between the **p**opliteal **a**rtery and the posterior **c**apsule of the **k**nee (iPACK).

- **Indications:** Analgesia after knee arthroplasty, cruciate ligament repair, and procedures involving the posterior aspect of the knee
- **Goal:** Local anesthetic infiltration over the posterior aspect of the femur underneath the popliteal artery
- **Local anesthetic volume:** 15 to 20 mL

General Considerations

Postoperative pain following total knee arthroplasty (TKA) is mediated by branches of the obturator (medial), femoral (anterior), and sciatic nerves (posterior). While the sciatic nerve block results in the best analgesia for the posterior aspect of the knee, motor weakness of the lower extremity preventing early rehabilitation and masking intraoperative common peroneal nerve (CPN) injury discourage the use of this analgesic modality. A muscle strength-sparing infiltration into the interspace between the popliteal artery and the posterior capsule of the knee (iPACK) is an alternative analgesic supplement to the femoral or adductor canal blocks for posterior knee pain. The iPACK block targets the sensory articular branches of the sciatic nerve while sparing the motor branches of the tibial nerve (TN) and CPN, avoiding the foot drop that occurs with the sciatic nerve block.

Limitations and Specific Risks

The iPACK block provides analgesia limited to the posterior aspect of the knee capsule, and therefore it should be viewed as a supplement to the femoral and/or adductor canal block. Additionally, ultrasound (US) imaging of the popliteal vessels and sciatic nerve to avoid their injury during iPACK can be difficult in obese patients.

The specific risks related to this technique are vascular injection or inadvertent nerve injury due to the proximity of the popliteal vessels and the sciatic nerve to the posterior knee capsule, where the needle passes during the infiltration. With the medial-lateral needle insertion technique, the saphenous nerve may be on the way and can be injured. Routine ultrasonographic identification of the nerve is recommended to determine the safe needle insertion site and pathway.

Anatomy

Innervation of the posterior knee is provided by articular branches that originate from the TN, CPN, sciatic, and the posterior division of the obturator nerve (Figure 31-1).

Articular branches from the TN are the main source of innervation to the posterior knee joint capsule. They originate either proximal or distal to the superior border of the medial femoral condyle and course transversely to the intercondylar region, where they further branch.

The articular branches from the sciatic and/or the CPN further divide into anterior and posterior branches to innervate the anterolateral and posterolateral capsule, respectively.

Finally, the articular branch from the posterior obturator nerve courses through the adductor hiatus, together with the femoral artery and vein, and enters the popliteal fossa. At the level of the femoral condyles, it divides into two to three terminal branches that supply the superomedial aspect of the posterior capsule.

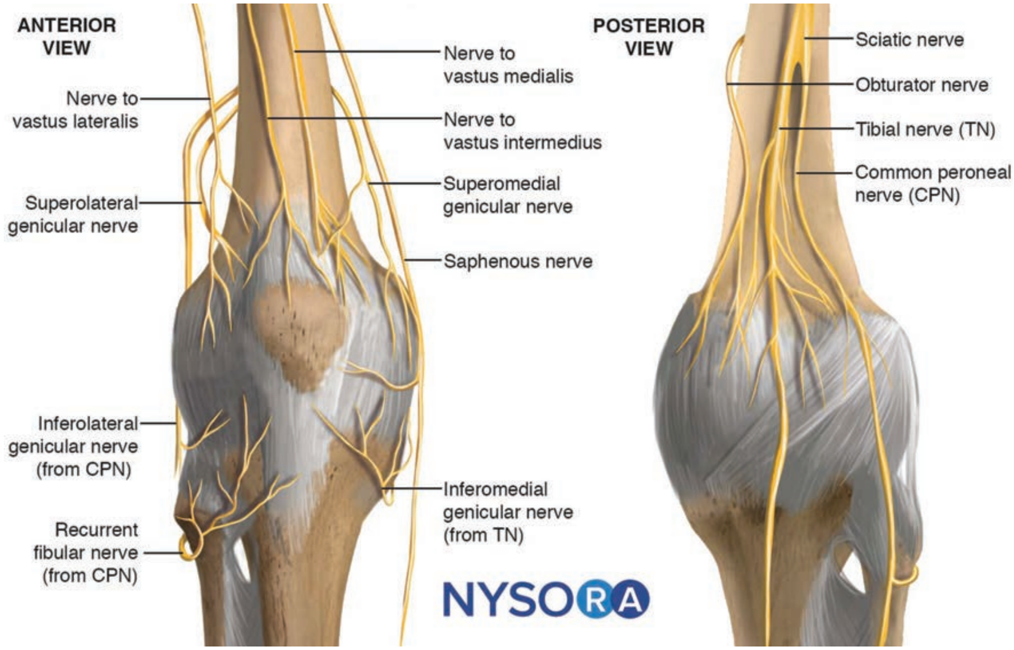


FIGURE 31-1. Anatomy of the anterior and posterior knee joint innervation.

Cross-Sectional Anatomy and Ultrasound View

At the popliteal fossa, proximally to the femur condyles, the flat surface of the femur is separated from the popliteal artery and vein by fat and loose tissue, where the sensory branches and vessels travel to supply the posterior capsule (Figure 31-2).

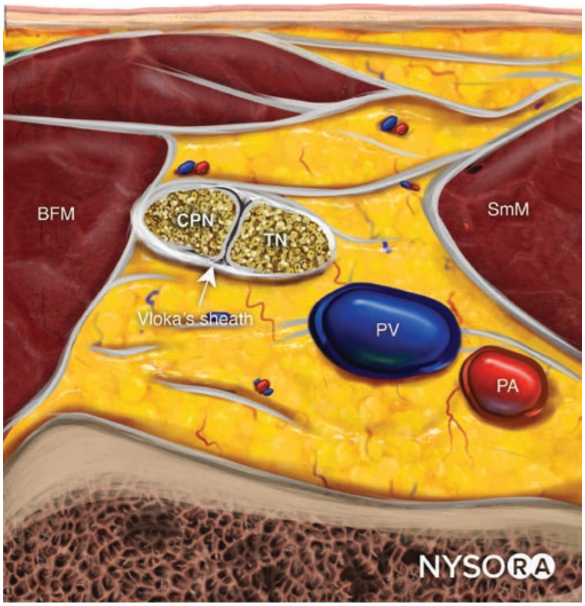


FIGURE 31-2. iPACK block ultrasound anatomy. PA, popliteal artery; PV, popliteal vein; SmM, semimembranosus muscle; StM, semitendinosus muscle; TN, tibial nerve; CPN, common peroneal nerve.

Distribution of Analgesia

The iPACK block is a motor-sparing technique that anesthetizes the small articular sensory nerves from the popliteal plexus resulting in analgesia of the posterior capsule of the knee. Cadaveric studies have found the spread of the injectate anteriorly suggesting that the technique may, in some cases, supply the anterolateral and anteromedial knee joint capsule.

Block Preparation

Equipment

- Transducer: Low-frequency curved or high-frequency linear transducer
- Needle: 80- to 100-mm, 20- to 22-gauge, short-bevel, insulated stimulating needle

Local Anesthetic

Optimal concentration and volume of local anesthetics (LAs) to perform an iPACK block have not been determined. Bupivacaine or ropivacaine in concentrations of 0.2% to 0.5% appear to be commonly used based on the information published.

Patient Positioning

The iPACK block can be performed with the patient in a supine position with the knee flexed or elevated on a footrest, or in a prone position (Figure 31-3).

Technique

Landmarks and Initial Transducer Position

The transducer is placed in a transverse orientation over the medial aspect of the thigh, approximately 2 cm above the patella. The goal is to identify the space between the femoral shaft and the popliteal artery. At this location, the TN and CPN can also be visualized deep and posterior to the popliteal vessels. The vastus medialis and sartorius muscles are located medially and the semimembranosus muscle posteriorly (Figure 31-4).

Scanning Technique

The iPACK block is performed proximal to the popliteal fossa crease. If the femoral condyles are initially visualized, slide the transducer proximally until the condyles disappear and the distal femoral shaft is identified.

Needle Approach and Trajectory

The needle is inserted in-plane, from the anteromedial aspect of the knee, toward the space between the popliteal artery and the femur. Normally, needle insertion in a steep angle is required to stay close to the femoral shaft and avoid puncture of the nerves and vessels. Once the posterior aspect of the popliteal artery is reached, inject 2 mL of the LA to confirm the proper position of the needle by observing how the space between the artery and the femur shaft is filled (Figure 31-5).

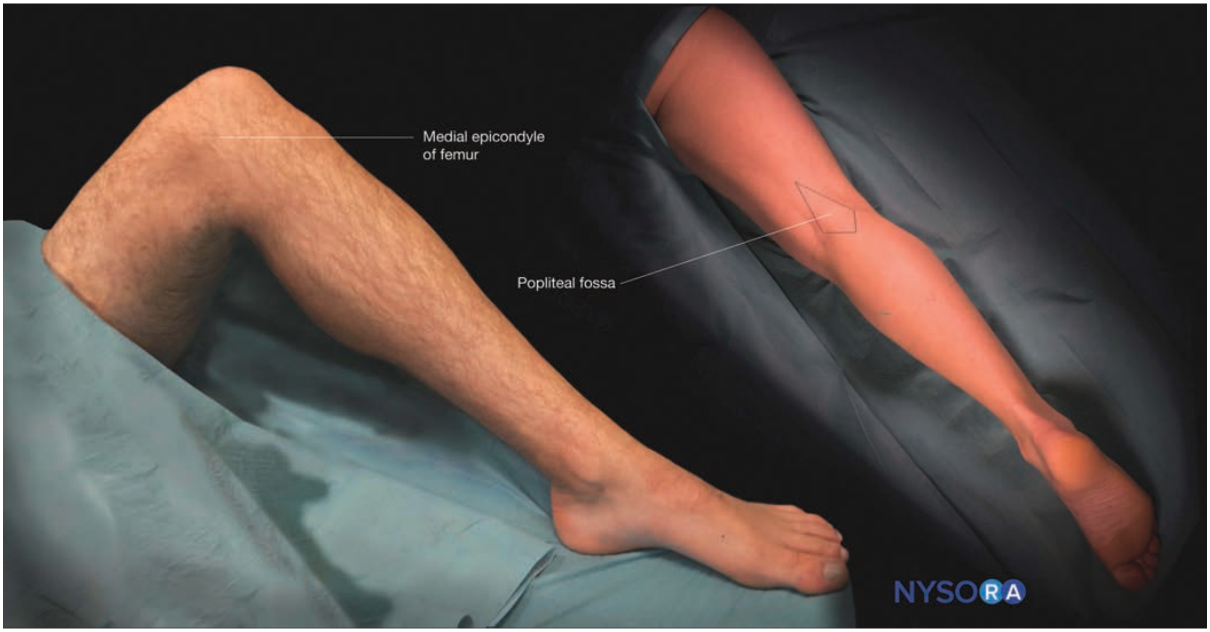


FIGURE 31-3. Patient position for different approaches for an iPACK block.

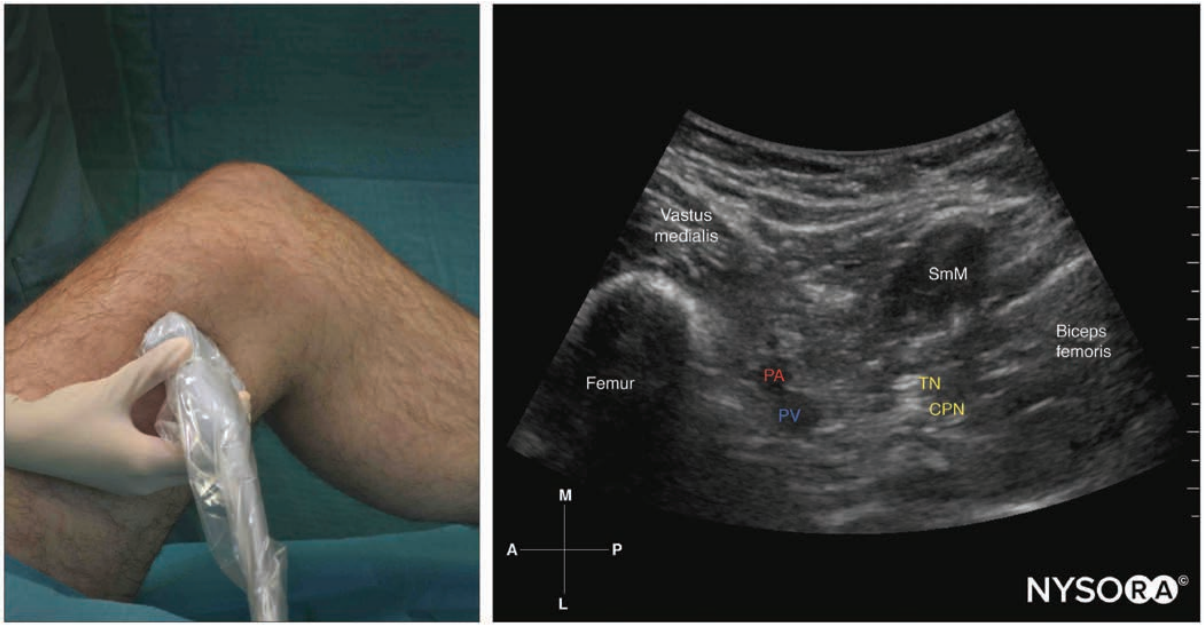


FIGURE 31-4. Transducer position and sonoanatomy for an iPACK block. SmM, semimembranosus muscle; StM, semitendinosus muscle; PA, popliteal artery; PV, popliteal vein; TN, tibial nerve; CPN, common peroneal nerve.

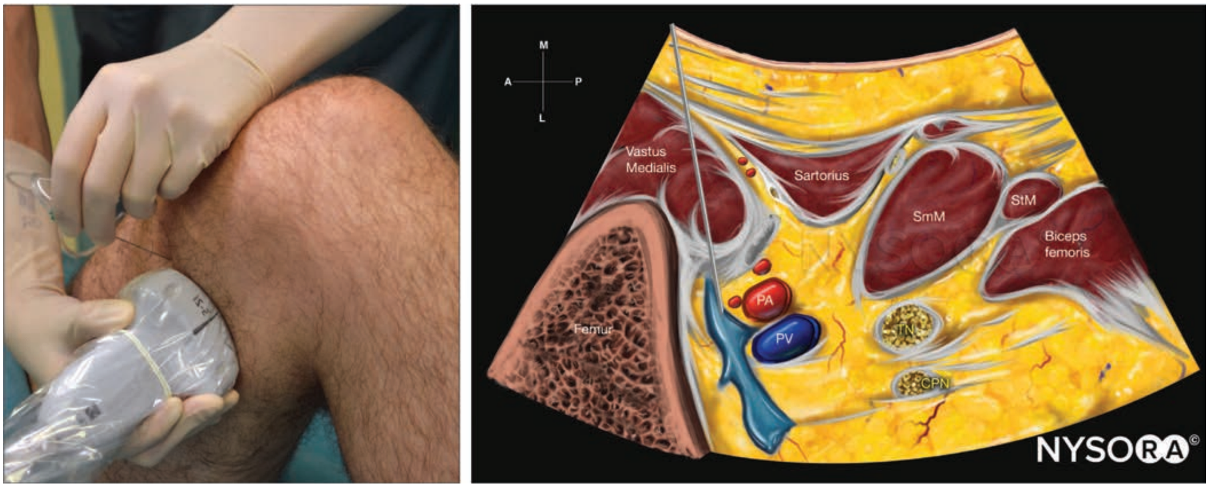


FIGURE 31-5. iPACK block reverse ultrasound anatomy with needle insertion in-plane. SmM, semimembranosus muscle; StM, semitendinosus muscle; PA, popliteal artery; PV, popliteal vein; TN, tibial nerve; CPN, common peroneal nerve.

Alternative Approach

Place the transducer over the popliteal fossa crease in order to visualize the TN, CPN, popliteal artery, and femoral condyles. From this location, slide the transducer proximally until the flat posterior aspect of the shaft of the femur becomes visible. When the space between the popliteal artery and femur shaft is clearly identified, the needle is inserted in-plane from the medial (or lateral) side, and advanced between the popliteal artery and the femur. The injection proceeds as described above (Figure 31-6).

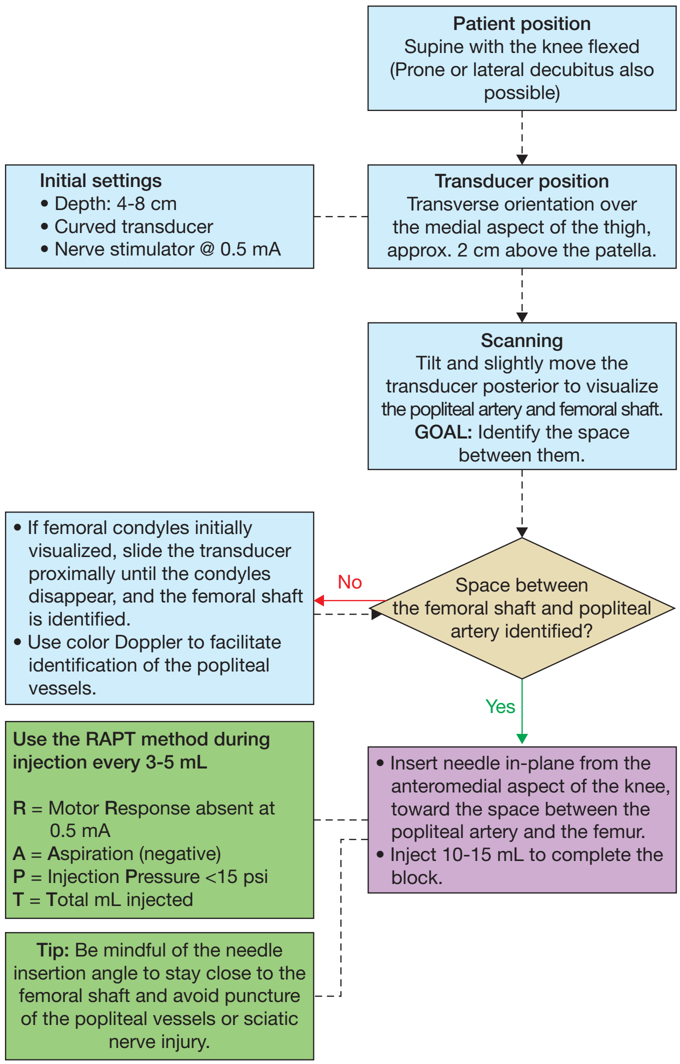
Problem-Solving Tips

- Use color Doppler to facilitate identification of the popliteal vessels.
- When performing a medial-to-lateral approach, needle insertion in a steep angle is required to stay close to the femoral shaft and avoid puncture of the nerves and vessels.

FIGURE 31-6. Alternative transducer position at the popliteal fossa to perform an iPACK block.

Flowchart

iPACK Block Technique Algorithm



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32 Ankle Block

BLOCK AT A GLANCE

Blockade of the four terminal branches of the sciatic nerve and the saphenous nerve (optional) at the level of the distal leg and ankle.

- **Indications:** Distal foot and toe surgery, transmetatarsal or toe amputations
- **Goal:** Local anesthetic (LA) spread surrounding each individual nerve
- **Local anesthetic volume:** 3 to 5 mL per nerve

General Considerations

The ankle block is a commonly performed regional anesthesia technique for procedures on the forefoot. Traditional techniques based on surface landmarks and nerve stimulation targeted the two deep nerves (tibial and deep peroneal) and required an additional subcutaneous ring infiltration around the ankle to block the three superficial nerves (superficial peroneal, sural, and saphenous). Ultrasound (US) guidance allows for precise identification of each nerve and a consistent blockade using lower volumes of LA. The quality, duration, and distribution of the blocks around the ankle are similar to those of more proximal approaches of the sciatic nerve.

The main advantage of the ankle block is the preservation of ankle mobility and thus facilitation of unassisted ambulation.

Limitations and Specific Risks

The main limitation is due to the fact that it requires multiple injections; the time required to complete the blockage is longer. An ischemia tourniquet at the level of the ankle is well-tolerated even with an ankle block. However, additional sedation or anesthesia is required for more proximal locations of the tourniquet. Specific complications of the ankle block are extremely rare.

Anatomy

The tibial nerve is the largest of the five nerves at the ankle level and provides innervation to the intrinsic muscles, bones, joints, and skin of the heel and sole of the foot. The nerve passes posterior to the medial malleolus, in close contact to the posterior tibial artery and veins, deep to the flexors retinaculum, where it divides into the calcaneal, medial, and lateral plantar nerves (Figure 32-1).

The deep peroneal nerve crosses the anterior surface of the ankle, deep to the tendons of the tibialis anterior, extensor hallucis longus muscles, and extensor digitorum longus next to the anterior tibial artery. The nerve enters the foot to innervate the extensor digitorum brevis and extensor hallucis brevis muscles and all the deep structures on the dorsum of the foot. It terminates as cutaneous fibers supplying skin between the hallux and second toe (Figure 32-1).

The superficial peroneal branch emerges at 10 to 20 cm proximal to the lateral malleolus to lie superficial to the crural fascia between the lateral and anterior muscular compartments, at 10 to 20 cm proximal to the lateral malleolus. It divides into two or three small branches and terminates as cutaneous fibers on the dorsal and lateral surface of the foot (Figure 32-1).

The sural nerve is formed by two components, from the tibial and common peroneal nerves, and runs superficially along the posterior midline of the leg. At the ankle, it courses lateral to the Achilles tendon, next to the lesser saphenous vein to innervate the lateral margin of the foot and ankle (Figure 32-1).

The saphenous nerve travels down the medial leg alongside the great saphenous vein. It innervates the medial malleolus and a variable portion of the medial aspect of the leg below the knee.

Cross-Sectional Anatomy

At the level of the ankle joint, the **tibial nerve** lies posterior or lateral to the posterior tibial artery and veins, deep to the flexor retinaculum and superficial to the flexor hallucis longus muscle and tendon. The **deep peroneal nerve** is located lateral to the anterior tibial artery between the anterior aspect of

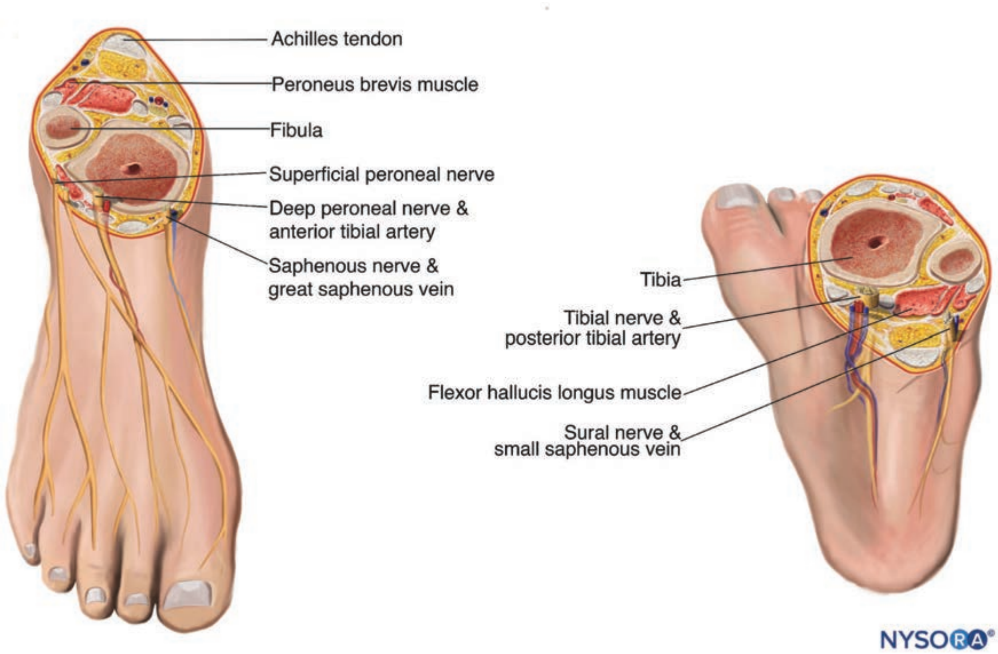


FIGURE 32-1. Relative position of the terminal nerves at the level of the ankle.

the tibia and the tendons of the extensor muscles. At the level of the midleg, the **superficial peroneal nerve** is located just deep to the fascia cruralis between the peroneal muscles and the extensor digitorum longus. The **sural nerve** lies between the lateral malleolus and the Achilles tendon intimately associated with the small saphenous vein and superficial to the deep fascia. The tiny distal branches of the **saphenous nerve** lie close to the saphenous vein, although they are difficult to visualize at the ankle. Figure 32-2 illustrates the relative position of the nerves at the level of the ankle.

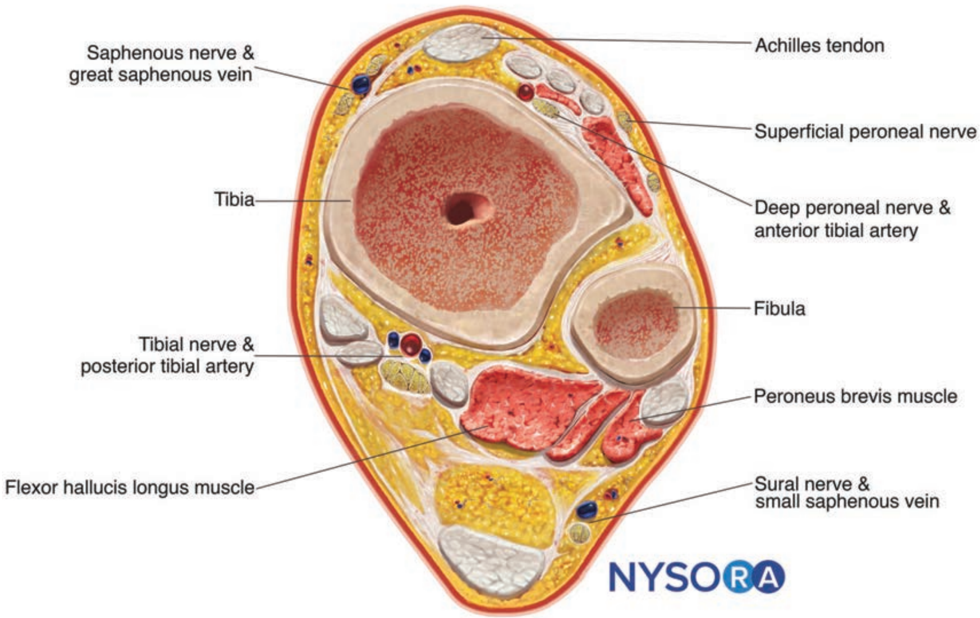


FIGURE 32-2. Cross-section at the level of the ankle illustrating the distribution and anatomic relationship of the nerves to perform an ankle block.

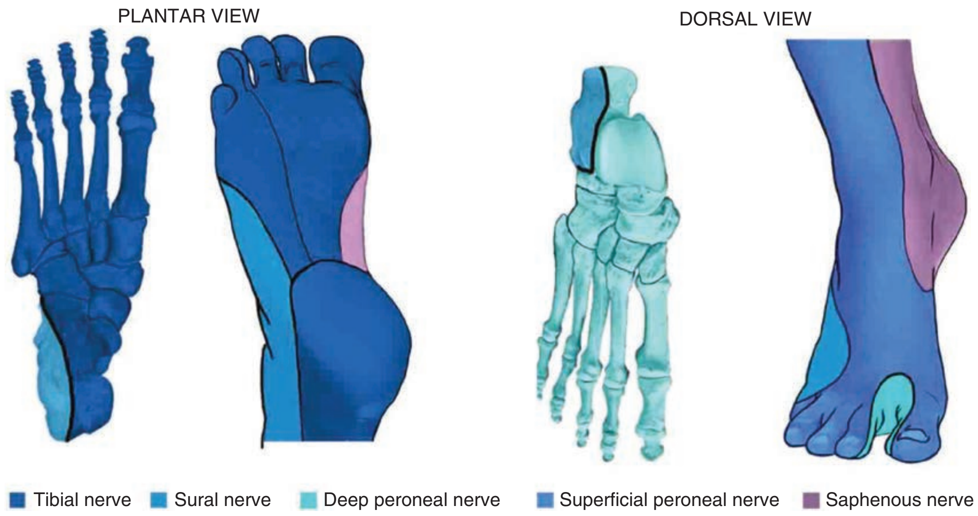


FIGURE 32-3. Sensory block distribution of the ankle.

Distribution of Anesthesia and Analgesia

An ankle block results in anesthesia of the entire foot distally to the ankle if the saphenous nerve is included (Figure 32-3). Selective blocks may be indicated to anesthetize only the area of interest.

Block Preparation

Equipment

- Transducer: High-frequency linear transducer
- Needle: 30- to 40-mm, 25-gauge needle

Local Anesthetic

To extend the duration of postoperative analgesia, long-acting LAs, such as bupivacaine 0.5% or ropivacaine 0.5%, are preferable.

Patient Positioning

The patient can rest in a comfortable supine position and the foot is elevated by placing support underneath the calf to facilitate the scanning around the ankle (Figure 32-4). Gentle internal or external rotation is helpful for better access to the tibial and sural nerves, respectively.

TECHNIQUE

Tibial Nerve

The transducer is placed in a transverse orientation between the medial malleolus and the Achilles tendon. The nerve can be seen as an oval hyperechoic structure immediately posterior to the posterior tibial artery and veins (Figure 32-5 and 32-6). Color Doppler can help in locating the vessels. To avoid misidentification with the tendons, the nerve's intimate relationship with

FIGURE 32-4. Ideal patient positioning to perform an ultrasound-guided ankle block.

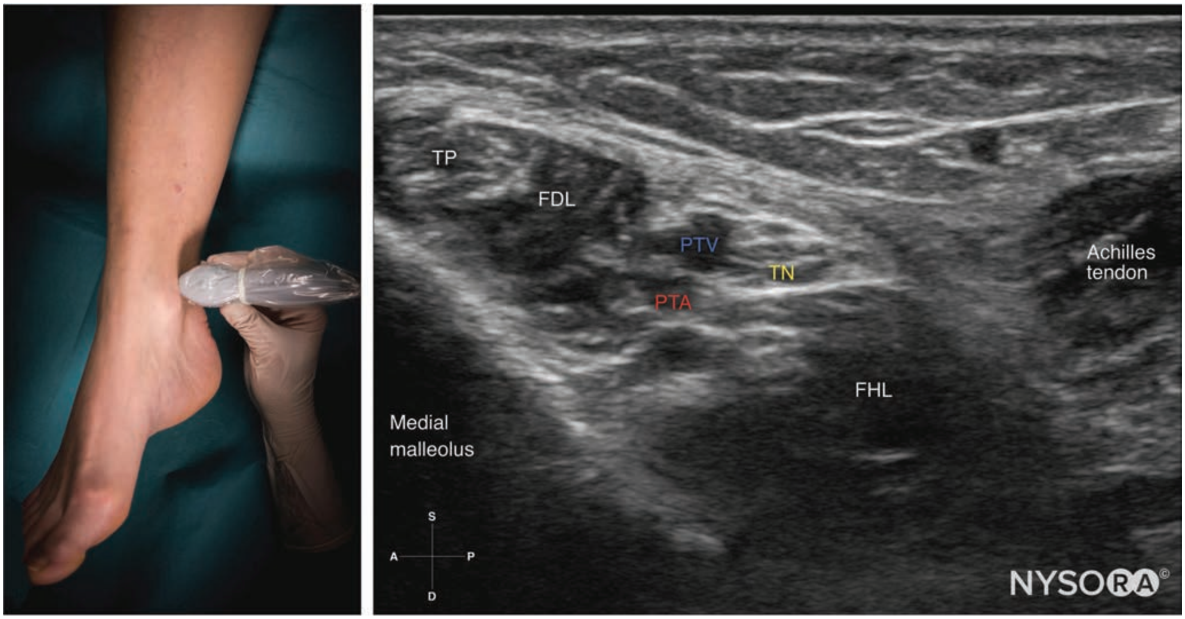


FIGURE 32-5. Transducer position and ultrasound anatomy to block the tibial nerve block. TP, tibialis posterior muscle; FDL, flexor digitorum longus; PTA, posterior tibial artery; PTV, posterior tibial vein; TN, tibial nerve; FHL, flexor hallucis longus.

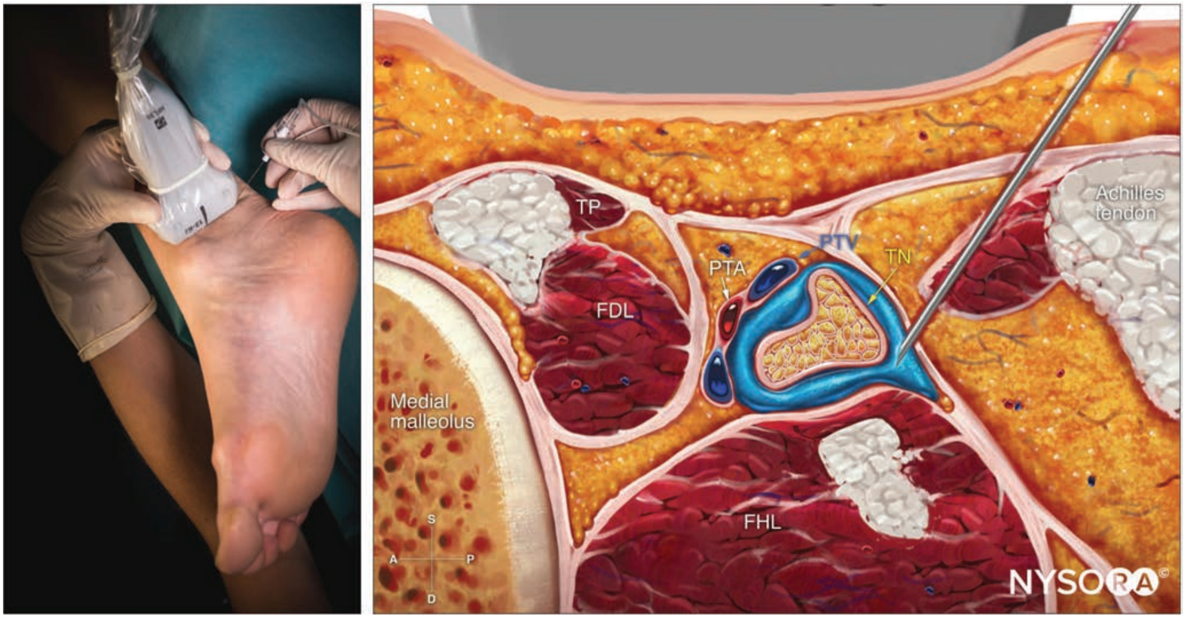


FIGURE 32-6. Reverse ultrasound anatomy of tibial nerve block with needle insertion in-plane. TP, tibialis posterior muscle; FDL, flexor digitorum longus; PTA, posterior tibial artery; PTV, posterior tibial vein; TN, tibial nerve; FHL, flexor hallucis longus.

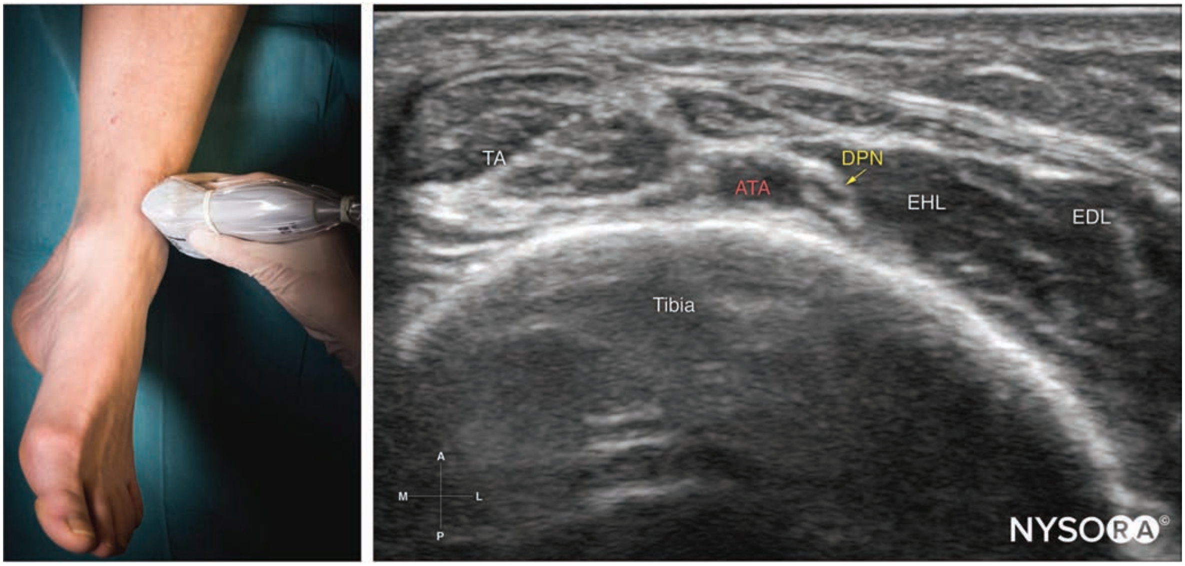


FIGURE 32-7. Transducer position and ultrasound anatomy to block the deep peroneal nerve. TA, tibialis anterior muscle; ATA, anterior tibial artery; DPN, deep peroneal nerve; EHL, extensor hallucis longus; EDL, extensor digitorum longus.

the artery should be kept in mind. If in doubt, tracking the structures proximally will clearly differentiate the nerve from the tendons as they transition into muscles.

Deep Peroneal Nerve

The transducer is placed in a transverse orientation on the anterior aspect of the ankle. The deep peroneal nerve can be seen as two small hypoechoic fascicles with a hyperechoic rim, immediately lateral or superficial to the anterior tibial artery. The nerve may be difficult to distinguish from the surrounding tissue (Figure 32-7 and 32-8).

Superficial Peroneal Nerve

The transducer is placed in a transverse orientation 10 to 15 cm proximal to the lateral malleolus. The nerve appears as a hypoechoic flat structure at the intersection

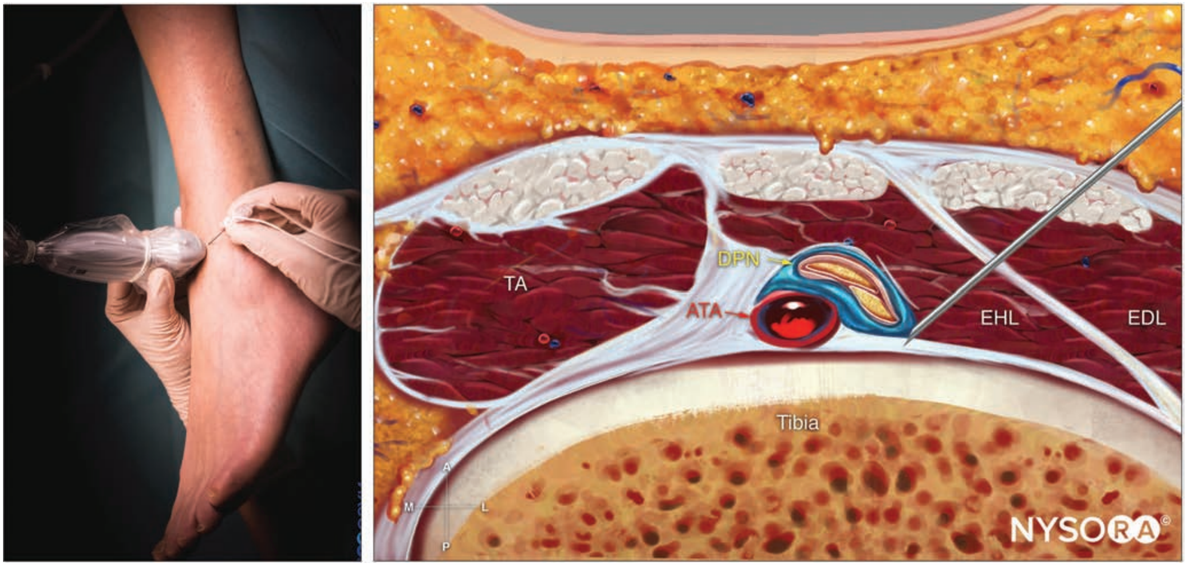


FIGURE 32-8. Reverse ultrasound anatomy of the deep peroneal block with needle insertion in-plane. TA, tibialis anterior muscle; ATA, anterior tibial artery; DPN, deep peroneal nerve; EHL, extensor hallucis longus; EDL, extensor digitorum longus.

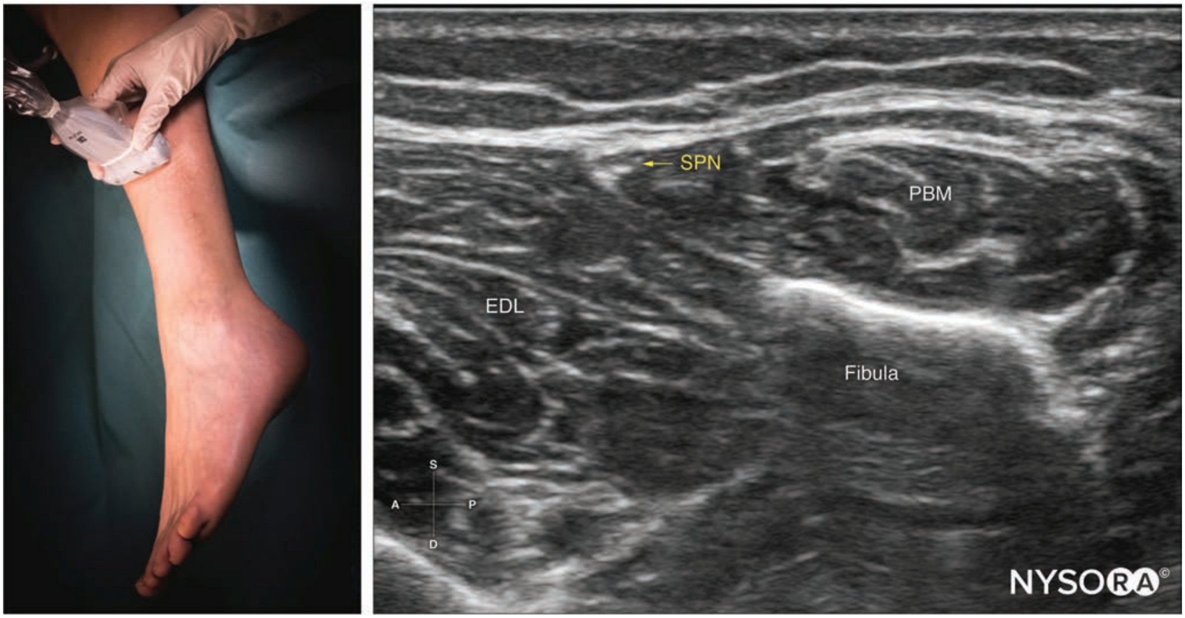


FIGURE 32-9. Transducer position and ultrasound anatomy to block the superficial peroneal nerve. EDL, extensor digitorum longus; SPN, superficial peroneal nerve; PBM, peroneus brevis muscle.

between the crural fascia and the intermuscular septum separating the lateral and anterior muscular compartments. Before injection, the nerve should be traced proximally, as it often divides before piercing the fascia, to avoid incomplete blocks (Figure 32-9 and 32-10).

Sural Nerve

The transducer is positioned in a transverse orientation between the posterior border of the lateral malleolus and the Achilles tendon. The sural nerve appears as a tiny hyperechoic

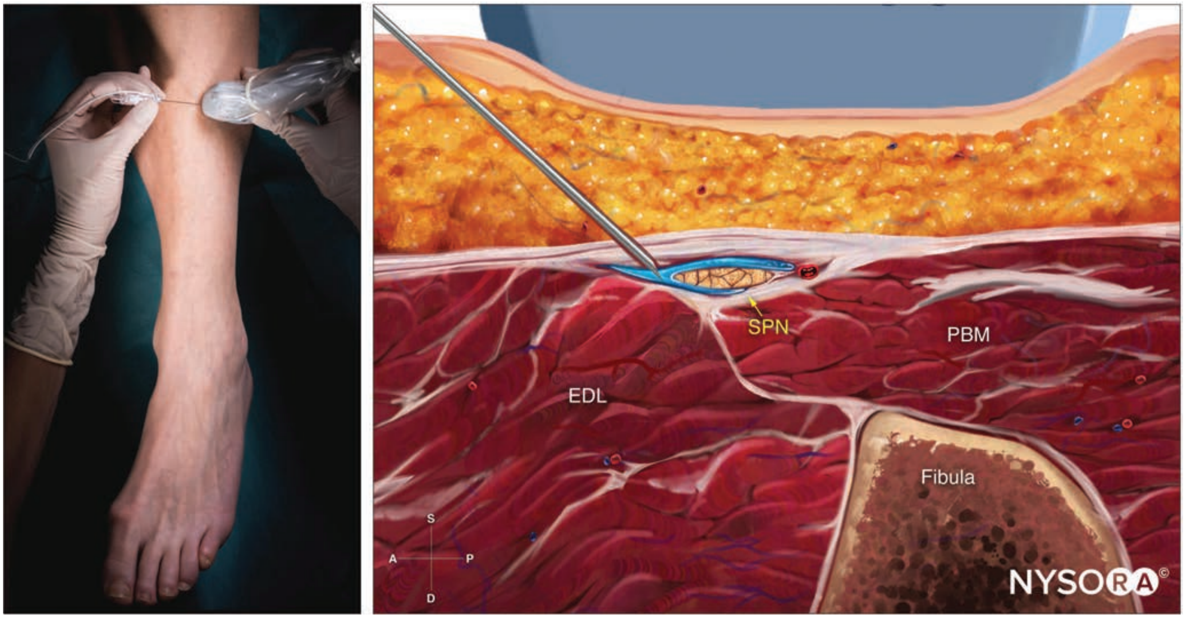


FIGURE 32-10. Reverse ultrasound anatomy of superficial peroneal nerve block with needle insertion in-plane. EDL, extensor digitorum longus; SPN, superficial peroneal nerve; PBM, peroneus brevis muscle.

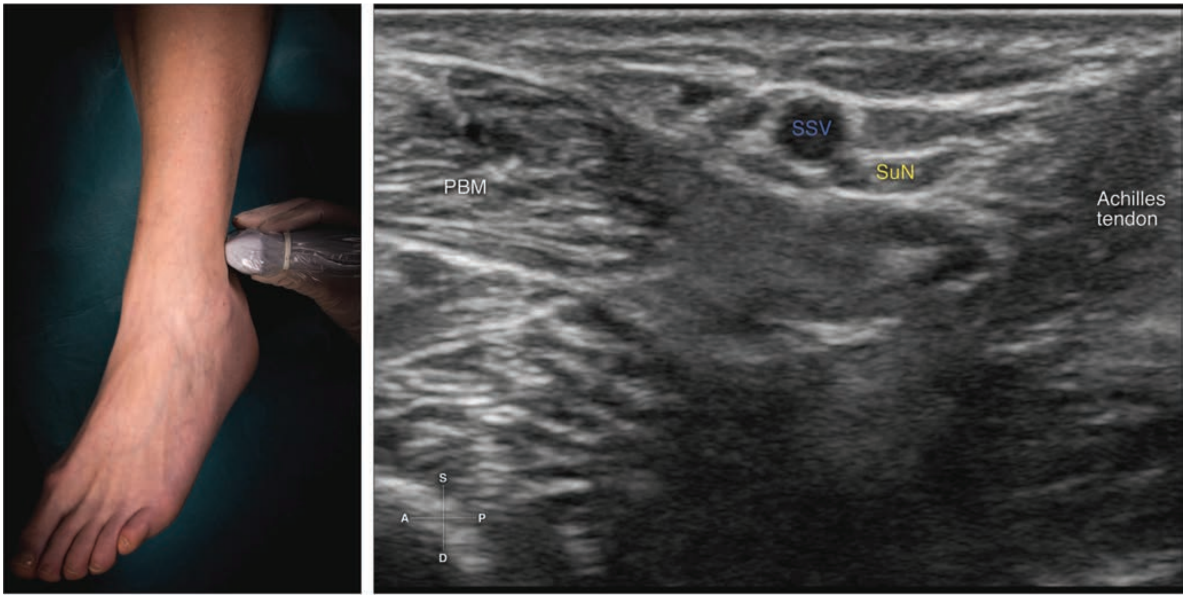


FIGURE 32-11. Transducer position and ultrasound anatomy to block the sural nerve. PBM, peroneus brevis muscle; SuN, sural nerve; SSV, small saphenous vein.

oval structure in close contact with the lesser saphenous vein (Figure 32-11 and 32-12).

Needle Approach

For each of the blocks, the needle can be inserted either in-plane or out-of-plane. Ergonomics often dictate which approach is the most effective (Figure 32-6, 32-8, 32-10, and 32-12).

Local Anesthetic Distribution

Ideally, the LA spreads immediately adjacent to the nerve; redirection to achieve circumferential spread is not necessary for the small nerves, as the LA diffuses quickly into the neural tissue. For the tibial nerve, the LA should be ideally injected within the neurovascular sheath to avoid delayed onset.

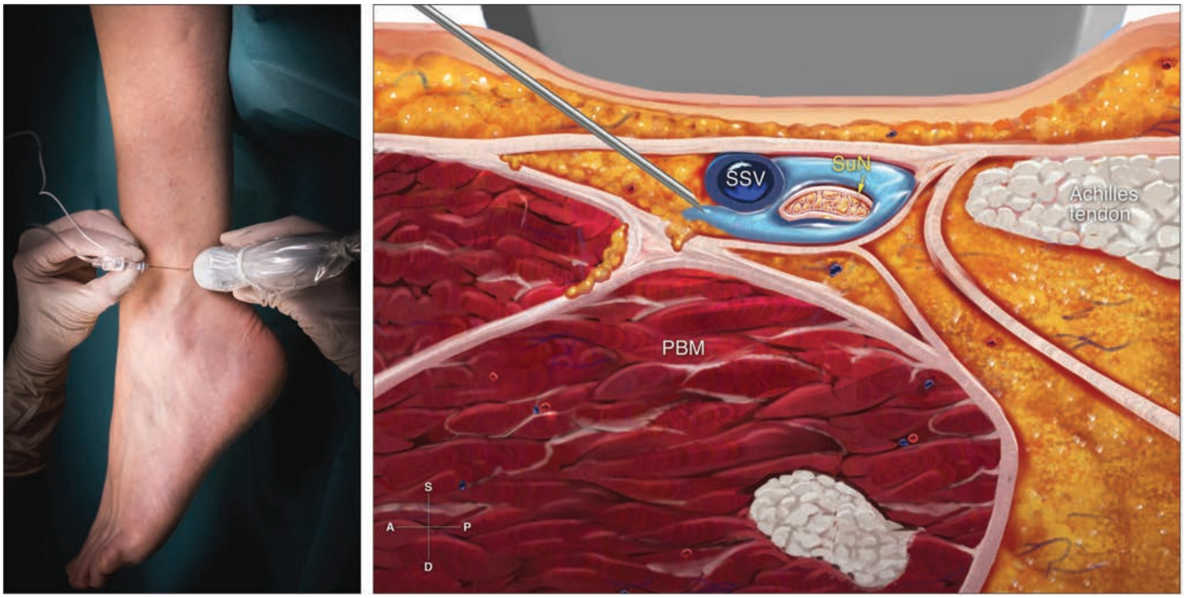


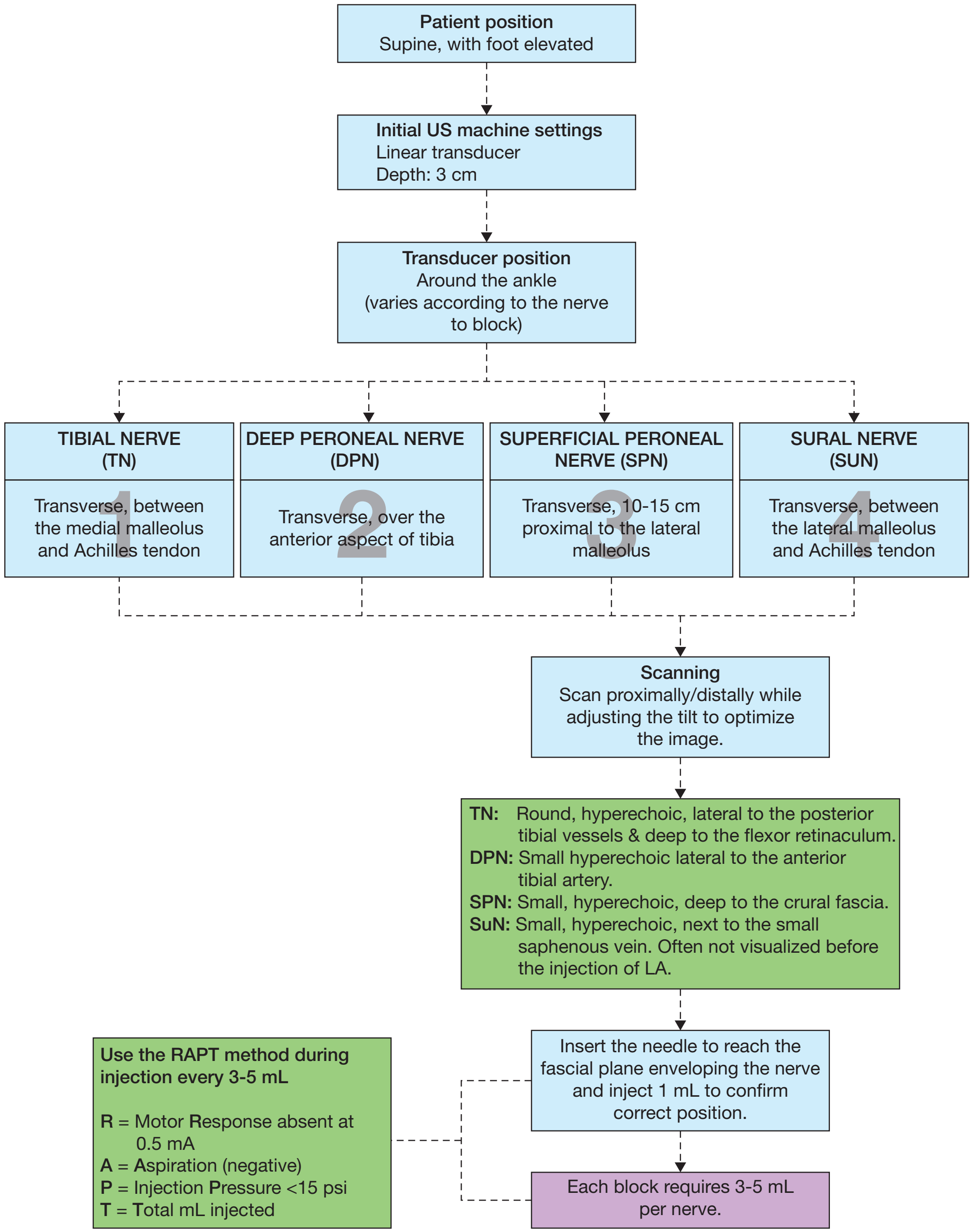
FIGURE 32-12. Reverse ultrasound anatomy of sural nerve block with needle insertion in-plane. PBM, peroneus brevis muscle; SuN, sural nerve; SSV, small saphenous vein.

Problem-Solving Tips

- Scanning a few centimeters craneo-caudally while adjusting the tilting of the probe will help to improve visualization of the small nerves.
- When scanning around the ankle, it is necessary to ensure good coupling of the probe with the surface of the skin.
- When using veins as landmarks, use as little pressure as possible on the transducer to permit the veins to fill and aspirate before injecting the LA.

Flowchart

Ankle Block Technique Algorithm



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SECTION 5

Trunk and Abdominal Wall Blocks

33 Intercostal Nerve Block

BLOCK AT A GLANCE

Injection of the local anesthetic into the intercostal space within the planes through which the intercostal nerves travel.

- **Indications:** Analgesia for rib fractures, postsurgical analgesia for chest and upper abdominal surgery (i.e., thoracotomy, thoracostomy, mastectomy, gastrostomy, and cholecystectomy), herpes zoster, or post-herpetic neuralgia
- **Goal:** Local anesthetic spread in the intermuscular plane around the intercostal nerve
- **Local anesthetic volume:** 3 to 5 mL at each level

General Considerations

The intercostal nerve block is a well-established nerve block technique to provide analgesia to the thoracic wall. The landmark-based technique was considered an "advanced" technique with a relatively high risk of complications. Expert use of ultrasound (US) helps to decrease the risk of pneumothorax as the pleura is readily identified and can be avoided. Intercostal blocks can be performed with small gauge needles and are a good alternative in patients needing analgesia following chest surgery, particularly when epidural analgesia is not indicated (e.g., anticoagulation enhanced recovery protocols).

Limitations and Specific Risks

For most indications, multiple-level intercostal nerve blocks are required to cover the area of interest, which increases the discomfort and the risk of adverse events. Reported complications of intercostal nerve blocks include pneumothorax (1%), injury to the peritoneum and abdominal viscera, local anesthetic systemic toxicity (LAST), hematoma due to injury to the intercostal artery, and inadvertent spinal anesthesia. It is widely known to be a nerve block procedure with one of the most rapid local anesthetic (LA) systemic uptake rates as the nerve runs in close contact with the corresponding artery and vein.

Anatomy

The spinal nerves T2-T12 innervate the thoracic wall and upper abdomen. After emerging from their respective intervertebral foramina, thoracic nerve roots divide into dorsal and ventral rami. The dorsal rami provide innervation to the skin and muscles of the paravertebral region. The ventral rami continue laterally as the intercostal nerves (Figure 33-1). Each intercostal nerve then pierces the posterior intercostal membrane approximately 3 cm lateral to the intervertebral foramen and enters the subcostal groove of the rib. Initially, the nerves travel between the parietal pleura and the intercostal membrane. However, just lateral to the angle of the rib, they enter the space between the innermost and internal intercostal muscles, where they continue for much of the remainder of their course along with the intercostal arteries and veins (Figure 33-2). Small collateral nerves cross the space and travel along the upper border of the rib below. At the midaxillary line, the intercostal nerve gives rise to the lateral cutaneous branch, which pierces the internal and external intercostal muscles. This branch provides innervation to the muscles and skin of the lateral chest and upper abdominal wall (Figure 33-1). The continuation of the intercostal nerve terminates as the anterior cutaneous branch, giving innervation to the skin and muscles of the anterior chest and abdominal wall, including the skin overlying the sternum and rectus abdominis.

Most of the fibers of the first thoracic nerve (T1) leave the intercostal space by crossing the neck of the first rib to join fibers from C8. Only a smaller bundle of T1 continues as an intercostal nerve to supply the muscles of the intercostal space. Fibers of the second, and sometimes third, intercostal nerve (T2 or T3) form the intercostobrachial nerve, which innervates the axilla and skin of the medial aspect of the upper arm as far distal as the elbow. The ventral ramus of T12 is called a subcostal nerve because it does not run between two ribs.

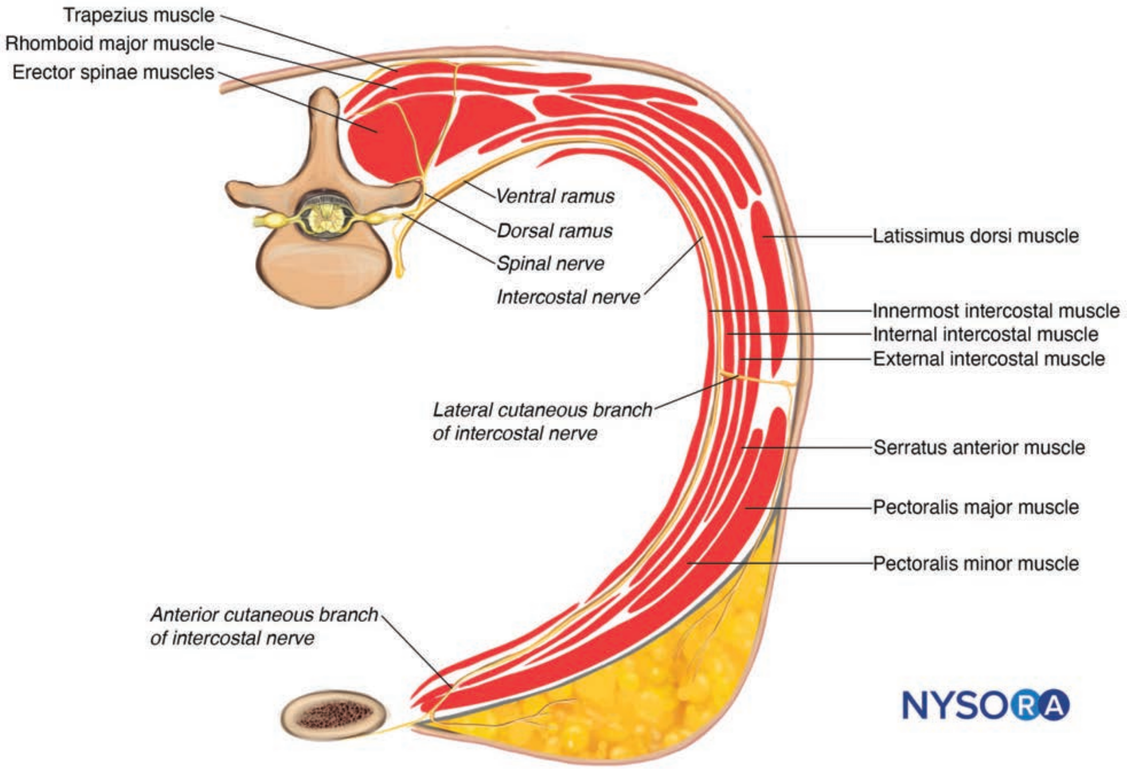


FIGURE 33-1. Schematic illustration of the anatomy of the thoracic spinal and intercostal nerves.

Cross-Sectional Anatomy and Ultrasound View

A sagittal cross-section of an intercostal space on the posterior aspect of the thoracic wall shows, from the surface to the lung: the skin and subcutaneous tissue, superficial muscles of the back, two ribs connected by three thin muscular layers (the external, internal, and innermost intercostal muscles), the endothoracic fascia, and the parietal and visceral layers of the pleura. Medially to the costal angle (Figure 33-3A), the intercostal space is seen deep under the erector spinae muscles. At this level, only the external intercostal muscle and the intercostal membrane are present, and the neurovascular bundle is in contact with the endothoracic fascia and the pleura underneath. Lateral to the costal angle, the neurovascular bundle is located in the subcostal groove between the internal and the innermost intercostal muscles, with the nerve being the most caudal structure (Figure 33-3B).

Distribution of Anesthesia and Analgesia

The distribution of anesthesia is unilateral and metameric along the segment innervated by the corresponding intercostal nerve. For a successful block, a sufficient number of injections in the correct intercostal spaces is necessary.

Block Preparation

Equipment

- Transducer: Linear transducer
- Needle: 30- to 50-mm, 22- to 25-gauge needle

Local Anesthetic

For a single-injection intercostal nerve block, 3 to 5 mL of bupivacaine 0.25% to 0.5% or ropivacaine 0.5% are

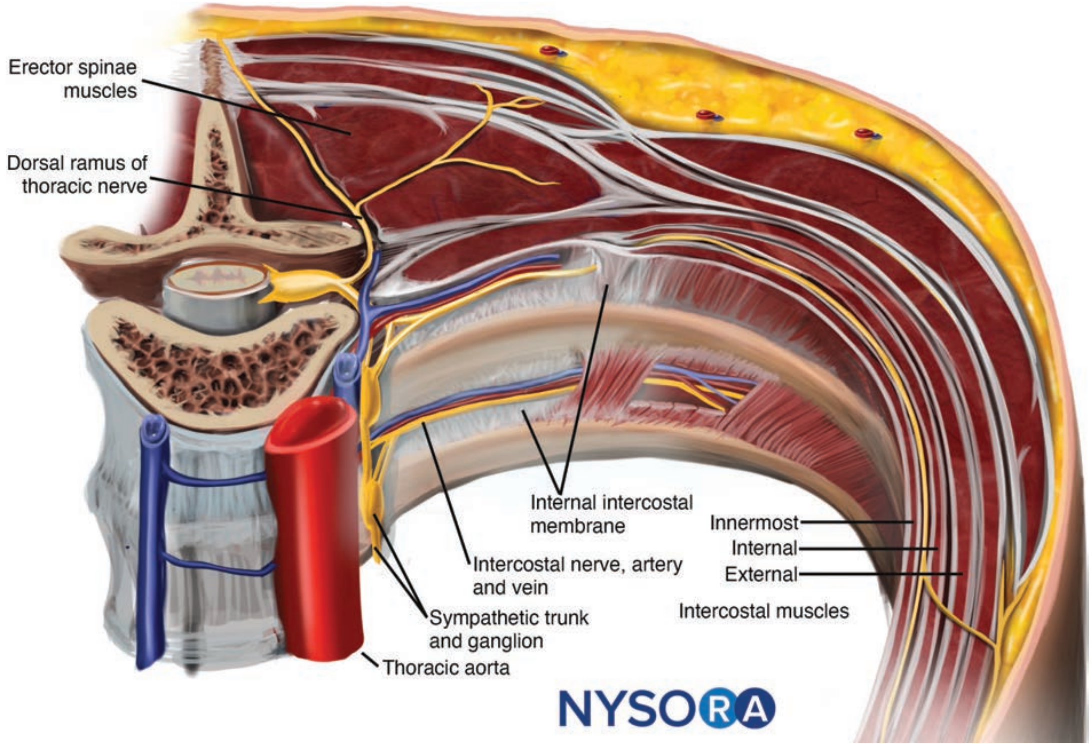


FIGURE 33-2. Anatomy of the intercostal nerve in the subcostal groove.

commonly used. The duration of analgesia is 6 to 12 hours for ropivacaine and up to 24 hours with bupivacaine with epinephrine. There is a large variability in duration from block to block. The addition of epinephrine may slow the systemic absorption and increase the maximum allowable dose with a single shot by 30%. Lidocaine 1% to 2% with epinephrine 1:200,000 to 1:400,000 is sometimes used for analgesia during chest tube insertion or diagnostic blocks.

For a multiple-injection intercostal nerve block, the maximum allowable dose needs to be calculated and the volume adjusted for each level. Maximum bupivacaine dose is 2 mg/kg (for plain solution) to 3 mg/kg (with epinephrine) and 7 to 10 mg/kg/day. The maximum lidocaine dose is up to 5 to 7 mg/kg and 20 mg/kg/day. In one study, liposomal bupivacaine was shown to be similarly effective as thoracic epidural analgesia.

Patient Positioning

An intercostal nerve block can be performed with the patient in the seated, lateral decubitus, or prone position (Figure 33-4). With the patient seated or in the lateral position, it is helpful to have the patient's spine arched with the arms extended forward resting on or holding a pillow. Support from an assistant may also improve the patient's comfort during the procedure. When the patient is placed in the prone position, a pillow should be placed under the upper abdomen with the arms allowed to hang at the sides of the bed. This position moves the scapula laterally and permits access to the posterior angles of the ribs above the level of T7.

Technique

Landmarks and Initial Transducer Position

Ribs can be counted with the US or starting from the twelfth rib (lowest palpable), or from the seventh rib (inferior tip of the scapula). The transducer is placed lateral to the angle of the rib, in a sagittal oblique orientation perpendicular to the direction of two consecutive ribs. Note that the angle of the transducer position changes slightly at different intercostal levels.

Scanning Technique

The inferior angle of the scapula is a good starting point for scanning. This corresponds to the seventh intercostal space when the patient is properly positioned. For the lateral approach, continue by scanning the intercostal space lateral to the costal angle. Color Doppler may help to identify the intercostal artery but it is not common to visualize the intercostal nerve itself (Figure 33-5). For a medial approach, the transducer is placed in a sagittal orientation 4 to 5 cm lateral to the spinous process to identify the pleura deep to the external intercostal muscle and the intercostal membrane.

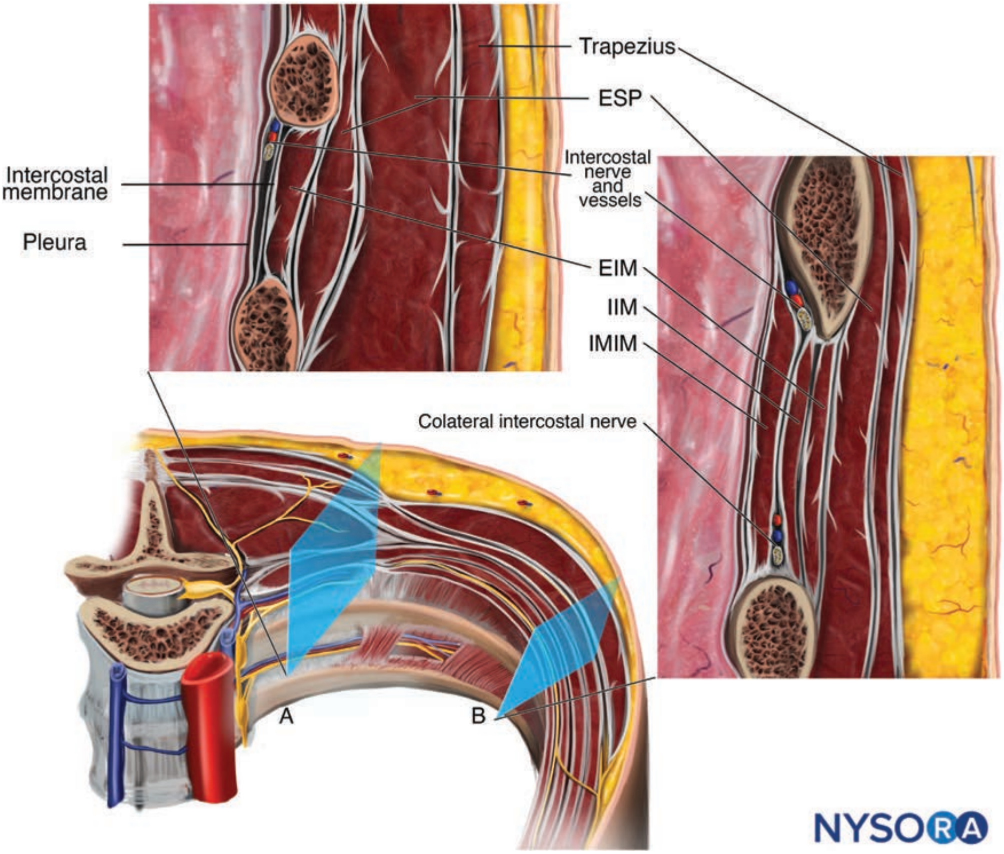


FIGURE 33-3. Sagittal cross-section anatomy of the intercostal nerve medial (A) and lateral (B) to the costal angle. ESP, erector spinae muscles; EIM, external intercostal muscle; IIM, internal intercostal muscle; IMIM, innermost intercostal muscle.

Needle Approach and Trajectory

The needle entry site is immediately below the inferior margin of the rib, somewhere between the costal angle and the posterior axillary line, proximal to the exit of the lateral branch, to ensure the complete block of the intercostal nerve. The needle is advanced, either in-plane or out-of-plane, to penetrate the external and internal intercostal muscles. The optimal target needle endpoint is a location just below the internal intercostal muscle to assure that the needle tip remains superficial to the parietal pleura (Figure 33-6). Hydrodissection facilitates visualization of the needle tip and identification of the space between the innermost and internal intercostal muscles. To identify the correct plane for injection consider using normal saline or dextrose to decrease the total dose of LA. If the block is performed medially to the costal angle, the needle is advanced below the external intercostal muscle. The displacement of the pleura with the injection confirms the correct position of the needle tip.

FIGURE 33-4. Patient position (sitting) for an ultrasound-guided intercostal nerve block.

Local Anesthetic Distribution

The LA solution injected into the subcostal groove spreads along the intercostal space and may reach both distally and proximally; some of the injectate may enter the paravertebral space as well if large volumes are used.

FIGURE 33-5. Transducer position and ultrasound image of an intercostal nerve block. EIM, external intercostal muscle; IIM, internal intercostal muscle; IMIM, innermost intercostal muscle.

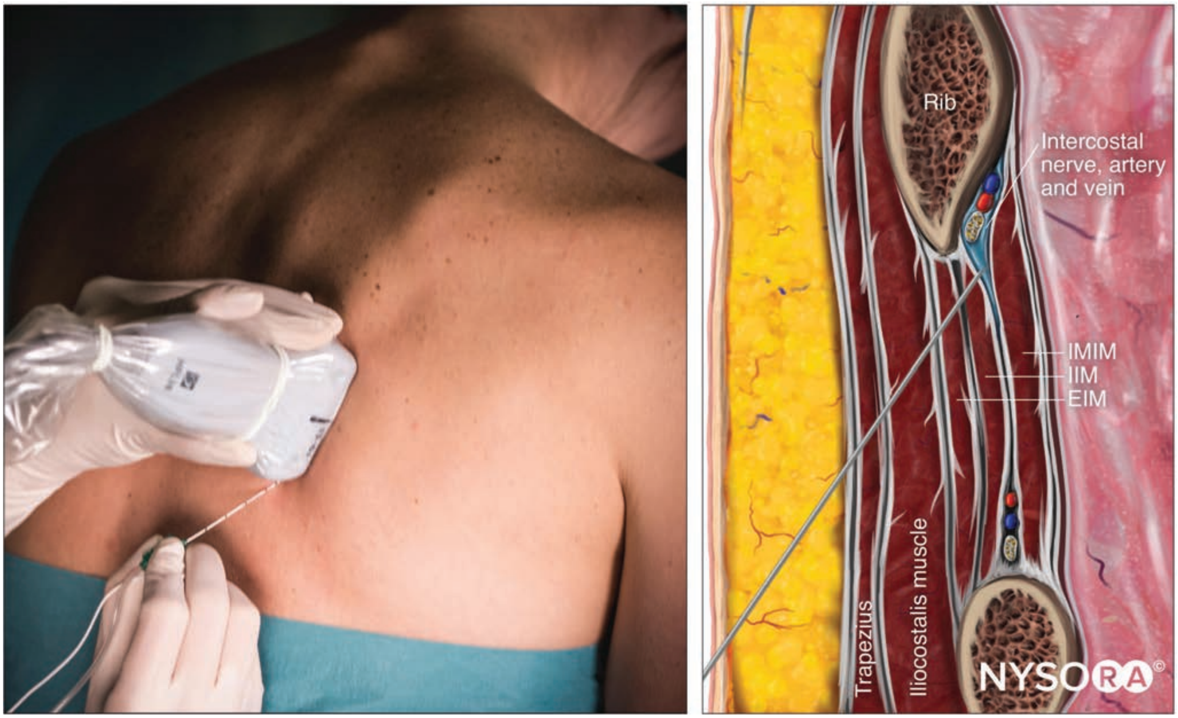
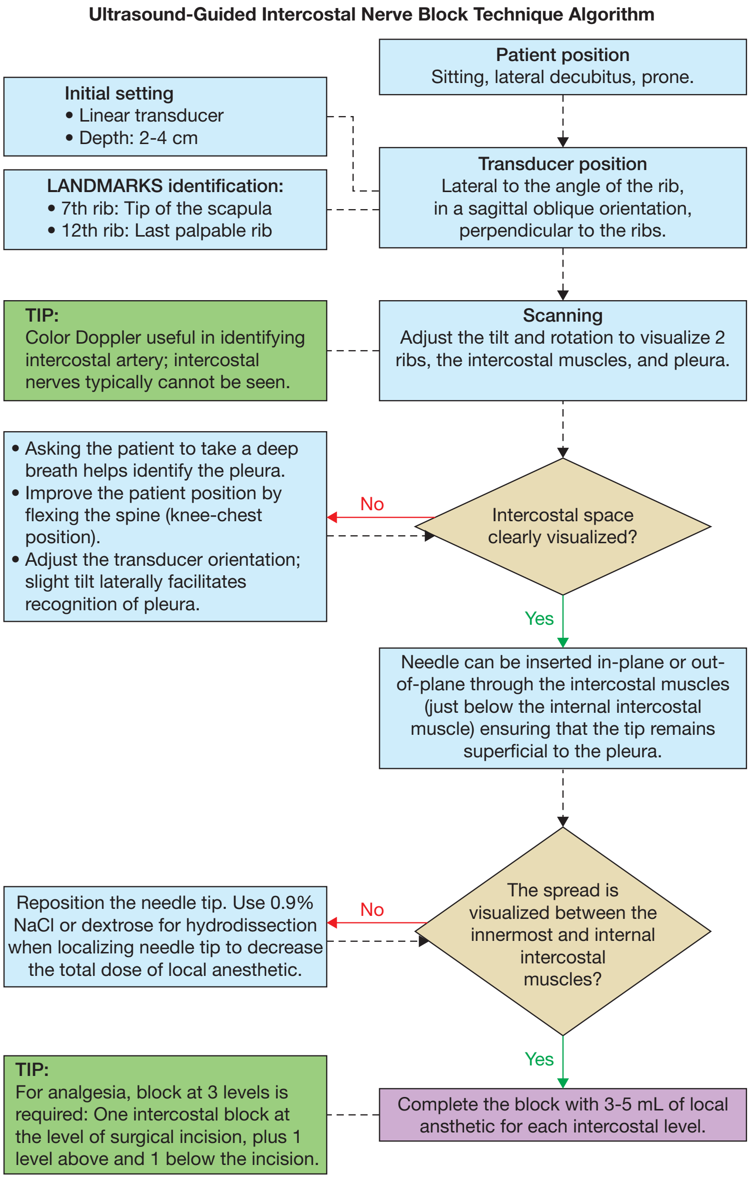


FIGURE 33-6. Intercostal nerve block reverse ultrasound anatomy illustration with needle insertion in-plane. EIM, external intercostal muscle; IIM, internal intercostal muscle; IMIM, innermost intercostal muscle.

Problem-Solving Tips

- Difficulties to visualize the target layer can often be obviated by adjusting the tilt of the US transducer.
- Perform hydrodissection as this often facilitates the visualization of the needle tip and identification of the correct tissue layer (space between the innermost and internal intercostal muscles).
- The innermost intercostal muscle is not always visualized, so it is not a useful landmark to guide the injection. The internal intercostal muscle is more readily identified and can serve as a surrogate sonographic target for needle placement.
- Intercostal nerve blocks above T7 may be difficult because of the scapulae; an alternative technique such as a paravertebral or epidural block should be considered.

Flowchart



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34 Pectoral Nerves Block

BLOCK AT A GLANCE

Injection of local anesthetic (LA) into the fascial plane between the pectoral muscles and between the pectoralis minor and serratus anterior muscles.

- **Indications**: Analgesia after breast surgery, thoracotomy, rib and clavicle fractures, and herpes zoster neuralgia
- **Goal:** LA spread along the interfascial planes to block the pectoral nerves and lateral branches of the intercostal nerves T3-T6
- **Local anesthetic volume:** 15 to 30 mL

General Considerations

Ultrasound (US)-guided pectoral nerves block (Pecs I and II) are novel fascial plane techniques introduced for analgesia after breast surgery. The techniques can be viewed as simpler alternatives to the epidural, paravertebral, or intercostal blocks, which require a greater degree of technical skills. These techniques are increasingly more commonly used due to their simplicity and documented efficacy. A recent meta-analysis concluded that the Pecs II block, in the context of multimodal analgesia, reduces opioid requirements after breast surgery. Recent evidence suggests that Pecs II is associated with a lower incidence of chronic pain after mastectomy.

Compared to the paravertebral block, Pecs I and II have several advantages: the targeted fascial planes are more superficial and easier to identify, the blocks can be performed in the supine position, and risk of complications is lower. However, the extent and quality of analgesia of Pecs I and II blocks are lower compared to paravertebral blocks, which can be used as a complete anesthetic for breast surgery.

The Pecs I was described first and consists of an interfascial injection of LA between the pectoralis major and minor muscles, targeting the medial and lateral pectoral nerves. Pecs II was then introduced as a modification to extend analgesia to the axillary fossa and upper intercostal nerves by adding a second infiltration into a deeper fascial plane between the pectoralis minor and serratus anterior muscles.

Limitations

Current US images are unable to identify the small nerve branches traveling in these fascial planes. Interindividual variability in both the extent and duration of sensory block is common, which limits the reproducibility of these blocks. The block of the long thoracic nerve may interfere with nerve monitoring during axillary fossa surgery.

Infiltration of large volumes and doses of LAs in vascularized intermuscular planes carries a risk of local anesthetic systemic toxicity (LAST). The most commonly reported complications are local hematoma. However, pneumothorax may also occur, particularly during the Pecs II, due to the proximity of the intercostal muscles and pleura.

Anatomy

The lateral and medial pectoral nerves are branches of the brachial plexus arising from the lateral and medial cords, respectively. These branches are interconnected by the ansa pectoralis, a fine neural network. They innervate the pectoralis major and minor muscles, the acromioclavicular joint, and contribute innervation to the ribs and clavicle through the origins and insertions of the pectoral muscles.

The **lateral pectoral nerve** pierces the clavipectoral fascia following the course of the pectoral branch of the thoracoacromial artery and cephalic vein, deep to the pectoralis major muscle, which it innervates. The **medial pectoral nerve** runs distally and pierces the pectoralis minor muscle sending branches to supply this muscle and the pectoralis major muscle (Figure 34-1).

The **intercostal nerves (III-VII)**, supplying the upper chest wall, travel between the innermost intercostal and internal intercostal muscles. Their lateral branches take off at the level of the anterior or midaxillary line piercing the internal and external intercostals, and serratus anterior muscles to reach the subcutaneous tissue where they divide into the anterior

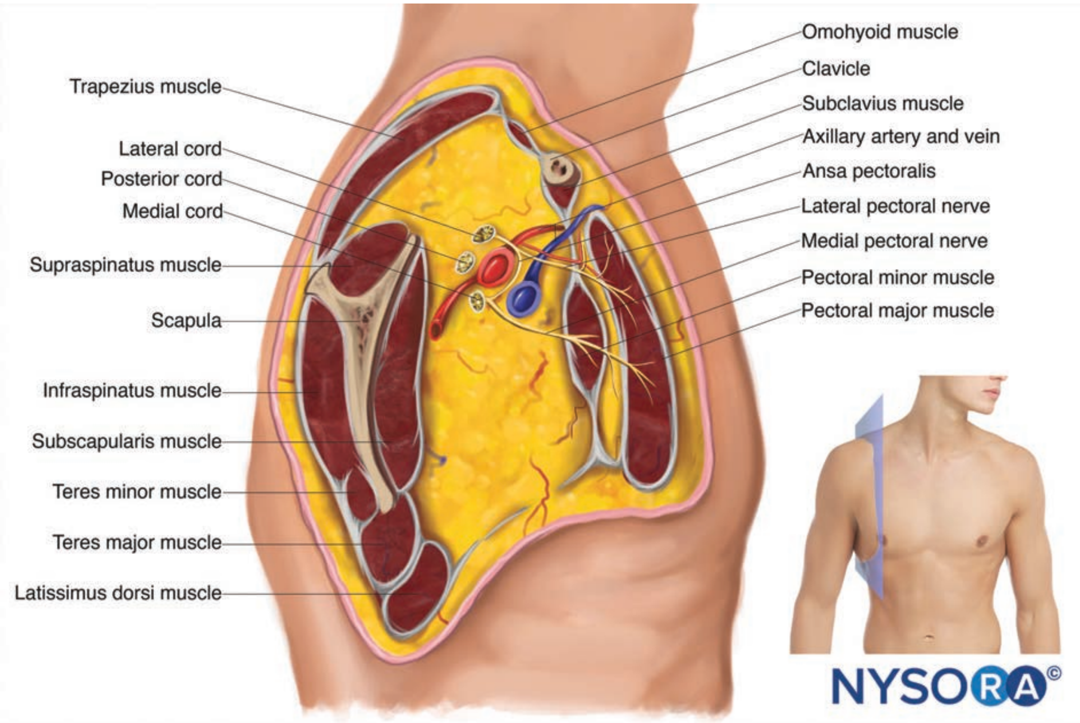


FIGURE 34-1. Sagittal section of the axilla showing the origin and course of the medial and lateral pectoral nerves.

and posterior branches (Figure 34-2). These branches innervate the subcutaneous tissue and thoracic fascia. The intercostal nerve continues anteriorly to become subcutaneous close to the midline, where it provides innervation to the parasternal area.

The lateral branch of the second intercostal, the **intercostobrachial nerve**, innervates the skin and subcutaneous tissue of the axilla and proximal medial side of the arm. The **long thoracic nerve** is a branch of the upper trunk of the brachial plexus that passes under the clavicle over the first and second ribs. It then descends inferiorly and laterally along the outer surface of the serratus anterior, between the anterior and posterior axillary lines. Here it gives off the branches to each digitation of the serratus muscle (Figure 34-3).

Cross-Sectional Anatomy and Ultrasound View

A cross-section of the lateral thoracic wall below the axillary fold (at the level of intersection between the third rib and anterior axillary line) shows the two interfascial compartments of interest for Pecs blocks. These compartments are (a) between the two pectoralis muscles and (b) between the pectoralis minor and serratus anterior muscles. Of note, that latter compartment communicates with the axilla (Figure 34-2). On US, the serratus anterior muscle is seen overlying the ribs and external intercostal muscles. The three muscular layers are seen separated by the hyperechoic fascial planes. The third and fourth ribs are seen as hypoechoic rounded structures casting an acoustic shadow, whereas the intercostal muscles and hyperechoic pleura line are seen connecting the ribs.

Distribution of Analgesia

An injection of LA between and deep to the pectoralis major and minor muscles anesthetizes the lateral and medial pectoral nerves, the lateral cutaneous branches of the intercostal nerves, and may block the intercostobrachialis and long thoracic nerves as well. However, analgesia and its efficacy vary. Figure 34-4 illustrates the dermatomes, myotomes, and osteotomes covered by this technique.

Block Preparation

Equipment

- Transducer: High-frequency linear transducer
- Needle: 80- to 100-mm, 22- to 25-gauge needle

Local Anesthetic

Bupivacaine, l-bupivacaine, or ropivacaine diluted to reach an appropriate volume is best suited for analgesia after breast surgery or thoracic wall incisions. Bupivacaine and

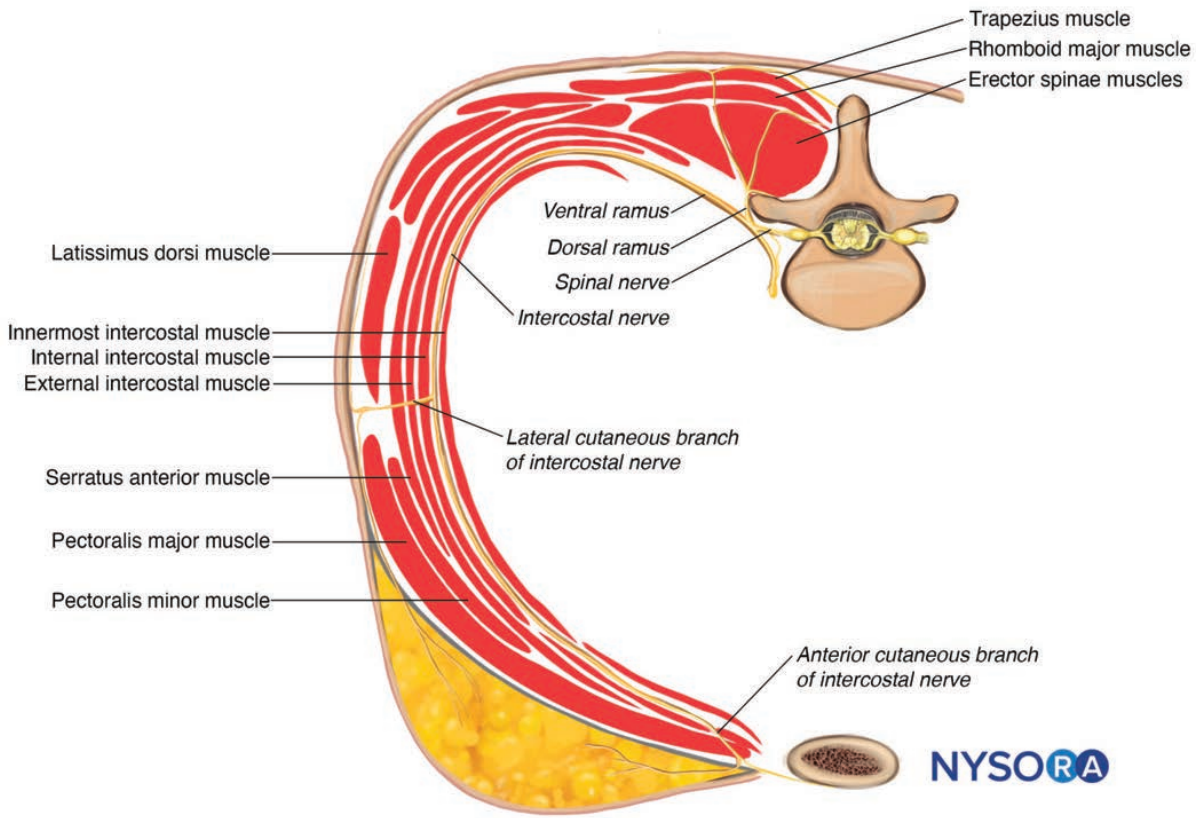


FIGURE 34-2. Schematic illustration of the anatomy, course, and branches of an intercostal nerve.

ropivacaine 0.25% to 0.50% are most commonly reported in the literature, not exceeding 0.2 to 0.4 mL/kg^{-1}.

Patient Positioning

The Pecs blocks can be performed with the patient in a supine position with the arm in 90° abduction or in the lateral position with the side to be blocked upwards, and the ipsilateral arm flexed forward (Figure 34-5).

Technique

Landmarks and Initial Transducer Position

The transducer is placed in a sagittal orientation at the mid-subclavicular area to identify the pectoralis major muscle.

Scanning Technique

The transducer is then moved caudally and laterally while counting the ribs until the lateral border of the pectoralis minor is identified deep to the pectoralis major muscle. At this point, the serratus anterior muscle is seen over the third and fourth ribs (Figure 34-6).

Needle Approach and Trajectory

The needle is advanced in-plane from medial to lateral toward the deep fascia of the pectoralis major muscle (Figure 34-7).

- Pecs I and the first injection of Pecs II: The LA is injected between the pectoralis major and minor muscles.
- The second injection of Pecs II: The injection is made between the pectoralis minor and serratus anterior muscles.

Local Anesthetic Distribution

After negative aspiration, 1 to 2 mL of LA is injected to confirm the correct injection site. The block is completed with 10 to 15 mL of LA in each fascial plane while observing the spread between the muscles. If the injection occurs within the muscle, the needle tip is repositioned (Figure 34-7).

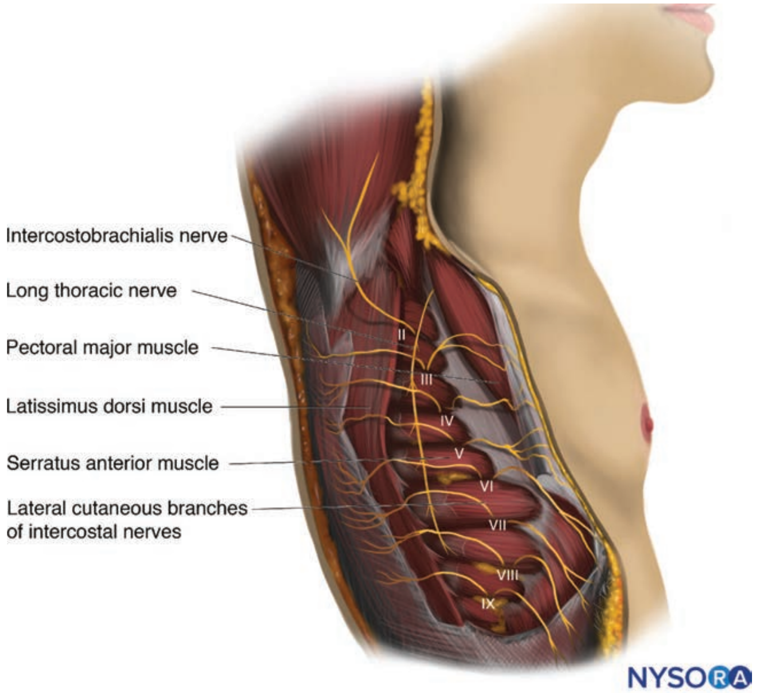


FIGURE 34-3. Anatomy and course of the long thoracic nerve along the surface of the serratus anterior muscle.

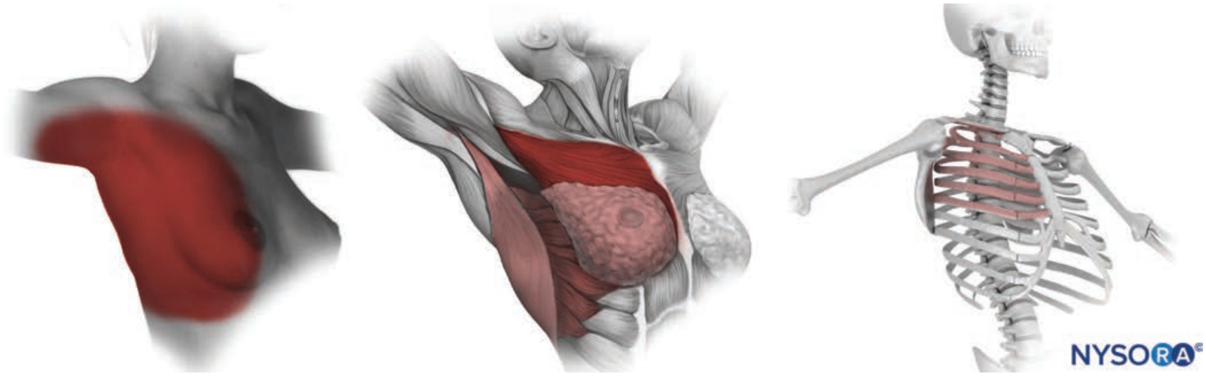


FIGURE 34-4. From left to right: dermatomes, myotomes, and osteotomes covered by a pectoralis block.

FIGURE 34-5. Patient position to perform a Pecs block.

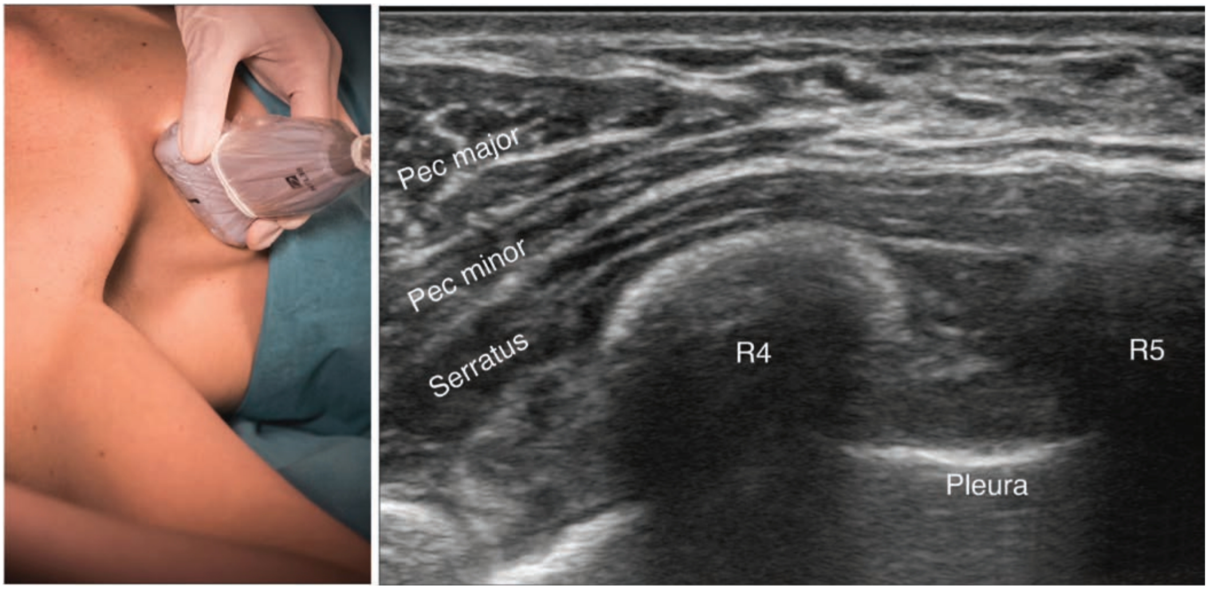


FIGURE 34-6. Transducer position and sonoanatomy to perform a Pecs block.

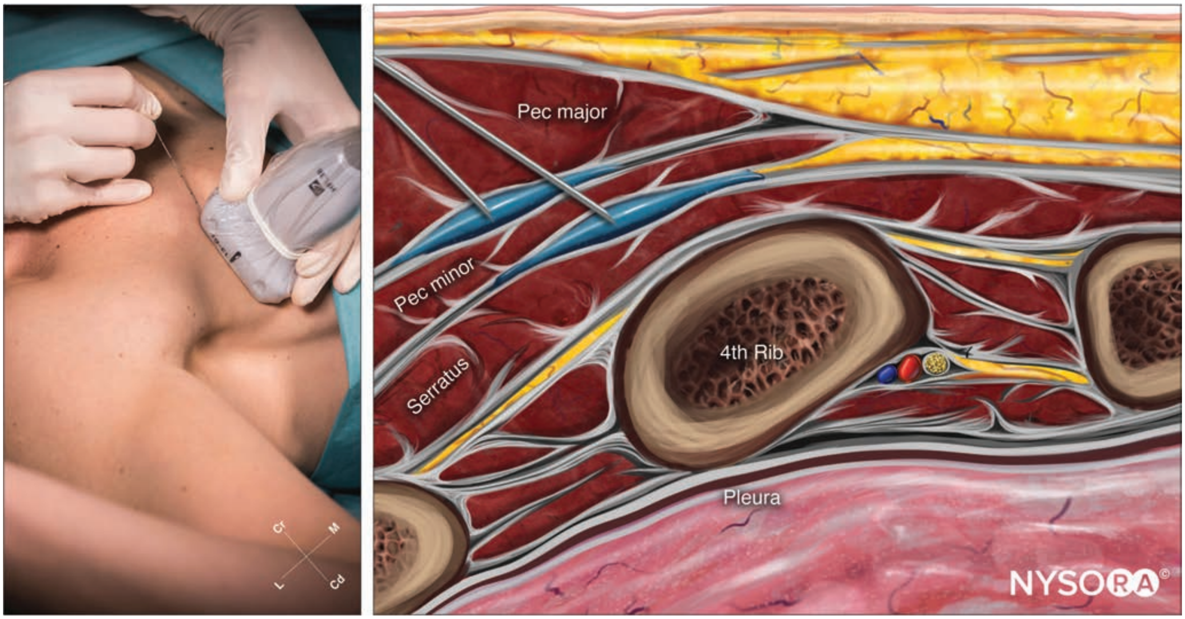
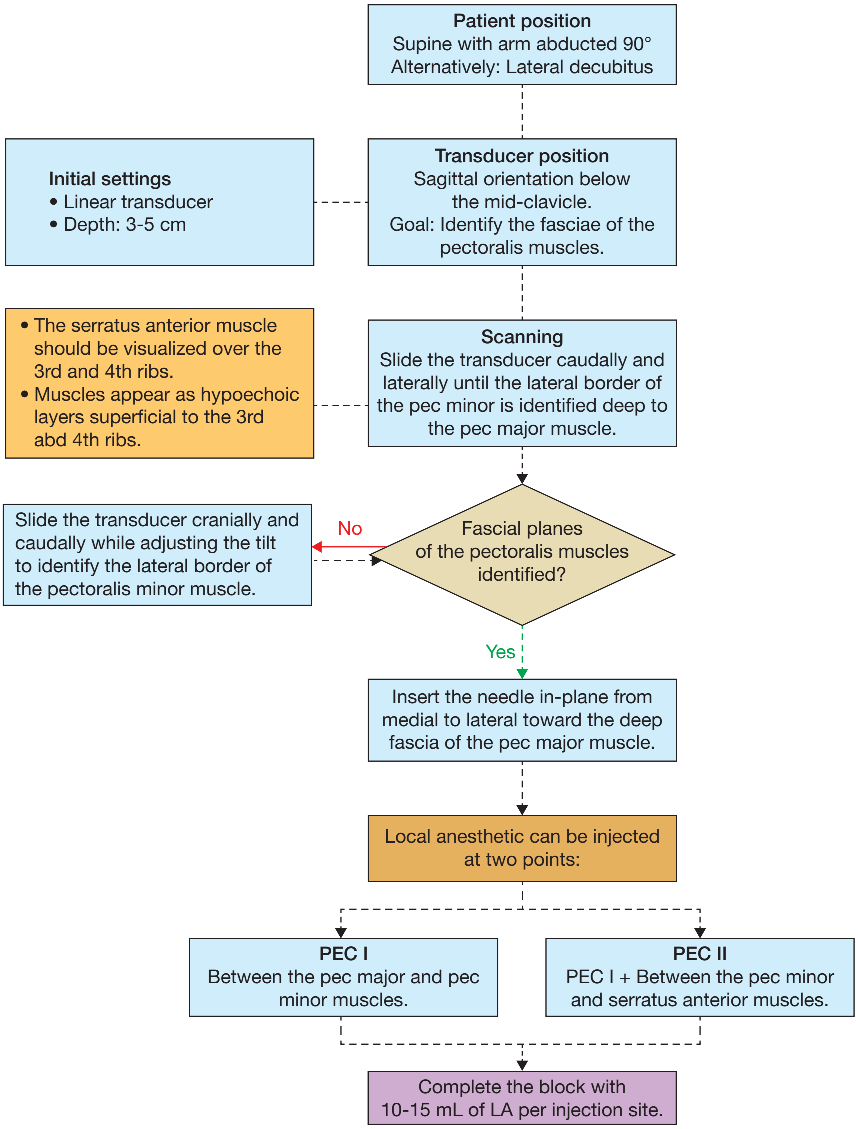


FIGURE 34-7. Pecs block; reverse ultrasound anatomy showing needle insertion in-plane.

Problem-Solving Tips

- The thoracoacromial artery can help to identify the interpectoral fascial plane. The spread of LA next to the artery ensures the blockade of the medial and lateral pectoral nerves.
- Slide the transducer cranially and caudally while adjusting the tilt to identify the lateral border of the pectoralis minor muscle.
- Some clinicians prefer to inject LA in the deepest fascial plane first (between the pectoralis minor and serratus anterior muscle) to preserve the US view.
- Needle tracking under US is important to decrease the risk of pneumothorax.

Pectoralis Plane Block Technique Algorithm



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35 Serratus Plane Block

BLOCK AT A GLANCE

Interfascial plane injection of local anesthetic (LA) either deep or superficial to the serratus anterior muscle at the level of the third-sixth ribs.

- **Indications**: Analgesia after breast surgery, thoracoscopy, rib fractures, and procedures requiring lateral or anterior thoracic wall incisions
- **Goal:** Spread of LA under the superficial or deep fascia of the serratus anterior muscle to block the lateral branches of the intercostal nerves III to VI
- **Local anesthetic volume:** 15 to 20 mL

General Considerations

The ultrasound (US)-guided pectoralis and serratus plane blocks are interventional analgesia techniques used after surgeries on the hemithorax. They are considered potential alternatives to the thoracic epidural, paravertebral, intercostal, and intrapleural blocks. Compared to the paravertebral or thoracic epidural, the serratus anterior plane block offers benefits in terms of simplicity, safety, and ease of performance. For instance, needle insertion away from the neuraxis and critical anatomical structures may reduce the risk of spinal cord injury, epidural hematoma or infection, or pleural puncture. However, in terms of analgesia, the serratus anterior plane block does not provide equivalent results to the thoracic paravertebral or epidural blocks. Also, the resulting analgesic patterns may vary according to the distribution of the injectate through the fascial planes, which is determined primarily by the volume, injection site, and injection force. To date, studies have shown that injections, either superficial or deep to the serratus anterior muscle, appear to have similar analgesic effects. Nonetheless, the minimum effective volume, optimal injection site, and the number of injections have not been well-established.

Limitations

The risk of local anesthetic systemic toxicity (LAST) should be considered due to the absorption of the medication across a large surface. Always keep the maximum dose of LAs in mind, consider using a pharmacologic marker (e.g., epinephrine) to detect intravascular injection, and be cautious with the dose especially in high-risk populations.

Anatomy

The thoracic wall is innervated by the intercostal nerves, originating from the ventral rami of the thoracic spinal nerves (T3-T10). The intercostal nerves travel under the inferior border of the ribs, between the innermost and internal intercostal muscles. At the midaxillary line, the lateral cutaneous branches arise from the intercostal nerves and pierce the intercostal and serratus anterior muscles. From there on, they divide into anterior and posterior branches to innervate the lateral aspect of the thoracic wall (Figure 35-1).

The serratus anterior muscle originates from the anterior surface of the first through eighth ribs, to insert on the medial aspect of the scapula. It is innervated by the long thoracic nerve (C5-C7), which is a branch of the brachial plexus. Myofascial planes are formed both superficial and deep to this muscle, which is pierced by the lateral cutaneous branches of the intercostal nerves before they further divide. The latissimus dorsi muscle is superficial and posterior to the serratus anterior muscle; it is innervated by the thoracodorsal nerve, a terminal branch of the posterior cord of the brachial plexus that travels with the thoracodorsal artery (branch of the subscapular artery) along the posterior wall of the axilla (Figure 35-2).

The lateral cutaneous branch of the second intercostal nerve is called the intercostobrachial nerve. After piercing

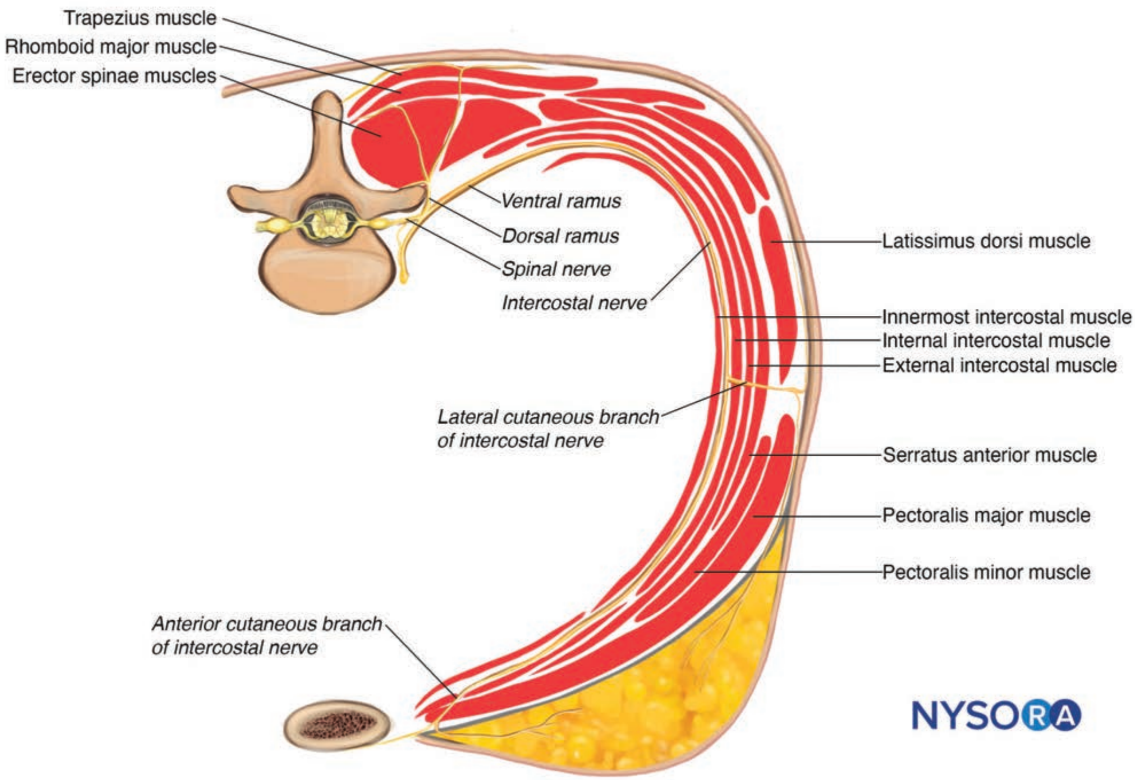


FIGURE 35-1. Anatomy course and branches of an intercostal nerve.

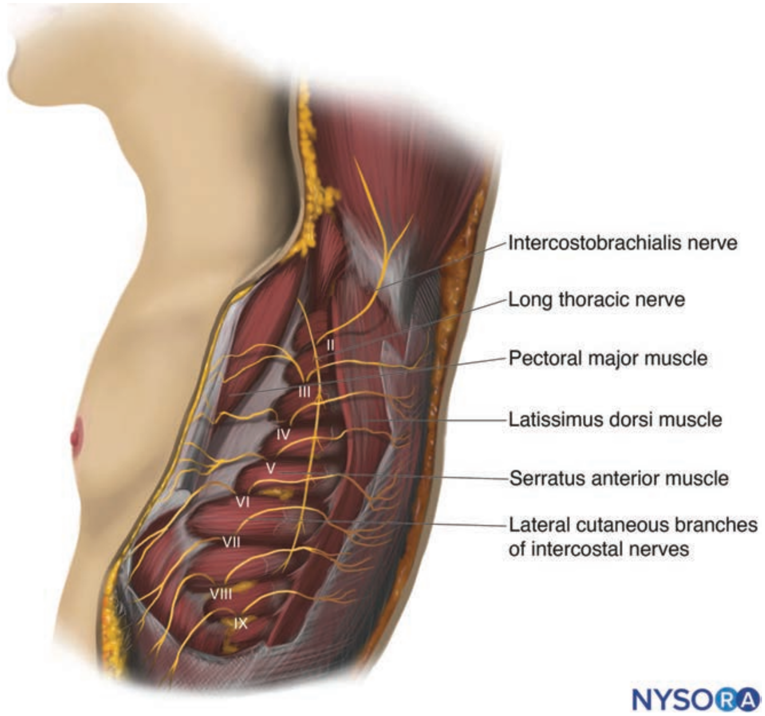


FIGURE 35-2. Anatomy of the serratus anterior muscle.

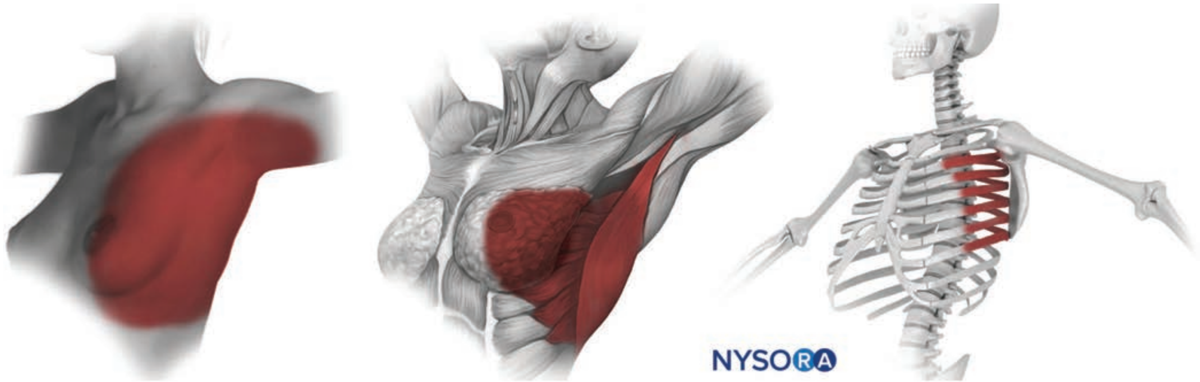


FIGURE 35-3. Analgesia distribution of a serratus plane block.

the serratus anterior muscle, it crosses the axilla to the medial side of the arm to provide cutaneous innervation to the axillary region and the upper half of the medial and posterior aspect of the arm (Figure 35-2).

Cross-Sectional Anatomy and Ultrasound View

A transverse view of the lateral thoracic wall just below the axilla shows the ribs and their corresponding intercostal muscles covered by the serratus anterior muscle and the subcutaneous tissue. When imaged by US, the fourth and fifth ribs appear as round hyperechoic lines casting an acoustic shadow behind, and the hyperechoic pleura line deeper between the two. The hypoechoic serratus and latissimus dorsi muscles appear superficial to the ribs with the latter posterior to the serratus anterior muscle. The thoracodorsal artery is often seen between the two muscles (Figure 35-1).

Distribution of Analgesia

An injection of LA superficial or deep to the serratus anterior muscle may reach the intercostobrachial, long thoracic, and thoracodorsal nerves as well as the lateral cutaneous branches of the intercostal nerves from T3 to T9 to a variable extent. The latter results in dermatomal analgesia of the ipsilateral hemithorax (Figure 35-3).

Block Preparation

Equipment

- Transducer: High-frequency linear transducer
- Needle: 50-mm, 22- to 25-gauge needle

Local Anesthetic

As with other thoracic fascial plane techniques, block success depends on the volume and distribution of the LA between the muscles. Long-acting LAs such as bupivacaine, levobupivacaine, and ropivacaine at concentrations of 0.25% to 0.5% are typically used in doses of 0.15 to 0.2 mL/kg. Of note, because LA absorption with this technique is high, avoid complications by calculating the maximum weight-dose.

Patient Positioning

The patient is placed either in the supine position with the arm abducted 90°, or in lateral decubitus with the side to be blocked facing up and the arm extended anteriorly to facilitate access to the axillary area (Figure 35-4).

FIGURE 35-4. Patient position to perform a serratus plane block.

Technique

The serratus anterior plane block can be performed at different levels between the anterior and posterior axillary lines and between the third through sixth ribs.

Transducer Position

The transducer is placed at the midaxillary line in an oblique orientation perpendicular to the main axis of the fourth and fifth ribs (**Figure 35-5**). Alternatively, the transducer can be initially placed in a sagittal orientation just below the mid-clavicular region to identify the pectoral major and minor muscles and then slowly moved caudally and laterally counting the ribs as they appear until the fifth rib is identified at the mid-axillary line.

Scanning Technique

At this level, the serratus anterior muscle is seen overlying the ribs. By sliding the transducer toward the posterior axillary line, the latissimus dorsi muscle will be seen as a thicker muscular layer superficial to the serratus anterior muscle. The thoracodorsal artery may be visualized between the two muscles (Figure 35-5). When not readily seen, the use of color Doppler may help to identify the artery.

Needle Approach and Trajectory

The needle is advanced in-plane, from superoanterior to posteroinferior to reach the fascial plane either superficial or deep to the serratus anterior muscle. A correct needle position is confirmed by injecting 1 to 2 mL of LA.

Local Anesthetic Distribution

The block is completed with 10 to 15 mL of LA while observing the spread along the superficial or deep fascia of the serratus anterior muscle. (**Figure 35-6**).

Problem-Solving Tips

- The thoracodorsal artery may help identify the plane between the serratus anterior and the latissimus dorsi muscle. Use color Doppler to identify the artery.
- Release the pressure on the transducer while injecting to allow better distribution of the LA.
- If the spread occurs into the serratus anterior muscle, the needle is withdrawn and directed either more superficially or deeper.
- Keep the needle under vision during advancement and aim the tip toward the ribs to decrease the risk of pneumothorax.

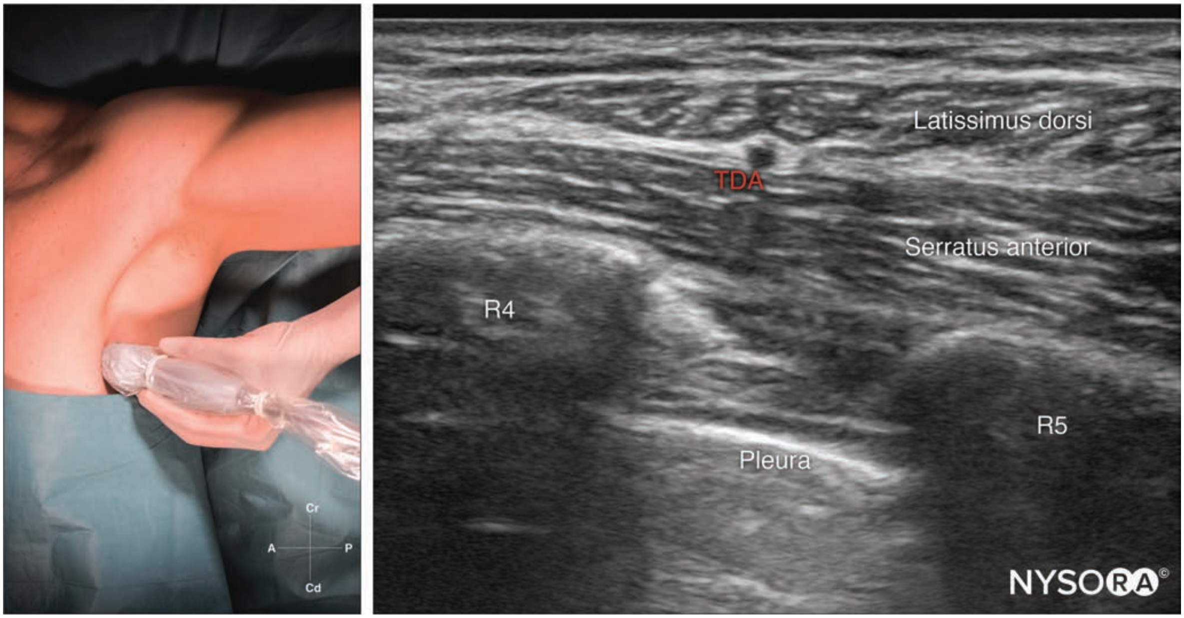


FIGURE 35-5. Transducer position and sonoanatomy for a serratus anterior plane block. TDA, thoracodorsal artery.

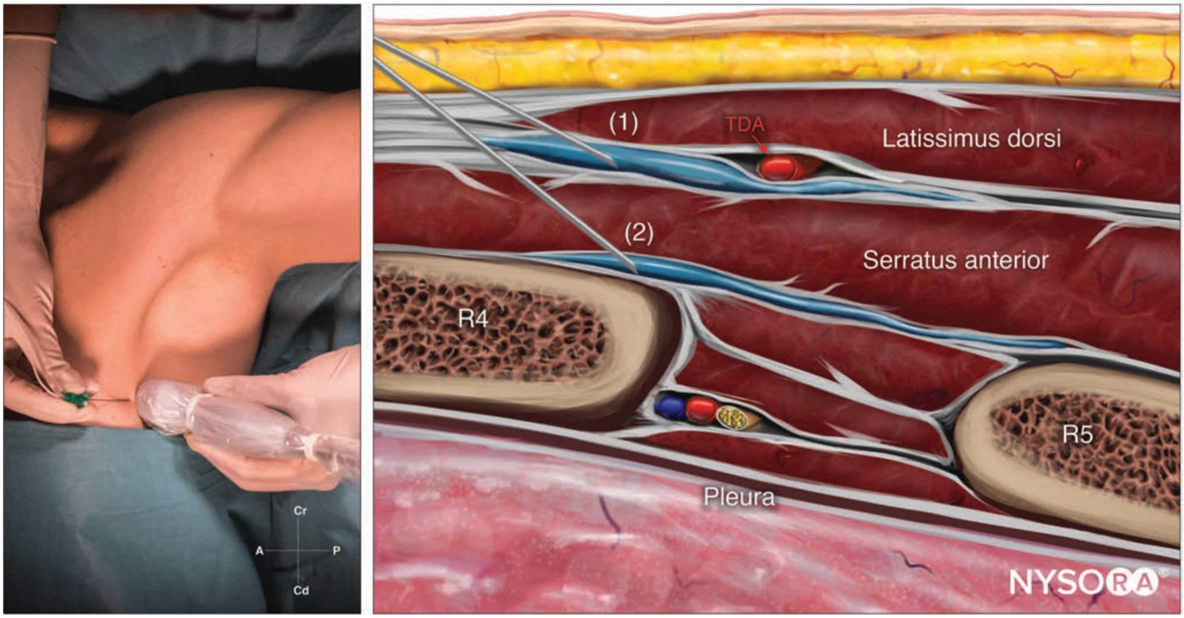
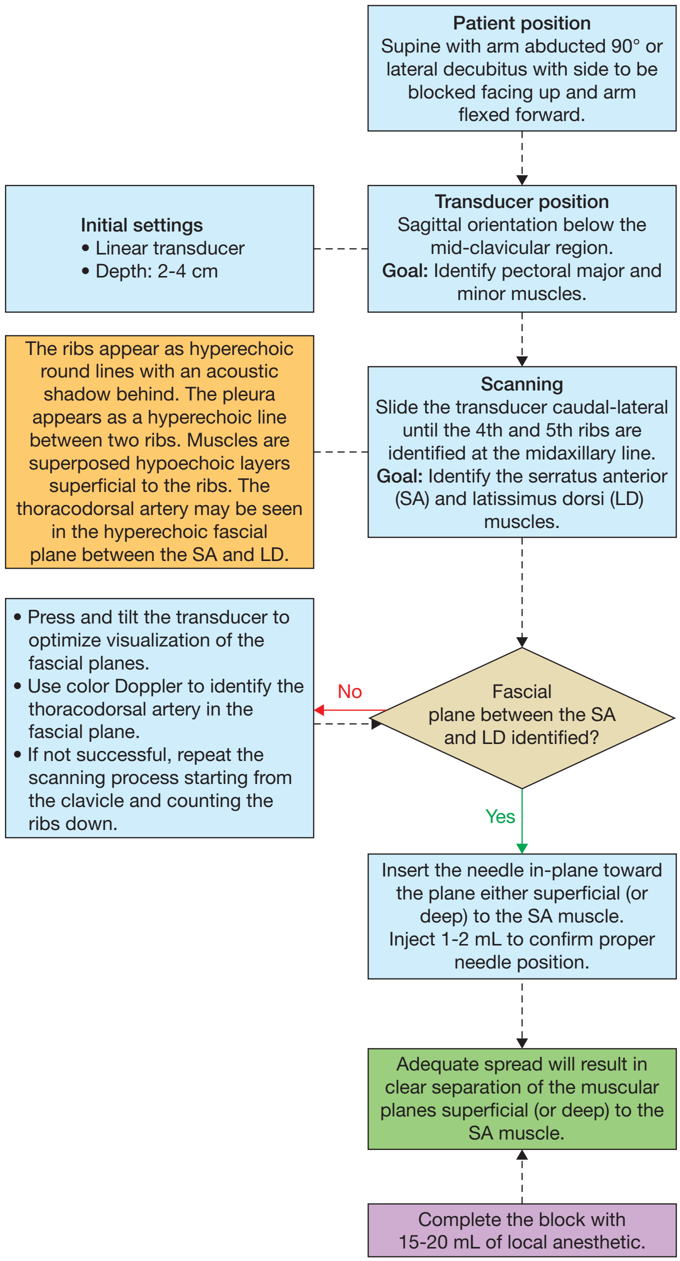


FIGURE 35-6. Serratus anterior plane block; reverse ultrasound anatomy with needle insertion in-plane and LA spread (1) between the latissimus dorsi and serratus anterior muscles, or (2) underneath the serratus anterior muscle. TDA, thoracodorsal artery.

Flowchart

Serratus Anterior Plane Block Technique Algorithm



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36 Paravertebral Block

BLOCK AT A GLANCE

Injection of local anesthetic into the thoracic paravertebral space.

- **Indications:** Analgesia after thoracic and breast surgery, rib fractures, and procedures involving the thoracic and upper abdominal wall
- **Goal:** Spread of local anesthetic into the paravertebral space around the spinal nerves as they arise from the intervertebral foramen
- **Local anesthetic volume:** 4 to 5 mL per space to be blocked

General Considerations

Thoracic paravertebral block (PVB) is a well-established analgesia interventional technique for patients having thoracic, chest wall, or breast surgery. Likewise, it is often used for pain management of patients with rib fractures. The PVB provides an effective unilateral block of the anterior and posterior branches of the corresponding spinal nerves, as well as the sympathetic chain. PVBs also may decrease the risk of chronic pain after breast and thoracic surgeries and reduce the recurrence of breast cancer, but this last possible benefit requires further confirmation.

Ultrasound (US) guidance helps to identify the paravertebral space (PVS) with more precision than the landmark-based technique. It also helps monitor the needle placement and the spread of the local anesthetic (LA). However, the use of US in the PVB requires a high degree of skill due to the close proximity of highly vulnerable structures and the depth of the PVS. The potential for complications and the challenges of the technique inspired the development of several alternative approaches targeting the branches of the spinal nerves at more distal and superficial locations. In this chapter, we describe general principles of thoracic PVB; readers are advised to use the anatomical and technique information presented here to devise their own approach in line with their experience.

Specific Risks and Limitations

The proximity of the needle tip to the pleura, neuraxial structures, and segmental arteries and veins carries the risk of pneumothorax, spinal cord injury, inadvertent spinal or epidural block, and vascular puncture. In patients on antithrombotic or thrombolytic therapy, the same precautions should be taken as for neuraxial techniques. One of the limitations of the PVB is the inconsistency of the craniocaudal spread of LA, which may require injections at multiple levels to cover the desired area.

Anatomy

The PVS is a wedge-shaped area between the heads and necks of the ribs that contain the thoracic spinal nerves and the sympathetic trunk (Figure 36-1). Its posterior wall is formed by the superior costotransverse ligament, the anterolateral wall by the parietal pleura with the endothoracic fascia. The medial wall is made by the lateral surface of the vertebral body and intervertebral disc. The PVS medially communicates with the epidural space via the intervertebral foramen inferiorly and superiorly across the head and neck of the ribs. Consequently, injection of LA into the PVS often results in unilateral (sometimes bilateral) epidural anesthesia. The cephalad limit of the thoracic PVS is not well defined, whereas the caudad limit is at the origin of the psoas muscle at L1. The PVS also communicates with the intercostal spaces laterally, resulting in the spread of the LA into the intercostal sulcus and resultant intercostal blockade as part of the mechanism of action.

Cross-Sectional Anatomy and Ultrasound View

The PVS can be insonated through the intertransverse windows with the transducer positioned either in a sagittal or transverse oblique orientation. In a transverse oblique

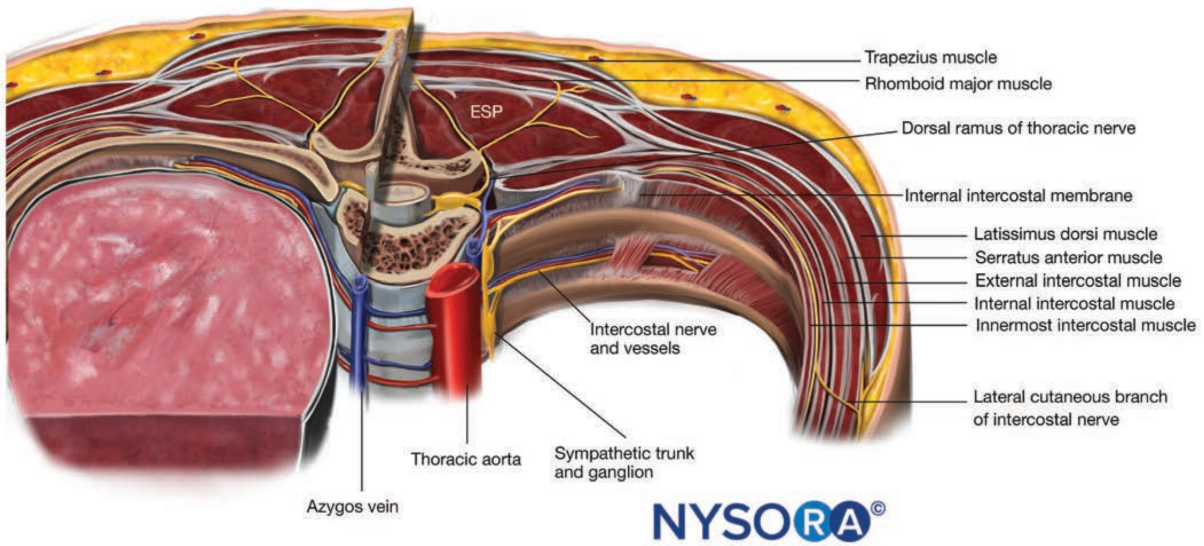


FIGURE 36-1. Anatomy of the paravertebral space. Left side: at the level of the rib; right side: at the level of the intercostal space. ESP, erector spinae muscles.

cross-section, the following structures can be identified: skin and subcutaneous tissue; trapezius, rhomboid, erector spinae, and external intercostal muscles; and the internal intercostal membrane. The pleura is seen as a bright hyperechoic interface moving with respiration. The PVS is identified as a wedge-shaped hypoechoic space demarcated by the internal intercostal membrane and the pleura below (Figure 36-2).

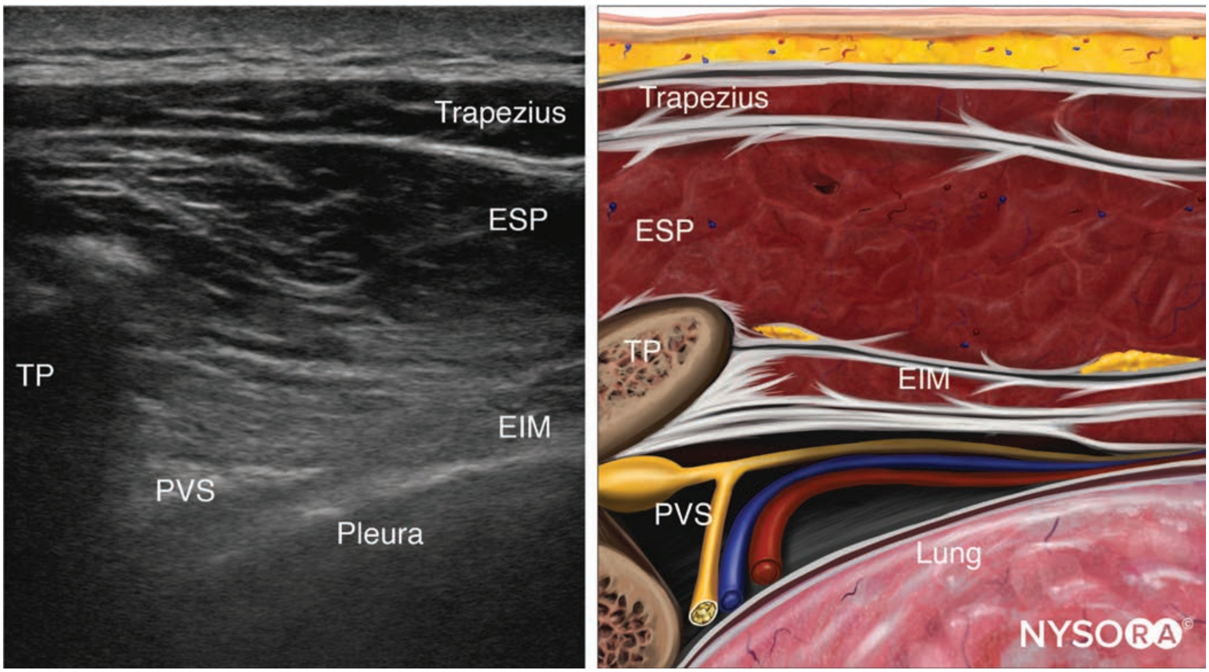


FIGURE 36-2. Cross-sectional oblique ultrasound view of the paravertebral space and reverse anatomy illustration. TP, transverse process; ESP, erector spinae muscles; PVS, paravertebral space; EIM, external intercostal muscle.

Distribution of Anesthesia and Analgesia

A PVB produces an ipsilateral somatic and sympathetic nerve block by a direct effect of the LA on the somatic and sympathetic nerves in the PVS, as well as extension into the intercostal space laterally and the epidural space medially. The overall contribution of epidural spread to the dermatomal distribution of anesthesia following a PVB is not well defined. Although the injections spread both cephalad and caudad to the site of injection, the dermatomal distribution of anesthesia following a single injection of a large volume varies (Figure 36-3). For that reason, a multiple injection technique, with small volumes (3-4 mL) of LA at several contiguous thoracic levels, is preferable over a single, large-volume injection. This is particularly important when reliable anesthesia over several ipsilateral thoracic dermatomes is desired, such as when a thoracic PVB is used for anesthesia during breast surgery. Segmental contralateral anesthesia, adjacent to the site of injection, occurs in approximately 10% of patients after single-injection PVB and may be due to epidural or prevertebral spread.

Block Preparation

Equipment

- Transducer: High-frequency linear transducer
- Needle: 80- to 100-mm, 21- to 22-gauge needle

Local Anesthetic

Bupivacaine, L-bupivacaine, or ropivacaine diluted to reach an appropriate volume are best suited for analgesia after breast surgery or thoracic wall incisions. Bupivacaine or ropivacaine 0.25% to 0.50% are commonly reported in the literature, not exceeding 0.2 to 0.4 mL/kg^{-1}.

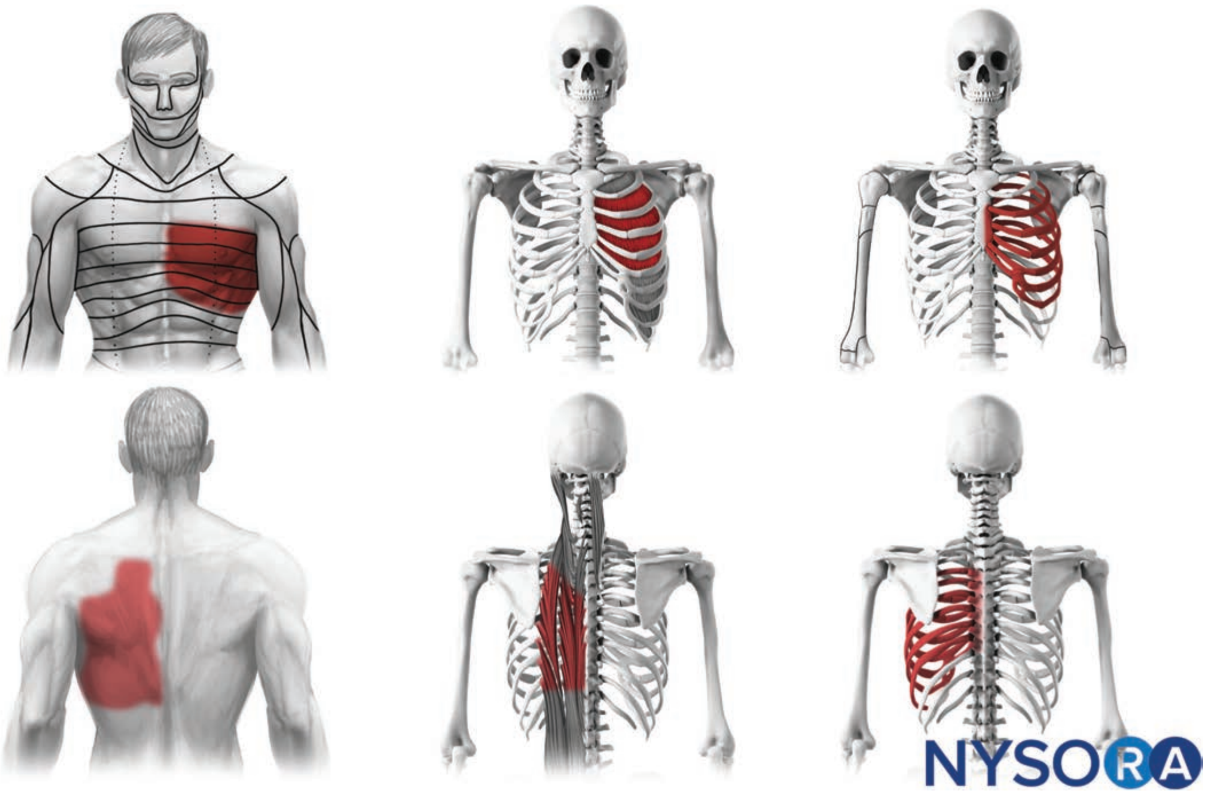


FIGURE 36-3. Distribution of anesthesia after a paravertebral block.

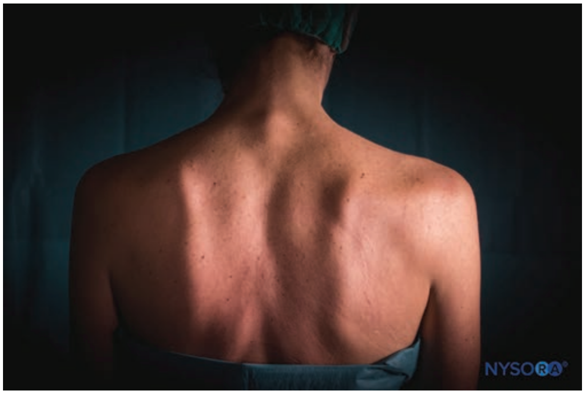


FIGURE 36-4. Patient position for a paravertebral block.

Patient Positioning

The PVB is frequently performed with the patient in a sitting position (Figure 36-4). Alternatively, it can be performed with the patient in the prone or in the lateral position with the side to be blocked facing upwards.

TECHNIQUES

Transverse Oblique

Landmarks and Initial Transducer Position

The transducer is positioned just lateral to the spinous process at the targeted level in a transverse oblique orientation parallel to the course of the ribs. The transverse processes and ribs are visualized as hyperechoic structures with acoustic shadowing below them (Figure 36-5A).

Scanning Technique

Once the transverse processes and ribs are identified, the transducer is moved slightly caudad into the intercostal space to identify the tip of the transverse process and the hyperechoic line of the pleura. By applying slight adjustments, the hyperechoic internal intercostal membrane can be visualized limiting the thoracic PVS and the adjoining intercostal space as a wedge-shaped hypoechoic layer (Figure 36-5B).

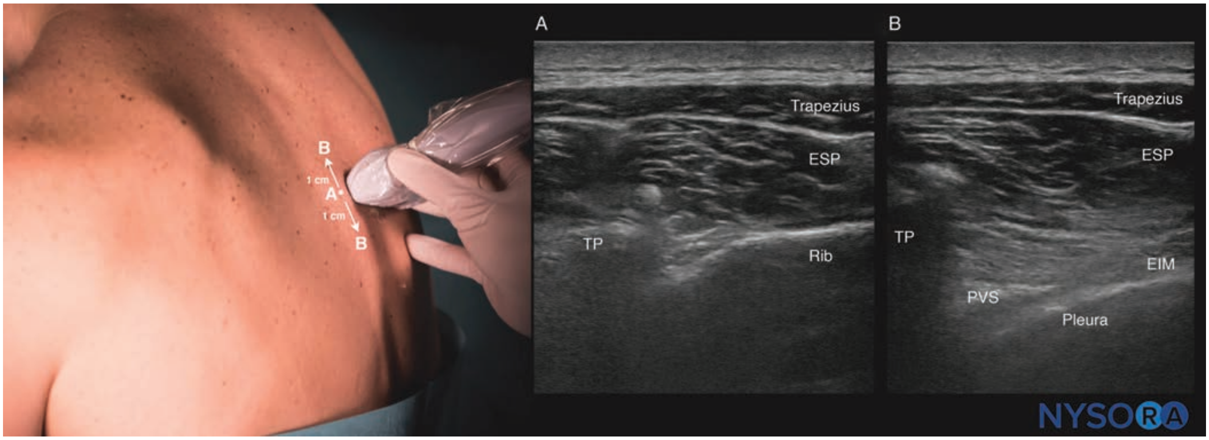


FIGURE 36-5. (A) Initial transducer position in a transverse oblique orientation parallel to the course of the rib, and the corresponding sonoanatomy. (B) Transducer position in transverse oblique orientation at the intercostal space and the corresponding sonoanatomy of the PVS. TP, transverse process; ESP, erector spinae muscles; PVS, paravertebral space; EIM, external intercostal muscle.

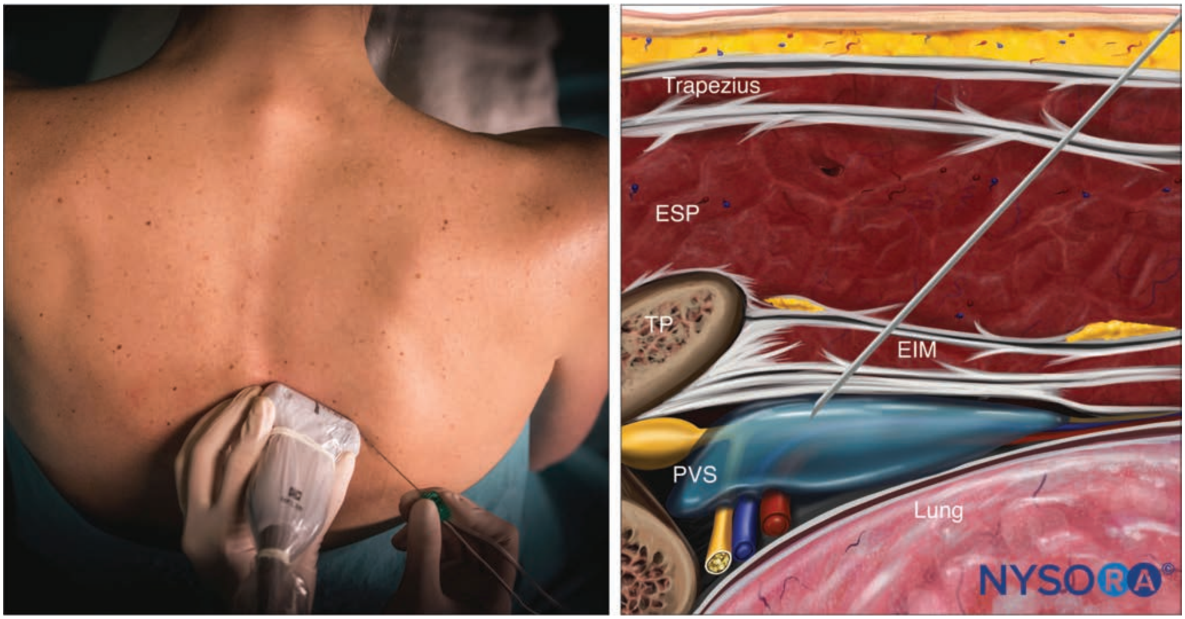


FIGURE 36-6. Reverse ultrasound anatomy of a paravertebral block when the transducer is placed in a transverse oblique orientation. TP, transverse process; ESP, erector spinae muscles; PVS, paravertebral space; EIM, external intercostal muscle.

Needle Approach and Trajectory

The needle is advanced in-plane from lateral to medial toward the PVS and after careful negative aspiration, 1 to 2 mL are injected. The goal of the technique is to inject the LA below the internal intercostal ligament and membrane, resulting in a downward displacement of the pleura, indicating the proper spread of the LA (Figure 36-6).

Sagittal

Landmarks and Initial Transducer Position

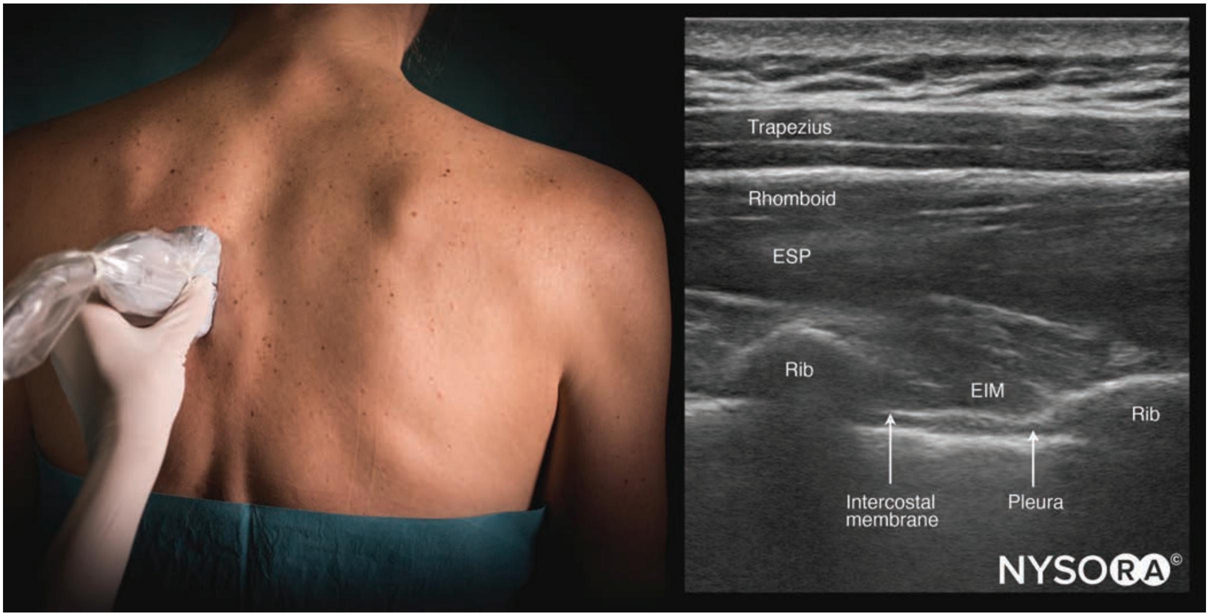
Place the transducer 5 to 6 cm laterally from the midline at the targeted level, and in a sagittal orientation, to identify the rounded ribs and parietal pleura underneath (Figure 36-7A).

Scanning Technique

The transducer is then moved medially progressively until the transverse processes are identified as deeper and square-shaped structures. Too medial transducer placement will yield an image of the laminae, at which point the transducer is moved slightly laterally to image transverse processes. Once the transverse processes are identified, the transducer is slightly tilted laterally to enhance the view of the hyperechoic pleura and the costotransverse ligament (Figure 36-7B).

Needle Approach and Trajectory

The needle is advanced in-plane from caudad to cephalad, or out-of-plane toward the PVS between the costotransverse ligament and the pleura (Figure 36-8). For the out-of-plane approach, the needle is inserted to contact the transverse



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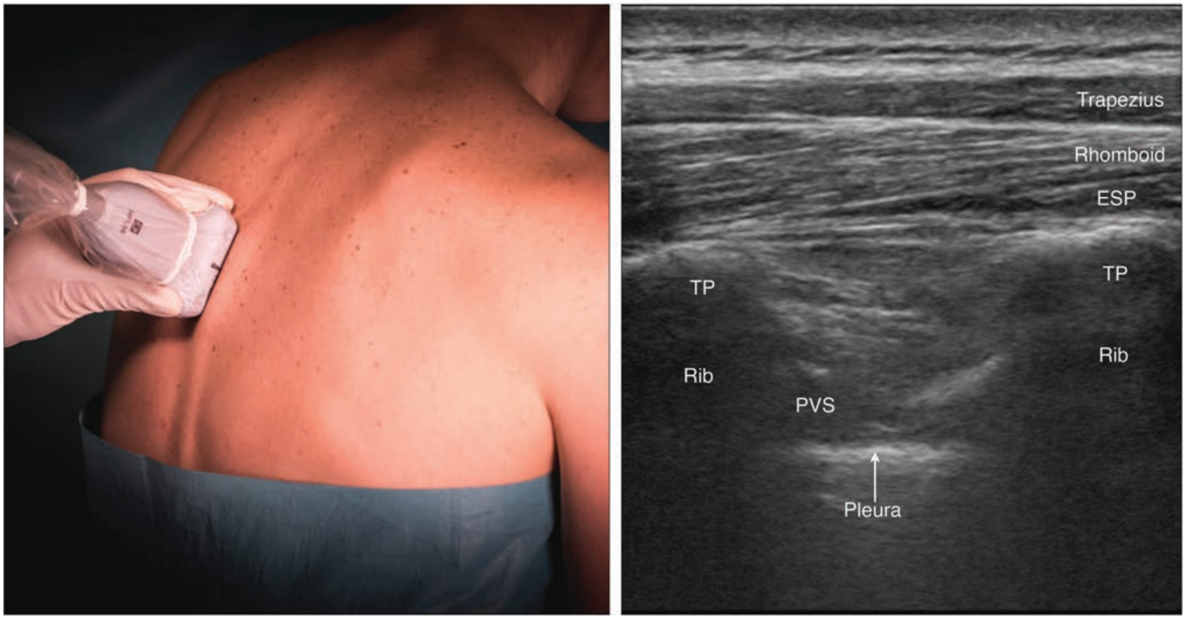


B

FIGURE 36-7. (A) Initial transducer position in a sagittal orientation 5 cm away from the midline and the corresponding sonoanatomy at this location. (B) Moving the transducer medially, the paravertebral space can be seen between the square shapes of the transverse processes and just superficial to the hyperechoic line of the pleura. TP, transverse process; ESP, erector spinae muscles; PVS, paravertebral space; EIM, external intercostal muscle.

FIGURE 36-8. Reverse ultrasound anatomy of a paravertebral block when the transducer is placed in a sagittal orientation. TP, transverse process; PVS, paravertebral space; ESP, erector spinae muscles.

process and then walked off the transfer process 1 to 1.5 cm deeper to inject the LA.

Local Anesthetic Distribution

The goal in both cases is to observe a downward displacement of the pleura. By scanning cranio-caudal, the LA can be seen spreading to the adjacent intertransverse spaces. This technique is then repeated at the desired levels.

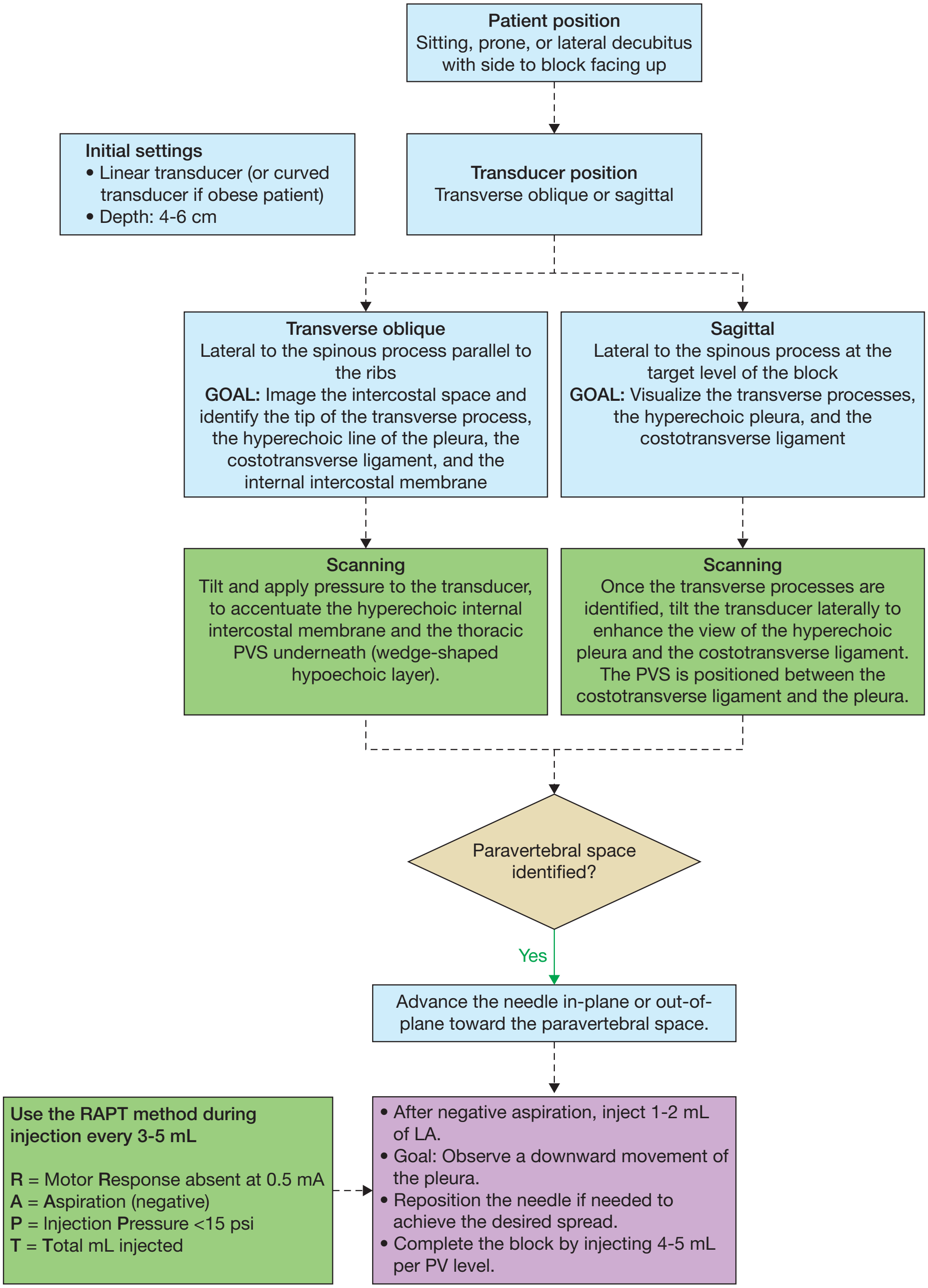
Problem-Solving Tips

Several recommendations are suggested to decrease the risk of potential complications with an ultrasound-guided thoracic PVB:

- For in-plane approaches, the visualization of the needle path at all times is crucial to reduce the risk of needle entry in unwanted locations (pleura, neuraxial space).
- The out-of-plane approach in the sagittal ultrasound-guided technique may be safer than the in-plane approach toward the neuraxis. This technique is analogous to the true-and-tried surface-based techniques with more accurate identification of the transverse processes.
- Insertion of a catheter through the needle placed in the PVS carries a risk of catheter misplacement into the epidural or mediastinal space, or through the pleura into the thoracic cavity.
- Orienting the bevel of the Tuohy needle tip away from the pleura may reduce the risk of penetrating the pleura.
- A fascial “pop” or “click” often is felt as the needle penetrates the internal intercostal membrane, alerting the operator of the needle position in the PVS.
- For a single site injection, LA (15-20 mL) is injected slowly in small increments, avoiding forceful high-pressure injection to reduce the risk of bilateral epidural spread.

Flowchart

Paravertebral Block Technique Algorithm



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37 Erector Spinae Plane Block

BLOCK AT A GLANCE

Interfascial plane injection of local anesthetic (LA) between the erector spinae muscles and the transverse processes at the segmental levels supplying the area of interest.

- **Indications**: Analgesia for rib fractures, back surgery, and chest wall procedures. Other potential indications are currently under investigation
- **Goal:** Spread of an LA in the plane deep to the erector spinae muscles aiming for a craniocaudal distribution along several vertebral levels to block the posterior (and possibly anterior) rami of the spinal nerves
- **Local anesthetic volume:** 20 to 30 mL

General Considerations

The erector spinae plane block (ESPB) is a novel interfascial plane technique, aiming to block the dorsal and ventral rami of the spinal nerves to provide multidermatomal analgesia of the cervical, thoracic, and lumbar levels. Several case reports and few randomized controlled clinical trials have been published supporting the clinical efficacy of the ESPB in a growing number of indications. The mechanisms of action are inadequately understood; spread into the paravertebral space is thought to be one of the possible sites of action but studies describing LA distribution after injection show considerable variability and conflicting results. Published reports describe single-shot techniques, followed by intermittent bolus and continuous infusion, performed primarily at the thoracic, lumbar, and some at the cervical level.

Specific Risks and Limitations

While there is insufficient data to remark on the risk of complications with an ESPB, a case of pneumothorax, a case of partial autonomic neuropathy, and a few cases of hematoma, suggest that the technique is not devoid of risks. Because injection targets can be well-identified with ultrasound (US) and the site of injection is distant from the neuraxis and major vascular structures, the potential for complications could be lower compared to a paravertebral block.

Because ESPB is a volume-dependent interfascial block, systemic levels of LAs could be higher than with most peripheral nerve blocks due to their absorption across a large surface. When performing an ESPB, consider using a pharmacologic marker (e.g., epinephrine), and be conservative with the LA dose especially in high-risk populations (e.g., elderly patients).

Anatomy

The erector spinae muscles comprise the iliocostalis, longissimus, and spinalis. They are located parallel along both sides of the spine; from the skull to the pelvis and sacral region, and from the spinous to the transverse processes extending to the ribs. They vary in size and structure at different levels of the spine. The erector spinae muscles are innervated by the dorsal rami of the spinal nerves and their function is to stabilize, extend, and laterally bend the spine (Figure 37-1).

Cross-Sectional Anatomy and Ultrasound View

The symmetrical erector spinae muscles lie over the transverse process and the lamina. The deep fascial plane is separated from the paravertebral space by the transverse processes and the intertransverse and costotransverse ligaments and muscles.

The roots of the spinal nerves exit the vertebral canal through the intervertebral foramina and divide into dorsal rami, which course posteriorly through the erector spinae to innervate the back musculature and adjacent skin; ventral rami, which continue as intercostal nerves from T1-T12 and innervate the anterolateral chest and abdominal wall; and communicating rami to the sympathetic trunk in the paravertebral space (Figure 37-2).

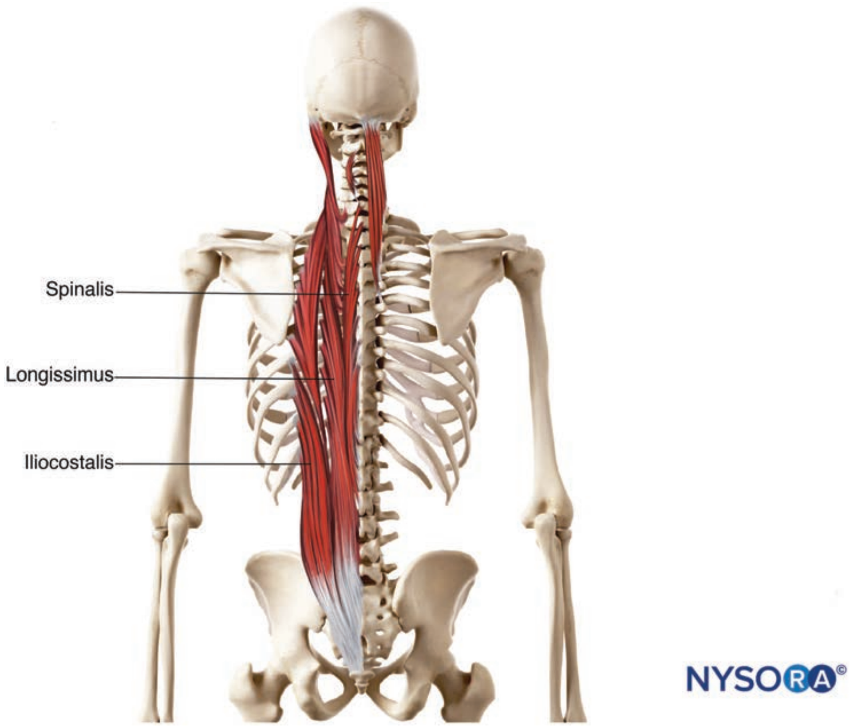


FIGURE 37-1. Anatomy of the erector spinae muscles.

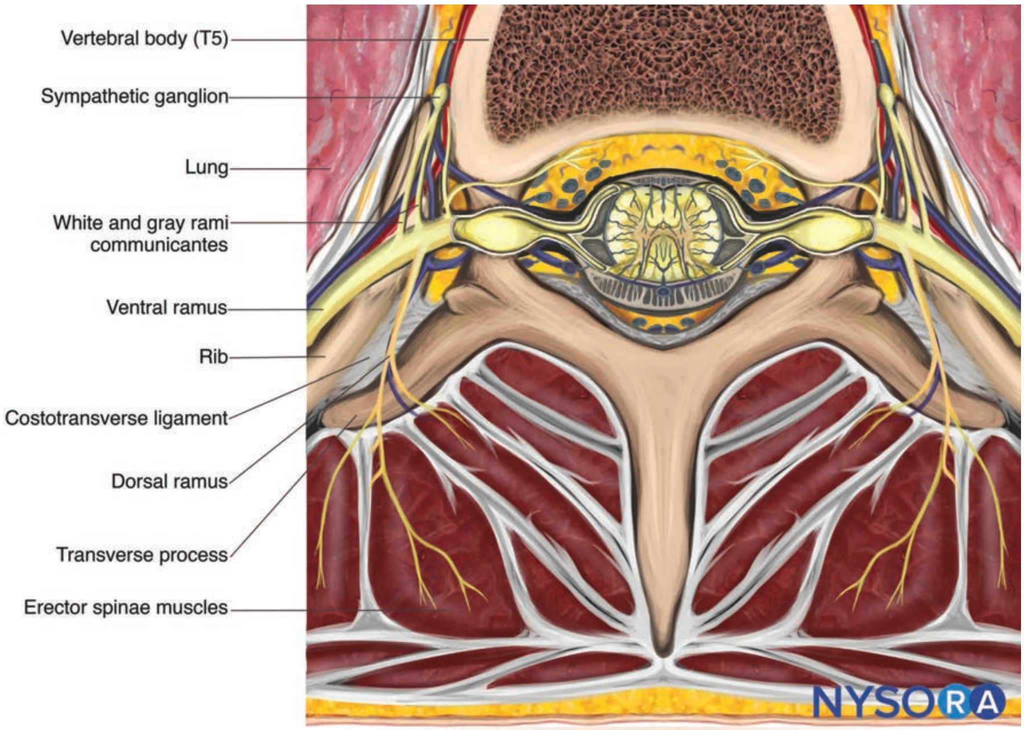


FIGURE 37-2. Cross-section of a thoracic vertebra illustrating a spinal nerve, the ventral and dorsal ramus, and their relationship with the erector spinae muscles.

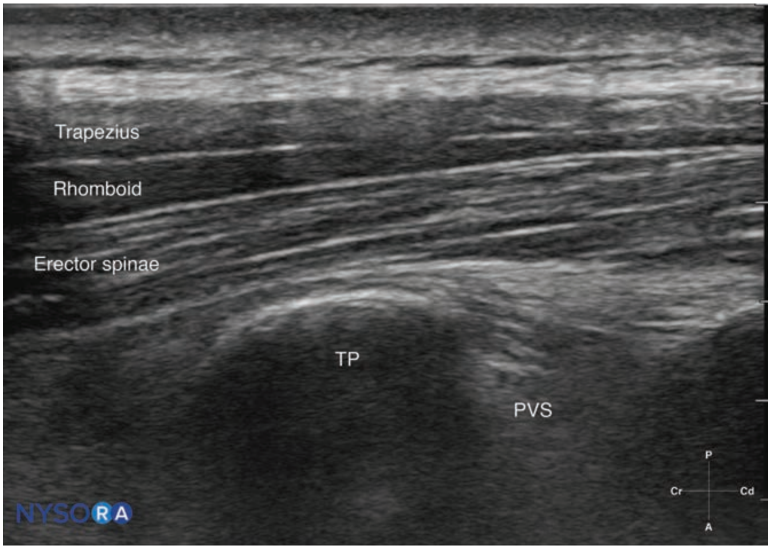


FIGURE 37-3. Sagittal paramedian sonoanatomy for an ESPB. TP, transverse process; PVS, paravertebral space.

Using a linear transducer positioned in a paramedian sagittal orientation, approximately 2 cm away from the midline, the transverse processes are identified as squared hyperechoic lines with an acoustic shadow behind (Figure 37-3). At higher thoracic levels (e.g., above T5), trapezius, rhomboid major, and erector spinae muscles can be identified as three layers superficial to the transverse processes. In the lower and midthoracic levels, only trapezius and erector spinae muscles can be seen.

Distribution of Anesthesia

Mechanisms of nerve blockade and distribution of the LA with this block are not well-understood. Studies suggest that LA after ESPB spreads in a cephalocaudal distribution, reaching mainly the dorsal rami, and rarely the ventral rami of the spinal nerves, and intercostal spaces. Although possible, distribution into the sympathetic chain, paravertebral, and epidural spaces is inconsistent (Figure 37-4).

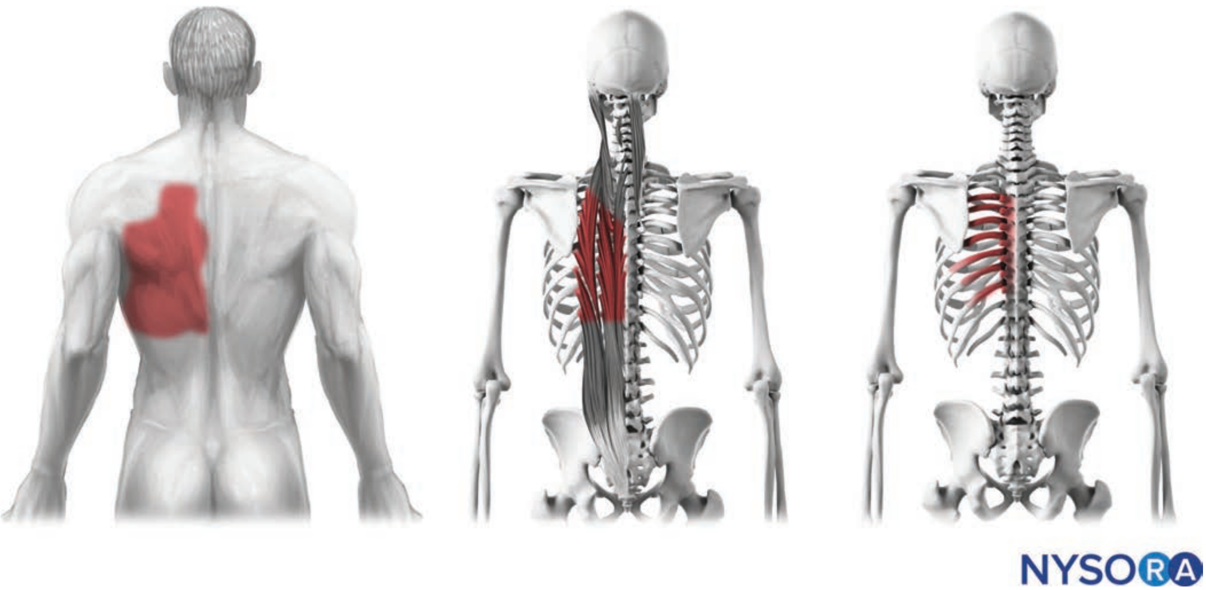


FIGURE 37-4. Sensory distribution of an ESPB.

Block Preparation

Equipment

- Transducer: A high-frequency, linear transducer can be used for thoracic levels, whereas a low-frequency, curved array transducer is better suited for lumbar ESPB.
- Needle: 50- to 100-mm, 22-gauge needle

Local Anesthetic

The ESPB is a fascial plane block; therefore, success depends on the volume of LA injected between the muscle and transverse process. Long-acting LAs or continuous infusions through catheters have been typically used.

Landmarks and Patient Position

The block can be performed with the patient in a sitting, lateral decubitus, or prone position. Identify the desired level of injection by counting down from the first rib (with US), or by palpating the bony landmarks of the back, and their corresponding vertebral levels (Figure 37-5).

Consider that after injection, the LA spreads both caudally and cranially; therefore, the targeted transverse process (level for the block) should be a central point according to the required levels for analgesia.

Technique

Initial Transducer Position and Scanning Technique

The transducer is placed in a paramedian sagittal orientation over the selected area approximately 2 cm away from the midline.

If the transducer is placed too medial, the thoracic laminae will be visualized as flat hyperechoic lines; slide the transducer laterally. When the transducer is placed too lateral, the ribs

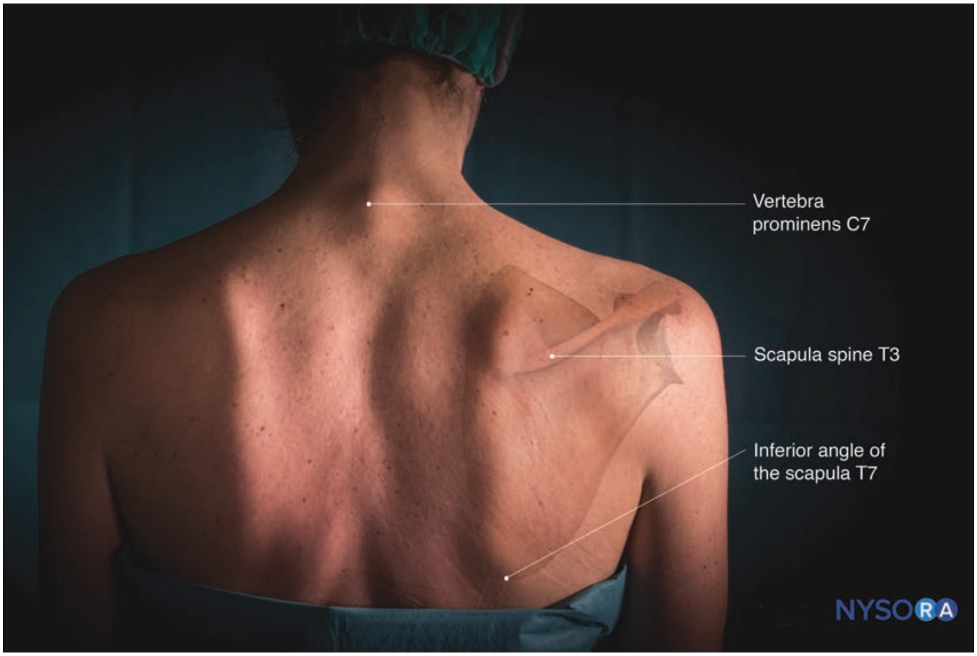


FIGURE 37-5. Patient position for an ESPB.

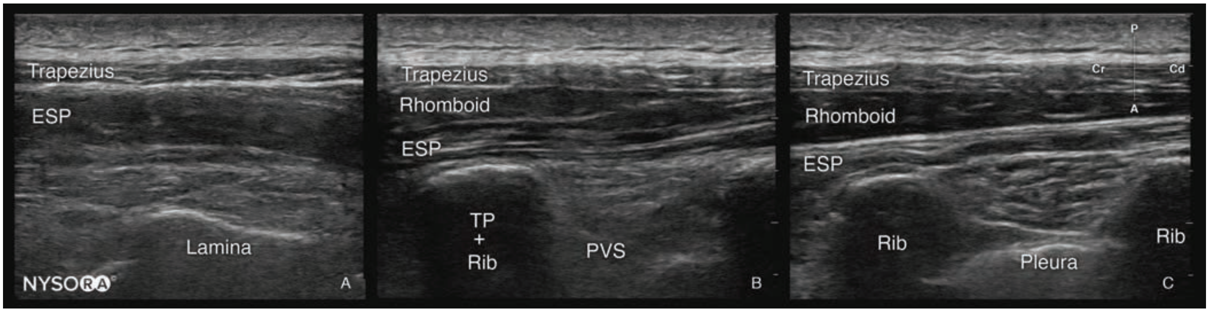


FIGURE 37-6. Scanning during an ESPB. (A) Transducer is placed too medial. (B) Adequate transducer position for an ESPB. (C) Transducer placed too lateral. ESP, erector spinae; TP, transverse process; PVS, paravertebral space; Cr, cranial; Cd, caudad; A, anterior; P, posterior.

will be visualized as round hyperechoic lines with an acoustic shadow underneath and an intermediate hyperechoic pleural line; slide the transducer medially (Figure 37-6). The transverse processes are identified as flat squared hyperechoic lines with an acoustic shadow behind. Note that with the transducer perpendicular to the transverse processes, the pleura is not visualized at the level where the block is performed (Figure 37-7).

Needle Approach and Trajectory

The needle is inserted in-plane in a cranial-to-caudal (or caudal-to-cranial) orientation until the needle tip contacts the transverse process. To confirm proper needle position, 1-3 mL of LA are injected.

Local Anesthetic Distribution

The spread should occur deep to the erector spinae muscle and superficial to the transverse process, extending to the adjacent levels.

The total volume to complete the block is 20 to 30 mL of LA spreading along the fascial plane deep several vertebral levels (Figure 37-8).

Problem-Solving Tips

- A high-frequency linear transducer can be used for lower thoracic levels, whereas a low-frequency curved array transducer may be better suited for lumbar injections or obese patients, where the erector spinae layers are deeper (greater depth than 4 cm).
- In-plane or out-of-plane needle insertion can be used.
- When pleura is imaged at any time, the transducer is placed or tilted too lateral. Slide medially and keep the transducer perpendicular until the transverse processes are identified and the pleura is no longer seen.
- ESPB is a fascial plane technique—therefore a volume-dependent block for success. However, be aware of the total dose of LAs, keeping in mind the risk of local anesthetic systemic toxicity (LAST) and resuscitative measures should it occur.
- Although multidermatomal coverage is usually expected, aim for injection at a vertebral level corresponding to the surgical incision. In continuous techniques, it is recommended that the catheter tip is also located at this level.
- For ESPB catheters, first inject 5 mL of LA to create a space in which the catheter can then be advanced.

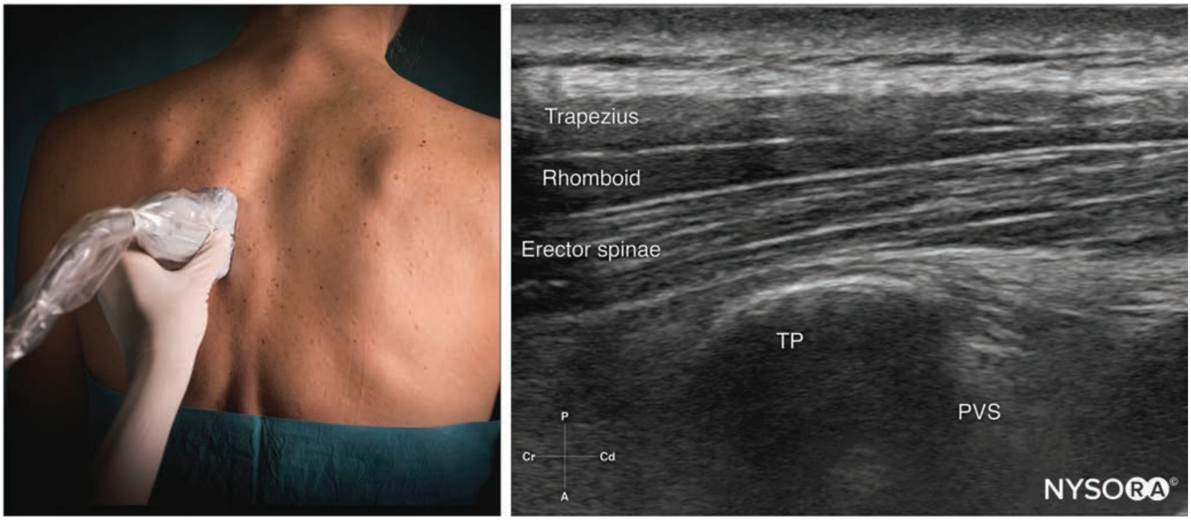


FIGURE 37-7. Transducer position and sonoanatomy to perform an ESPB at the level of T5. TP, transverse process; PVS, paravertebral space; Cr, cranial; Cd, caudad; A, anterior; P, posterior.

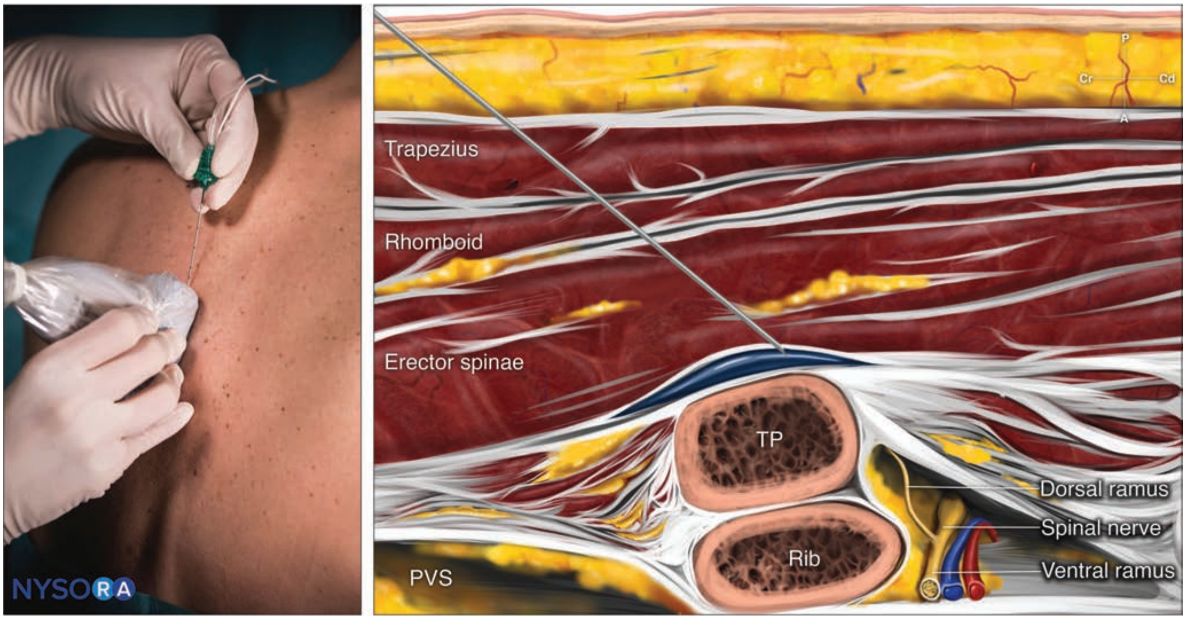
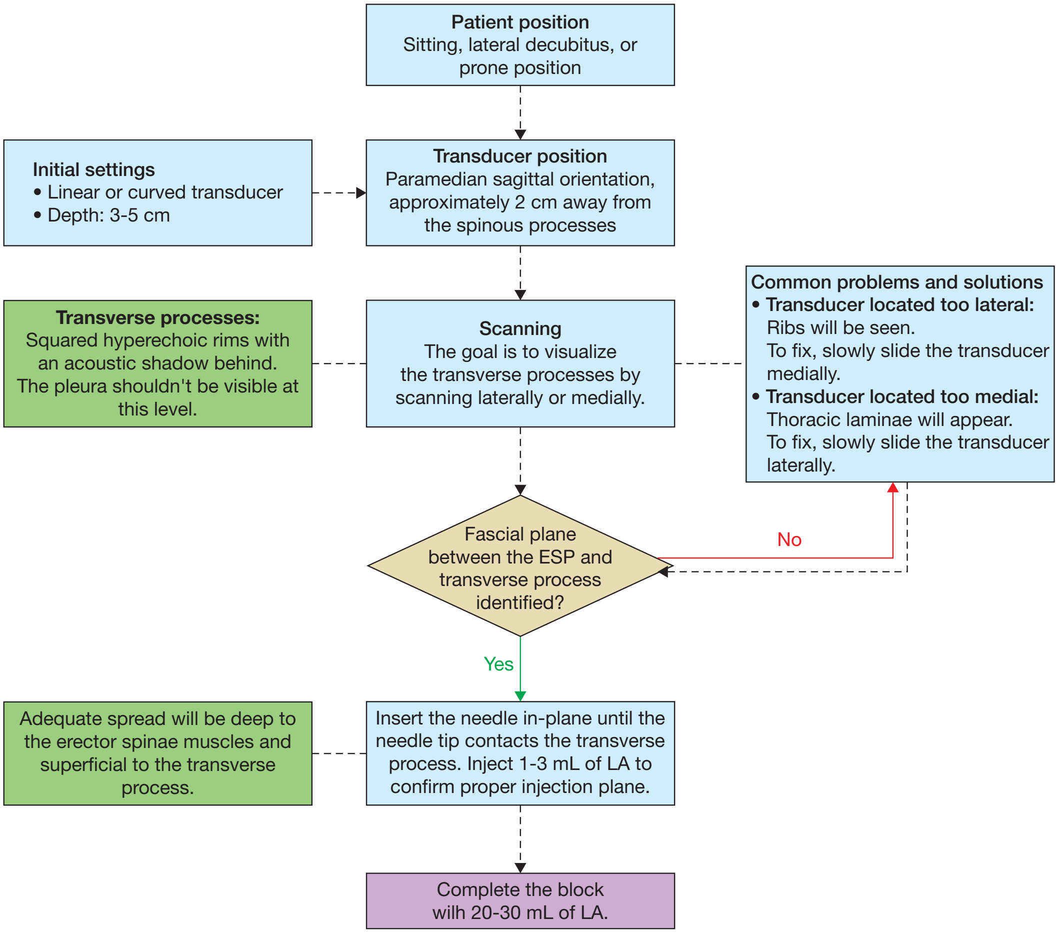


FIGURE 37-8. Reverse ultrasound anatomy of an ESPB with needle insertion in-plane. Also visualized: A spinal nerve exiting from the paravertebral space (PVS) and the dorsal ramus traveling posteriorly to innervate the back muscles. TP, transverse process; Cr, cranial; Cd, caudad; A, anterior; P, posterior.

Flowchart

Erector Spinae Plane Block Technique Algorithm



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38 Transversus Abdominis Plane Blocks

BLOCK AT A GLANCE

Fascial plane injections of the local anesthetic (LA) between the transversus abdominis and internal oblique muscles.

- **Indications**: Analgesia for the abdominal wall and the parietal peritoneum
- **Goal:** Spread of an LA in the plane to block the lateral and anterior branches of the spinal nerves T6-L1
- **Local anesthetic volume:** 10 to 20 mL per site, depending on the required block extension and the maximum recommended dose

General Considerations

The ultrasound (US)-guided transversus abdominis plane (TAP) block is a commonly used analgesic technique for surgeries involving the abdominal wall, as part of a multimodal postoperative pain treatment. Analgesia with a TAP block is limited to the somatic component and highly dependent on the extent of interfascial spread. Several approaches along the fascial plane have been described to block specific areas of the abdominal wall. The efficacy of a TAP block has been documented in a variety of indications, such as cesarean delivery, hysterectomy, cholecystectomy, colectomy, prostatectomy, and hernia repair.

Limitations

Similar to other fascial plane infiltrations, the duration, extent, and quality of the analgesia show considerable variability, which depends on the amount of LA that effectively reaches the targeted nerves.

Anatomy

Analgesic effects of the US-guided TAP block can be explained by the organization of the thoracolumbar nerves along the musculofascial anatomy of the anterolateral abdominal wall. There are four paired muscles in the anterolateral abdominal wall: the rectus abdominis (superficial, parallel in the midline), the external oblique, internal oblique, and transversus abdominis muscles (deep and most lateral). The myofascial plane of interest for the TAP block is located between the transversus abdominis and the internal oblique muscles.

The abdominal wall is innervated by the thoracoabdominal nerves (T6-T12) and the ilioinguinal/iliohypogastric nerves (L1). After emerging from the paravertebral space, the ventral rami of the intercostal nerves travel into the TAP plane between the transversus abdominis and the internal oblique muscles. At the level of the midaxillary line, the ventral rami give out the perforating lateral cutaneous branches, which innervate the lateral abdominal wall. Segmental nerves from T6-T9 enter the TAP medial to the anterior axillary line, while the other nerves enter progressively more laterally. Intercostal nerves eventually enter the sheath of the rectus abdominis muscle at its lateral margin (linea semilunaris). Here, the intercostal nerves give out the perforating anterior cutaneous branches that provide innervation of the anteromedial abdominal wall (Figure 38-1). The transversalis fascia covers the internal surface of the transversus abdominis muscle and aponeurosis, separating them from the underlying preperitoneal fat and peritoneum.

Cross-Sectional Anatomy and Ultrasound View

The disposition and interrelation of the muscular layers of the abdominal wall vary depending on the level of the cross-section. (Figure 38-2).

When a linear transducer is positioned transversely over the abdominal wall, the abdominal muscles are identified as long hypoechoic structures deep to the subcutaneous tissue.

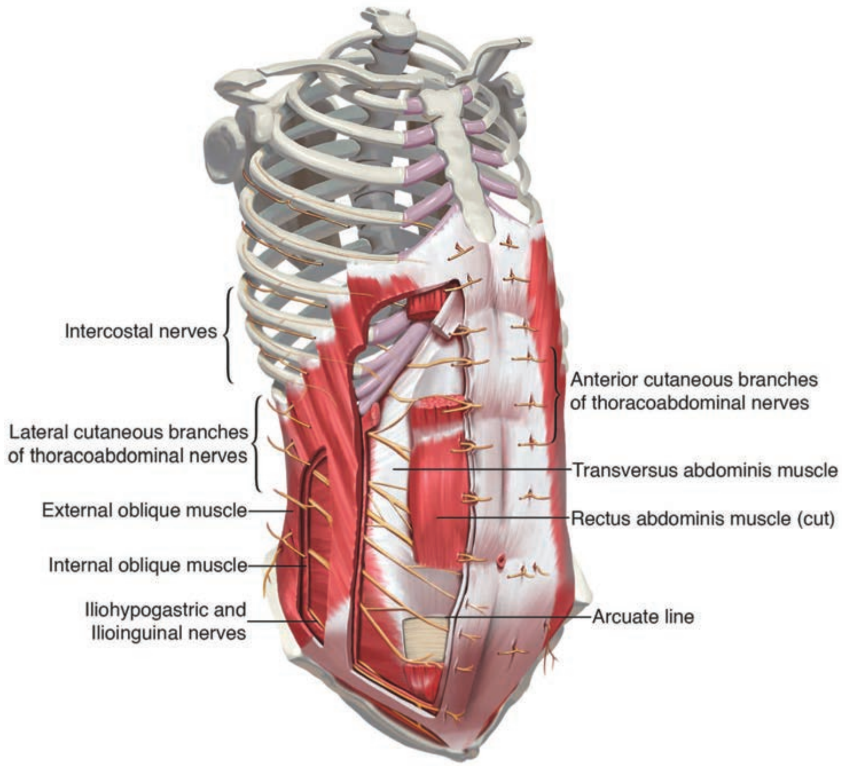


FIGURE 38-1. Anatomy and innervation of the abdominal wall.

The external oblique is the most superficial, the internal oblique is located in between, and the transversus abdominis is the deepest. The fasciae enveloping each muscle are visualized as hyperechoic layers that aid recognition of the myofascial planes. Deep to the transversus abdominis muscle, the fascia transversalis and peritoneum appear also as hyperechoic lines, hardly differentiable from each other.

Distribution of Analgesia

The distribution of somatic analgesia with a TAP block depends on the injection site and the volume of LA used (Figure 38-3). A **subcostal approach** to the TAP block will result in a cutaneous sensory block of the ipsilateral upper quadrant of the anterior abdominal wall. When the injection is medial to the linea semilunaris T6-T7 will be covered, whereas a more lateral injection will cover T9-T10. Of note, the skin lateral to the anterior axillary line will not be covered. However, a **lateral approach** to the TAP will block the skin covering the ipsilateral lower quadrant of the abdominal wall, T10-T12 dermatomes, while L1 will not be consistently covered. The **posterior approach** may block the T9-T12 dermatomes of the anterior and possibly the lateral abdominal wall between the costal margin and iliac crest. The **ilioinguinal and iliohypogastric block** will anesthetize the L1 dermatome (skin of the inguinal area).

Block Preparation

Equipment

- Transducer: High-frequency linear transducer
- Needle: 50- to 100-mm, 22- to 25-gauge needle

Local Anesthetic

Usually, a large volume of low-concentration LA is required for the effectiveness of the TAP block. A minimum volume of 15 mL is recommended for a single injection site (0.2-0.3 mL/kg). Always keep in mind the weight of the patient to ensure that the maximum safe dose is not exceeded. This is especially important when a bilateral or combined TAP

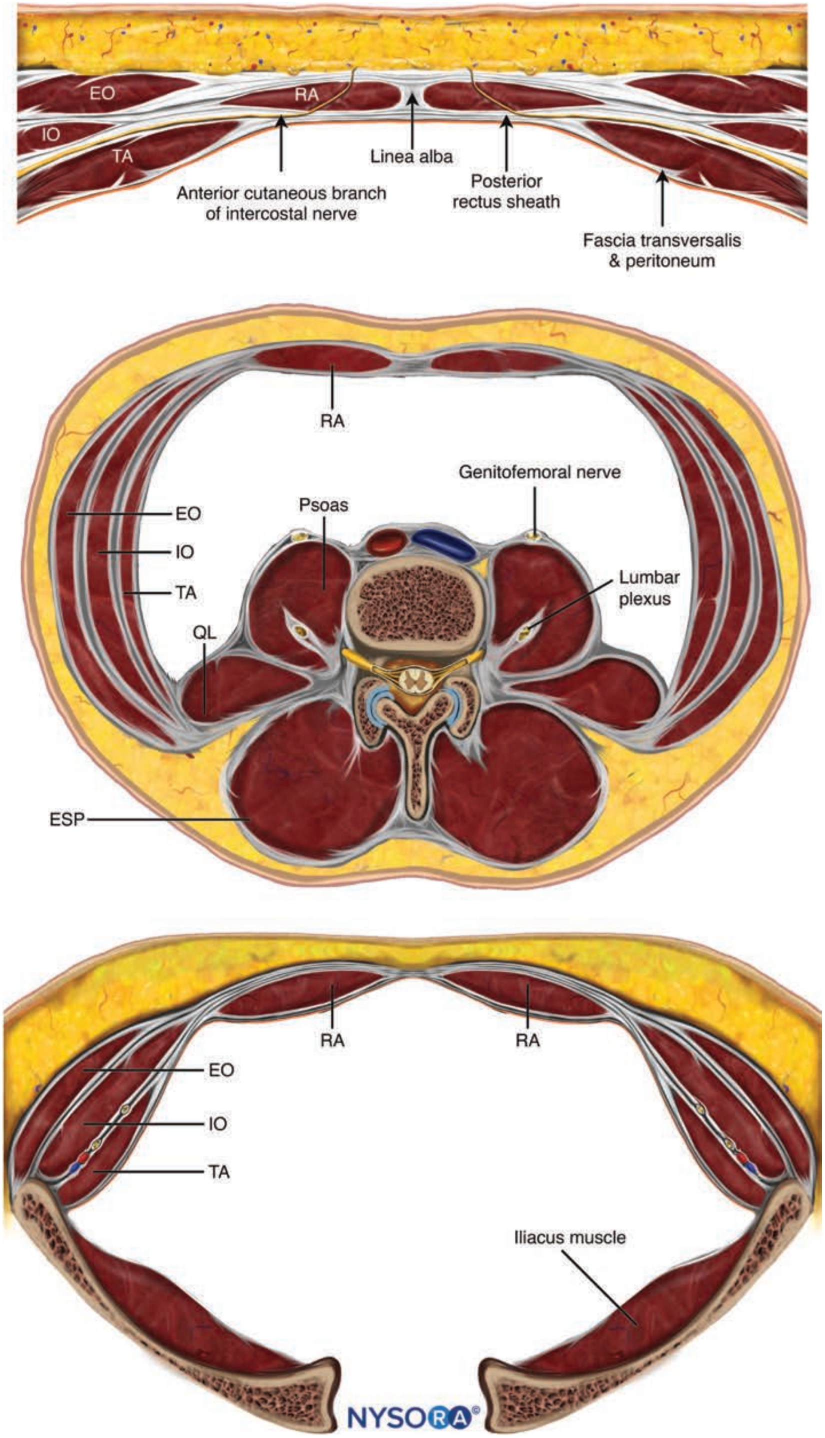


FIGURE 38-2. Crossection of the popliteal fossa proximally to the femur condyles. BF, biceps femoris muscle; CPN, common peroneal nerve; PA, popliteal artery; PV, popliteal vein; SmM, semimembranosus muscle; TN, tibial nerve.

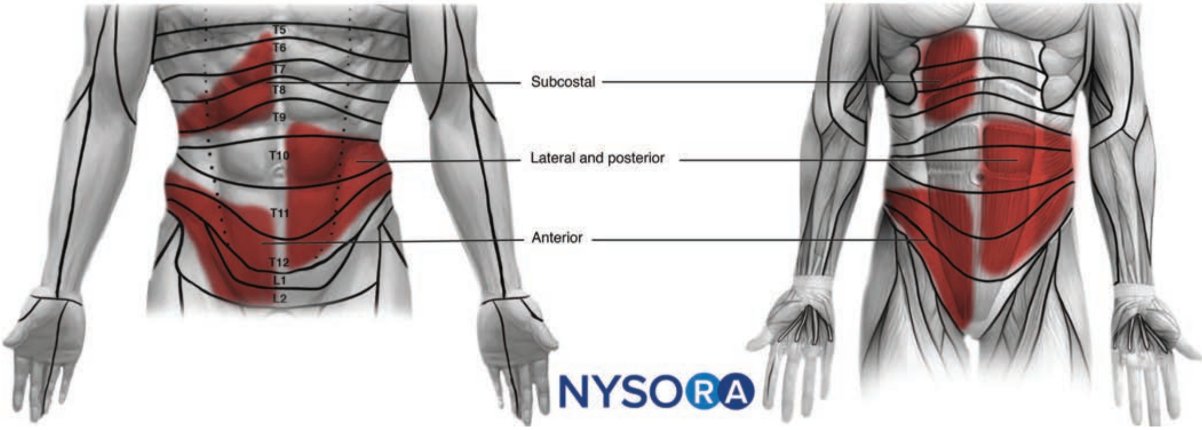


FIGURE 38-3. Analgesia distribution of a TAP block.

blocks are to be performed, or when a TAP block is combined with other interventional analgesia techniques.

Patient Positioning

For the subcostal, lateral, and ilioinguinal-iliohypogastric approaches, the patient is placed in a supine position. For the posterior approach, a lateral or semilateral decubitus position is required.

TECHNIQUES

A. Ultrasound-Guided Subcostal TAP Block

Landmarks and Initial Probe Position

The transducer is placed in an oblique orientation, alongside the lower margin of the rib cage, lateral to the xiphoid process as medial and cranial as possible.

Scanning Technique and Injection Sites

The rectus abdominis muscle and its posterior sheath are visualized superficial to the transversus abdominis muscle. At this level, only the aponeurosis of the internal oblique is visible between the transversus and the external oblique muscles. Applying some pressure and tilting the transducer may help to optimize the image for better identification of the myofascial planes (Figure 38-4).

Needle Approach and Trajectory

The needle is inserted in-plane and advanced from medial to lateral (alternatively, lateral to medial). The endpoint of injection is the fascial plane between the rectus abdominis and the transversus abdominis muscle (injection site 1) or between the internal oblique and the transversus abdominis muscles (injection site 2). Of note, when T6-T8 coverage is desired, the injection point should be between the rectus and transverse abdominis muscles (Figure 38-5).

B. Ultrasound-Guided Lateral TAP Block

Landmarks and Initial Probe Position

The transducer is placed in a transverse orientation over the midaxillary line between the subcostal margin and the iliac crest (Figure 38-6).

Scanning Technique

The three hypoechoic layers of the abdominal wall muscles are visualized; from superficial to deep are the external oblique, internal oblique, and the transversus abdominis muscles.

Needle Approach and Trajectory

The needle is inserted in-plane at the anterior axillary line and advanced in an anterior-to-posterior direction. The endpoint of injection is the fascial plane between the internal oblique and transversus abdominis muscle approximately in the midaxillary line (Figure 38-7).

C. Ultrasound-Guided Posterior TAP Block

An alternative approach is to inject the LA in the most posterior end of the TAP, close to the quadratus lumborum.

Landmarks and Initial Probe Position

With the patient in a lateral decubitus position, the transducer is placed in a transverse orientation over the midaxillary line between the subcostal margin and the iliac crest (Figure 38-8).

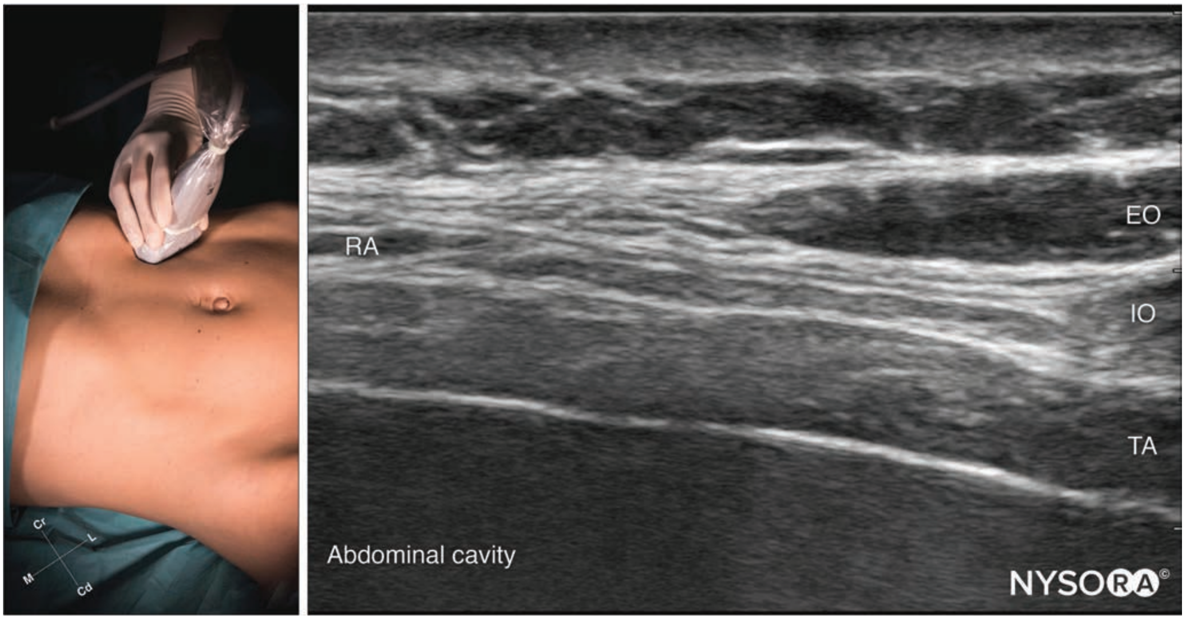


FIGURE 38-4. Transducer position and sonoanatomy to perform a subcostal TAP block. RA, rectus abdominis; EO, external oblique; IO, internal oblique; TA, transversus abdominis.

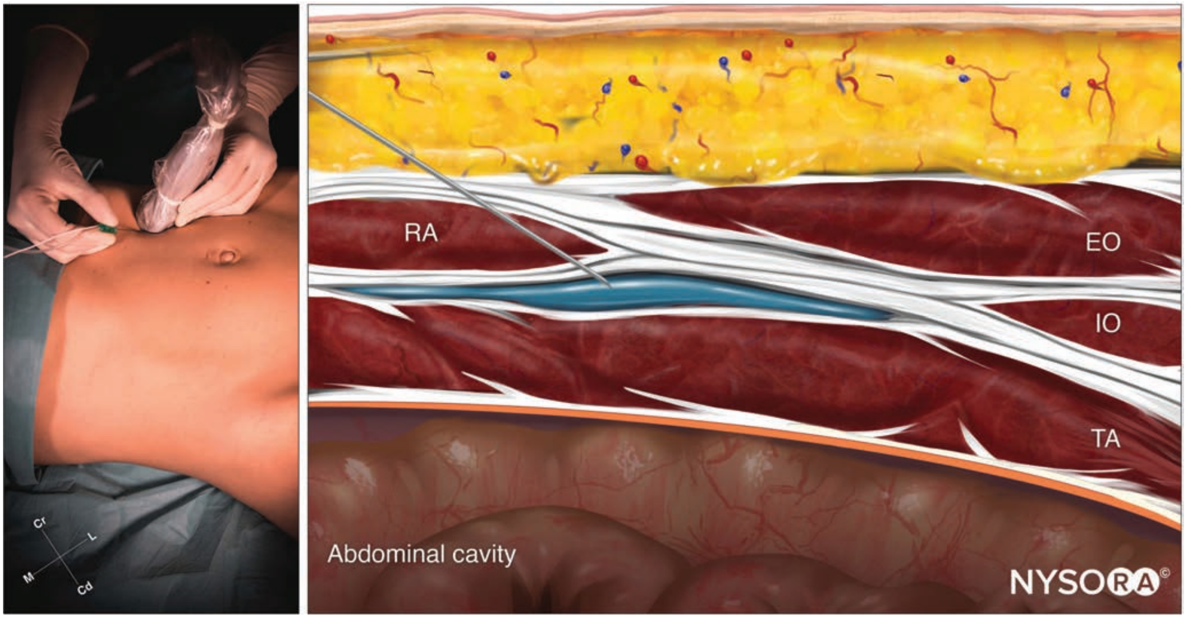


FIGURE 38-5. Subcostal TAP block; reverse ultrasound anatomy showing needle insertion in-plane. RA, rectus abdominis; EO, external oblique; IO, internal oblique; TA, transversus abdominis.

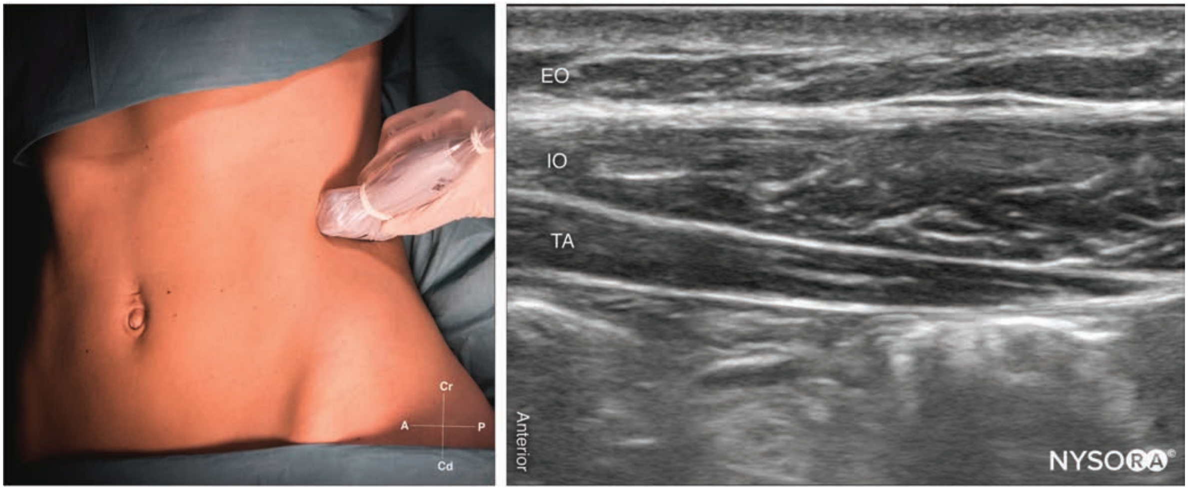


FIGURE 38-6. Transducer position and sonoanatomy to perform a lateral TAP block. EO, external oblique; IO, internal oblique; TA, transversus abdominis.

Scanning Technique

The abdominal wall muscles are identified and the transducer is moved posteriorly following the fascial plane between the internal oblique and transversus abdominis muscles until their posterior insertion. The target is the most posterior end of the TAP lateral to the quadratus lumborum muscle.

Needle Approach and Trajectory

The needle is inserted in-plane in the midaxillary line, from anterior to posterior and advanced through the abdominal muscles until it reaches the end of the TAP, always superficial to the fascia transversalis (Figure 38-9).

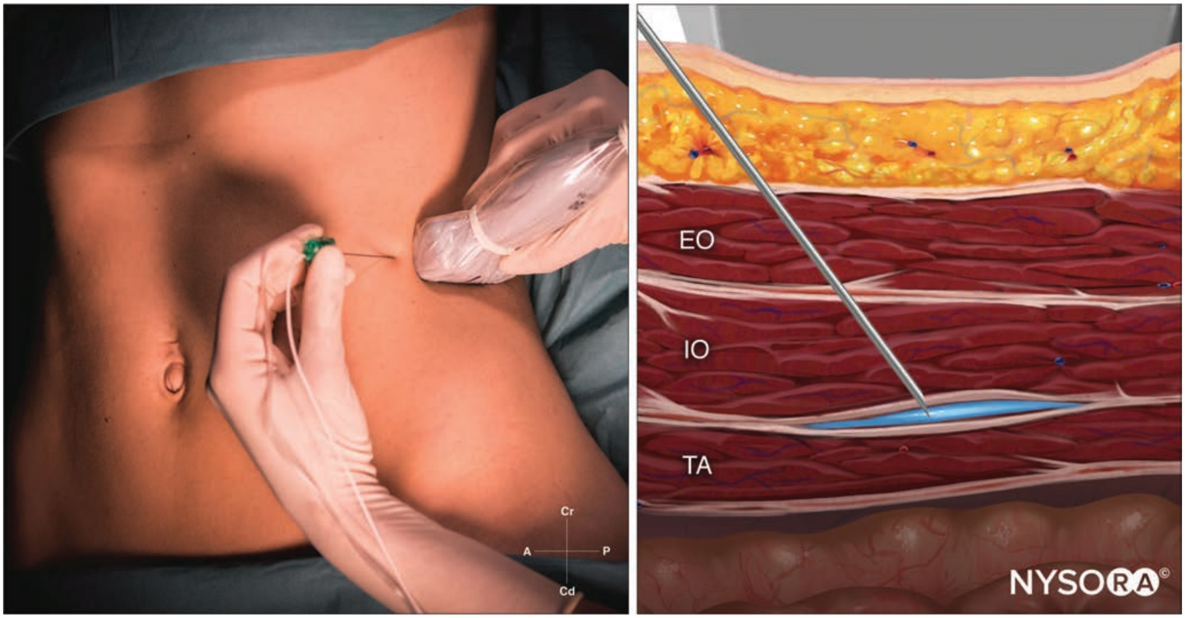


FIGURE 38-7. Lateral TAP block; reverse ultrasound anatomy showing needle insertion in-plane. EO, external oblique; IO, internal oblique; TA, transversus abdominis.

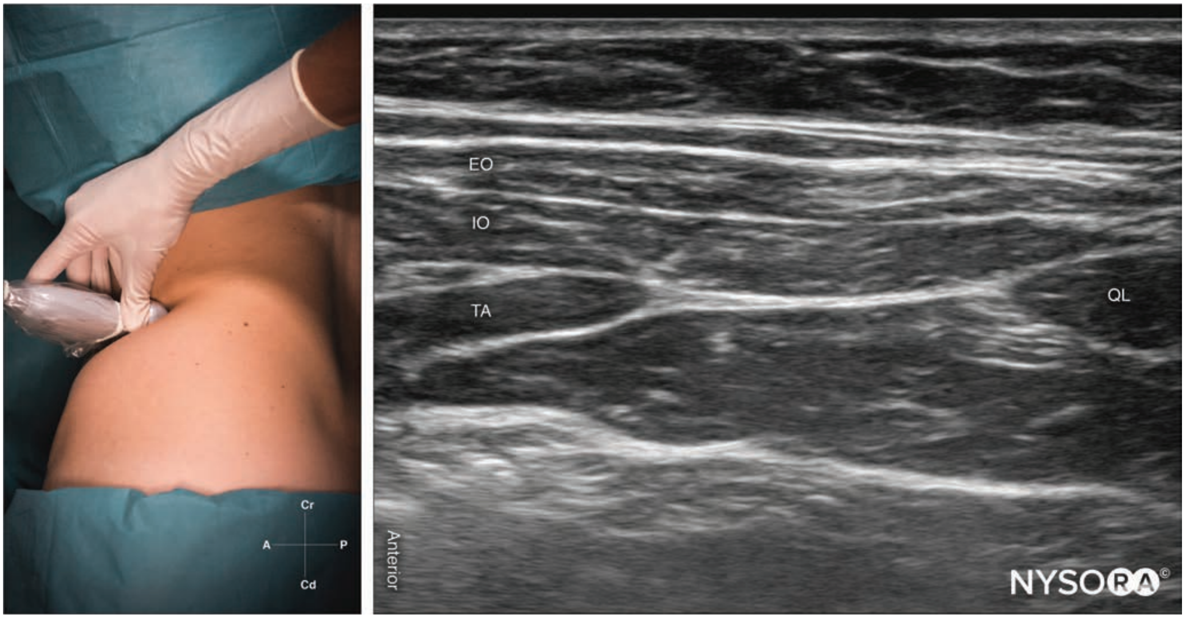


FIGURE 38-8. Transducer position and sonoanatomy to perform a posterior TAP block. EO, external oblique; IO, internal oblique; TA, transversus abdominis; QL, quadratus lumborum.

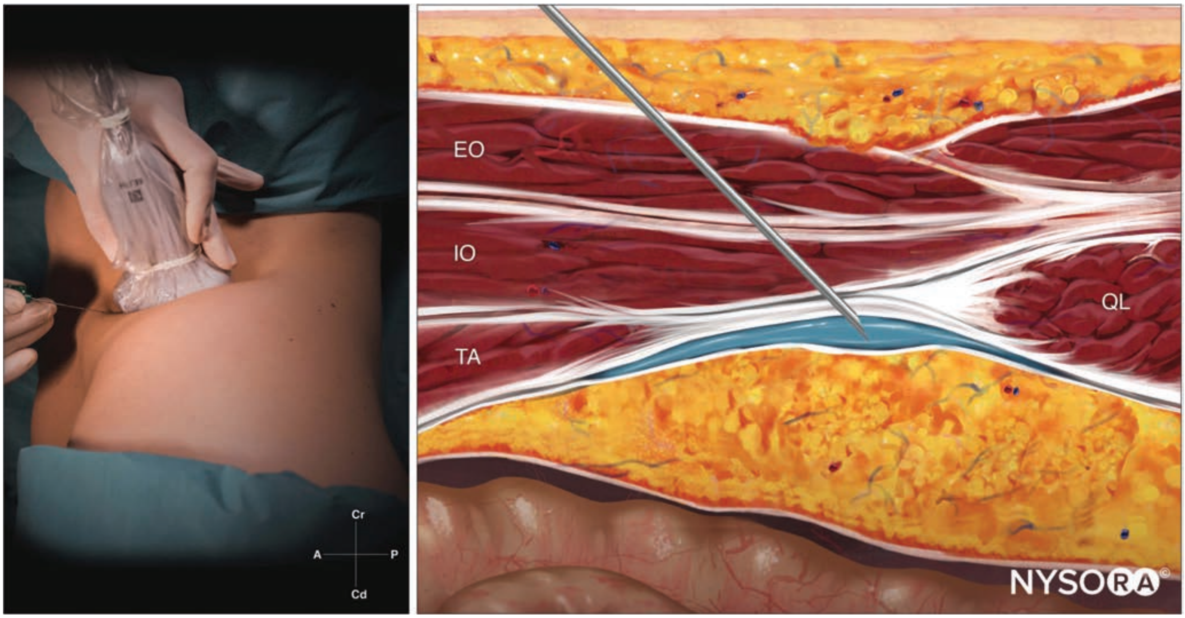


FIGURE 38-9. Posterior TAP block; reverse ultrasound anatomy showing needle insertion in-plane. EO, external oblique; IO, internal oblique; TA, transversus abdominis; QL, quadratus lumborum.

D. Ultrasound-Guided Ilioinguinal-Iliohypogastric Block (Anterior TAP Block)

Landmarks and Initial Probe Position

The transducer is placed in an oblique orientation with the lateral edge over the anterior superior iliac spine (ASIS) and the medial edge pointing toward the umbilicus (**Figure 38-10**).

Scanning Technique

Applying pressure while tilting the transducer caudally can optimize visualization of the three muscle layers of the anterior abdominal wall: external oblique, internal oblique, and transversus abdominis. If only two muscular layers are seen, the transducer should be moved further cephalad and laterally until the three muscles are visualized.

Needle Approach and Trajectory

The needle is inserted in-plane, medial-to-lateral or lateral-to medial, and advanced until the needle tip is placed between the internal oblique and transversus abdominis muscle (**Figure 38-11**).

Problem-Solving Tips

- For precise identification of the muscular layers, trace them to the anterior or posterior insertion where they can be better differentiated.
- As the direction of the muscular fibers differs between the three layers, tilting the probe in both directions helps to identify their limits.
- Ilioinguinal and iliohypogastric block: If only internal oblique and transversus abdominis muscles are identified, the nerves may have already left TAP and be superficial to the internal oblique muscle after piercing it. The transducer should be repositioned by scanning more cranially and laterally until the three layers of muscles are visualized.
- Ilioinguinal-iliohypogastric block: Color Doppler may help identify the circumflex iliac artery, helping confirm the proper injection plane.
- For success with a TAP block, choose the best fitting approach by considering the distribution of segmental nerves.
- An out-of-plane technique may be better in obese patients. Administer intermittent small boluses (0.5-1 mL) as the needle is advanced through the internal oblique muscle to confirm the position of the needle tip.

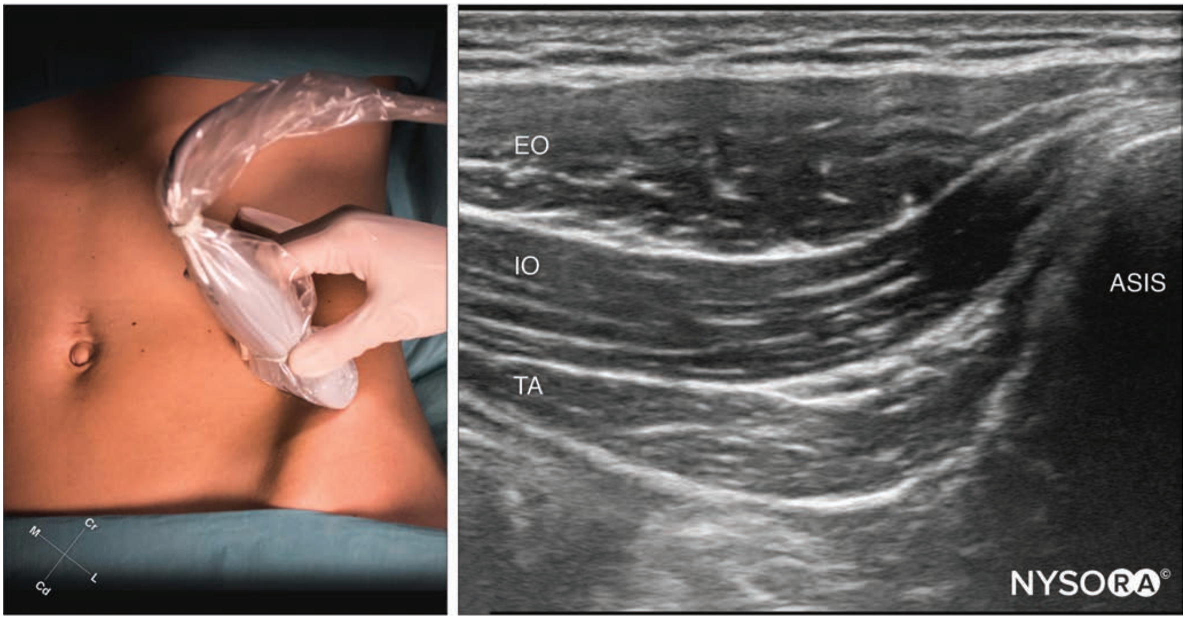


FIGURE 38-10. Transducer position and sonoanatomy to perform an anterior TAP block. EO, external oblique; IO, internal oblique; TA, transversus abdominis; ASIS, anterior superior iliac spine.

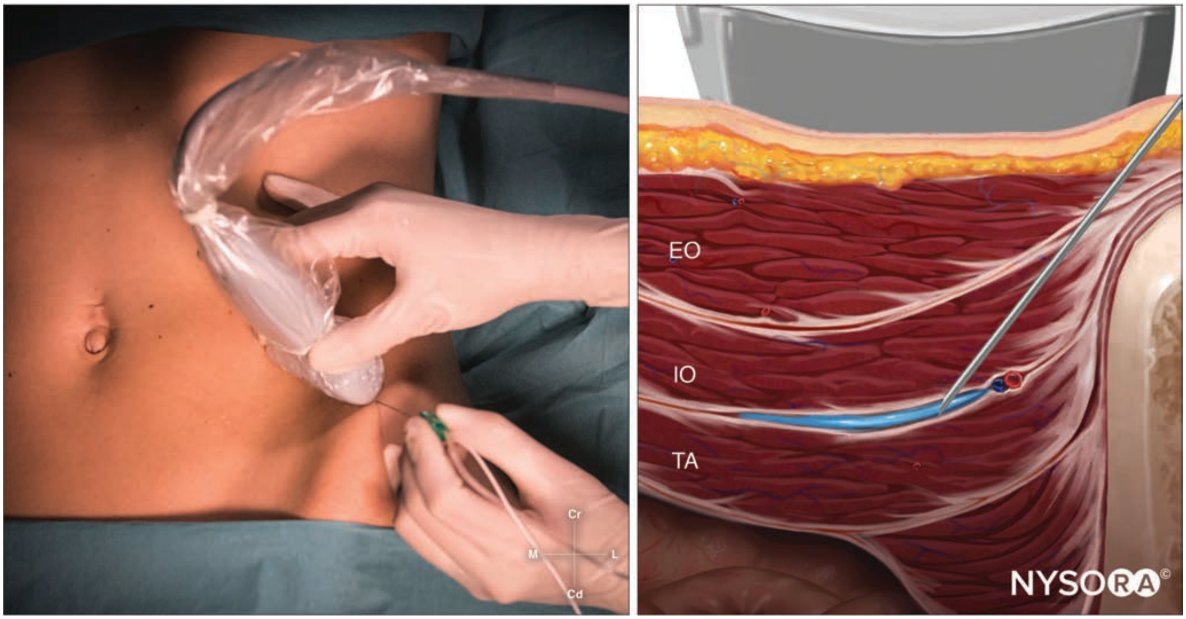
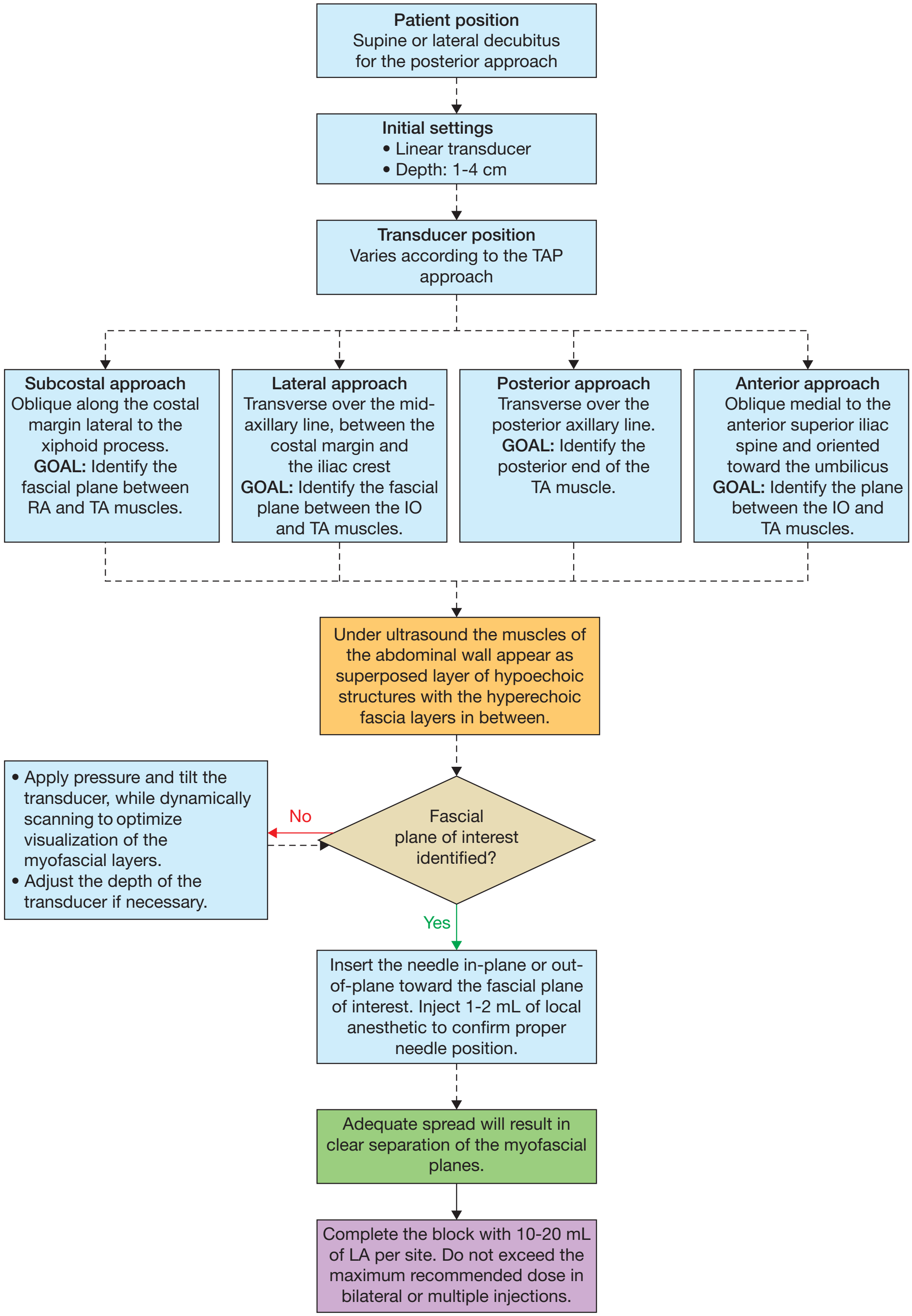


FIGURE 38-11. Anterior TAP block; reverse ultrasound anatomy showing needle insertion in-plane. EO, external oblique; IO, internal oblique; TA, transversus abdominis.

Flowchart

Transversus Abdominis Plane (Tap) Block Technique Algorithm



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39 Rectus Sheath Block

BLOCK AT A GLANCE

Fascial plane injection of local anesthetic (LA) between the rectus abdominis muscle and its posterior sheath.

- **Indications:** Postoperative analgesia for midline abdominal incisions (e.g., umbilical hernia repair, periumbilical surgeries)
- **Goal:** Spread of the LA along the fascial plane to block the anterior cutaneous branches of the intercostal nerves
- **Local anesthetic volume:** 10 to 15 mL

General Considerations

The rectus sheath block provides somatic analgesia at the abdominal midline, therefore it is indicated in abdominal surgery involving a midline laparotomy. The block is commonly used in the pediatric population for umbilical hernia repair. In adults, it is also used for single-incision cholecystectomy and some gynecologic procedures. Ultrasound (US) guidance allows for greater reliability in administering LA in the correct plane, making this block more reproducible, and decreasing the risk for potential for complications. Continuous rectus sheath blocks have also been also described in patients after laparotomy. Among the reported advantages are reduced opioid requirements, earlier mobilization, and avoidance of complications related to neuraxial techniques.

Limitations

The duration, extent, and quality of analgesia with a rectus sheath block can vary. As with other fascial plane techniques, efficacy depends on the spread of the LA, and therefore, the volume of LA that reaches the targeted nerves. Although ultrasound may reduce the risk of complications, peritoneal and bowel puncture can occur if the needle depth and path are not controlled. Puncture of the epigastric vessels that may be in the path of the needle can lead to hematoma formation in the rectus sheath.

Anatomy

The rectus abdominis muscles are vertically paired, oval-shaped muscles on the anterior abdominal wall. They are connected together in the midline by the linea alba. They originate from the pubic symphysis and pubic crest and insert in the xiphoid process and costal cartilages of ribs 7 to 10. The rectus abdominis muscle is enclosed by the rectus sheath, which is formed by the aponeurosis of the three laterally located muscles: the external oblique, internal oblique, and transversus abdominis. The anterior layer of the rectus sheath is complete in its entirety, while the posterior layer is absent at the lower quarter of the rectus abdominis muscle (Figure 39-1). This is known as the arcuate line, which defines the point where the posterior aponeurosis of the internal oblique and the transversus abdominis muscles become part of the anterior rectus sheath, leaving only the transversalis fascia to cover the rectus abdominis muscle posteriorly. This arcuate line is found one-third of the distance from the umbilicus to the pubic crest.

The abdominal wall is innervated by the thoracoabdominal nerves (T6-T12) and the ilioinguinal/iliohypogastric nerves (L1). After giving off the perforating lateral cutaneous branches, the intercostal nerves continue to travel in the plane between the transversus abdominis and internal oblique muscles and eventually enter the sheath of the rectus abdominis at its lateral margin (linea semilunaris). Here, the nerves are located in the space between the rectus abdominis muscle and its posterior rectus sheath before giving out the perforating anterior cutaneous branches that provide innervation of the anteromedial abdominal wall.

Cross-Sectional Anatomy and Ultrasound View

A transverse section of the anterior abdominal wall shows the rectus muscles as symmetric fusiform structures separated by the linea alba. The transversalis fascia and peritoneum

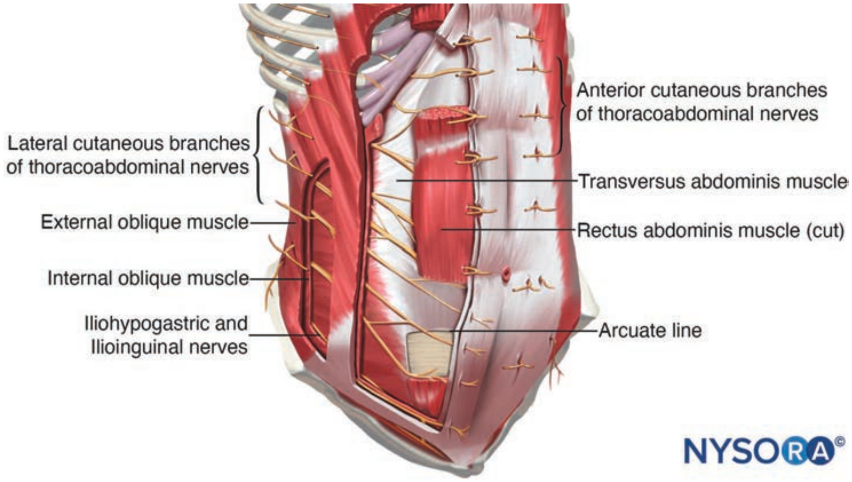

FIGURE 39-1. Anatomy and innervation of the abdominal wall.

separate the muscles from the abdominal cavity and its content (Figure 39-2).

US imaging reveals the rectus abdominis muscle as a hypoechoic oval structure surrounded by its hyperechoic epimysium. If the transducer is placed transversely between the costal margin and the arcuate line (i.e., cephalad to the umbilicus), the posterior rectus sheath is seen as a well-defined hyperechoic fascial layer deep to the rectus abdominis muscle. As previously described, caudal to the arcuate line, the posterior rectus sheath is not present, and the posterior aspect of the rectus abdominis muscle is only covered by the fascia transversalis and peritoneum.

The branches of the intercostal nerves that innervate the abdominal wall are difficult to visualize by US. However, the fascial planes in which they travel are readily identified, which is all that is necessary for the rectus sheath block. Additionally, color Doppler can be used to identify the small epigastric arteries that travel in the same plane. Their identification can be used as additional confirmation of the correct fascial plane for injection and to avoid their puncture during the procedure.

Distribution of Analgesia

A bilateral rectus sheath results in analgesia of the anteromedial abdominal wall and periumbilical area (spinal dermatomes 9, 10, and 11). The limited area of analgesia requires a prudent and realistic selection of the indications (Figure 39-3).

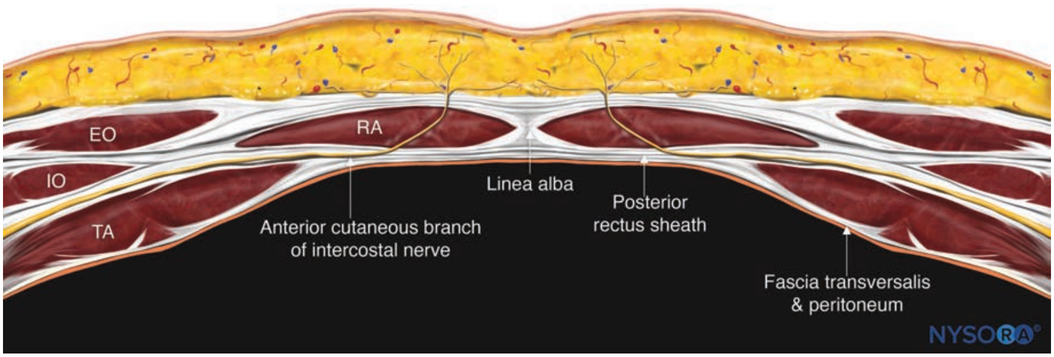

FIGURE 39-2. Cross-section of the rectus abdominis muscle cephalad to the arcuate line showing the course and distribution of the anterior cutaneous branches of the intercostal nerves. EO, external oblique; IO, internal oblique; TA, transversus abdominis; RA, rectus abdominis.

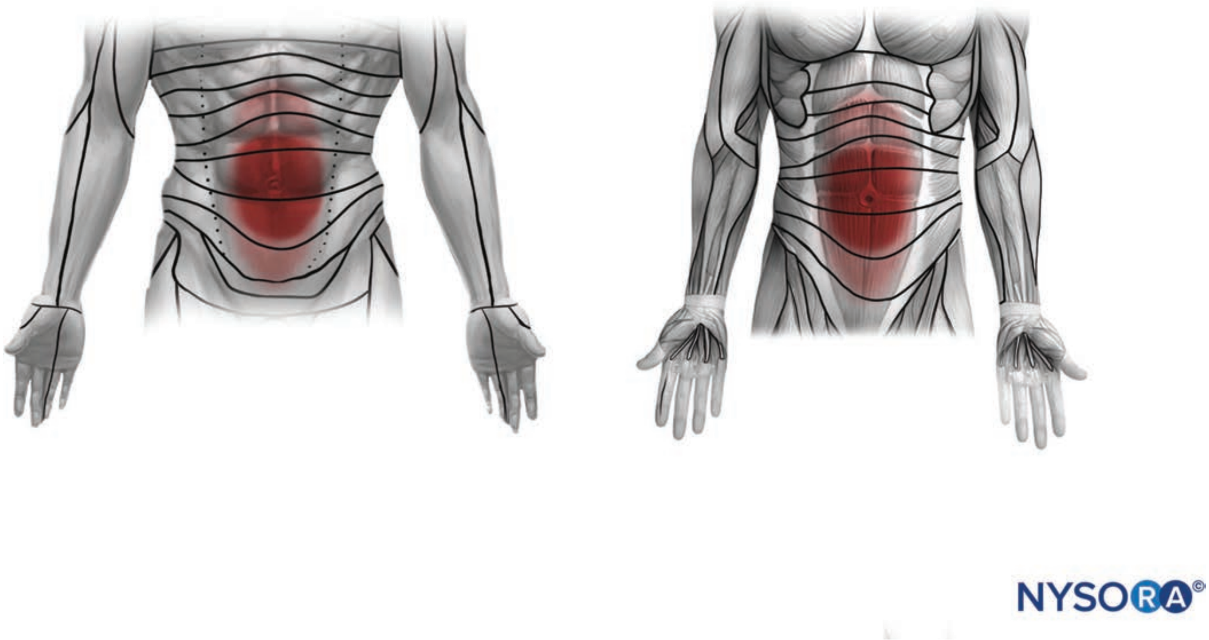

FIGURE 39-3. Analgesia distribution of a rectus sheath block.

Block Preparation

Equipment

- Transducer: Linear transducer
- Needle: 50- to 100-mm, 22-gauge needle

Local Anesthetic

In an adult patient, 10 mL of LA (e.g., 0.5-0.375% ropivacaine) per side is usually sufficient for a successful blockade. In children, a volume of 0.1 mL/kg per side is adequate for effective analgesia.

Patient Positioning

To perform a rectus sheath block, position the patient in supine.

Technique

Landmarks, Initial Probe Position, and Scanning Technique

The transducer is placed superior to the umbilicus, in a transverse orientation and slightly lateral to the midline (Figure 39-4). The first goal is to visualize the rectus abdominis muscle, its posterior rectus sheath, and the hypoechoic space between them. Color Doppler can be used to identify the epigastric arteries to aid in the correct fascial plane detection and avoid their puncture.

Alternatively, the transducer can be applied sagittally. The transducer is rotated 90° and positioned in the midpoint between the xiphoid process and the umbilicus. A sagittal transducer orientation results in a longitudinal view of the rectus abdominis muscle covered by the hyperechoic posterior rectus sheath underneath.

Needle Approach and Trajectory

The needle is inserted in-plane in a medial-to-lateral (or lateral-to-medial) direction through the subcutaneous tissue. The needle traverses the anterior rectus sheath body of the rectus abdominis muscle until the tip reaches the space between the epimysium of the muscle and the posterior rectus sheath (Figure 39-5). An out-of-plane technique is also suitable and often preferred in obese patients. After negative aspiration, 1 to 2 mL of LA is injected to verify needle tip location.

Local Anesthetic Distribution

An adequate spread will lift the epimysium of the rectus abdominis muscle while displacing the posterior fascia and the peritoneun downward (Figure 39-5). The block is done bilaterally.

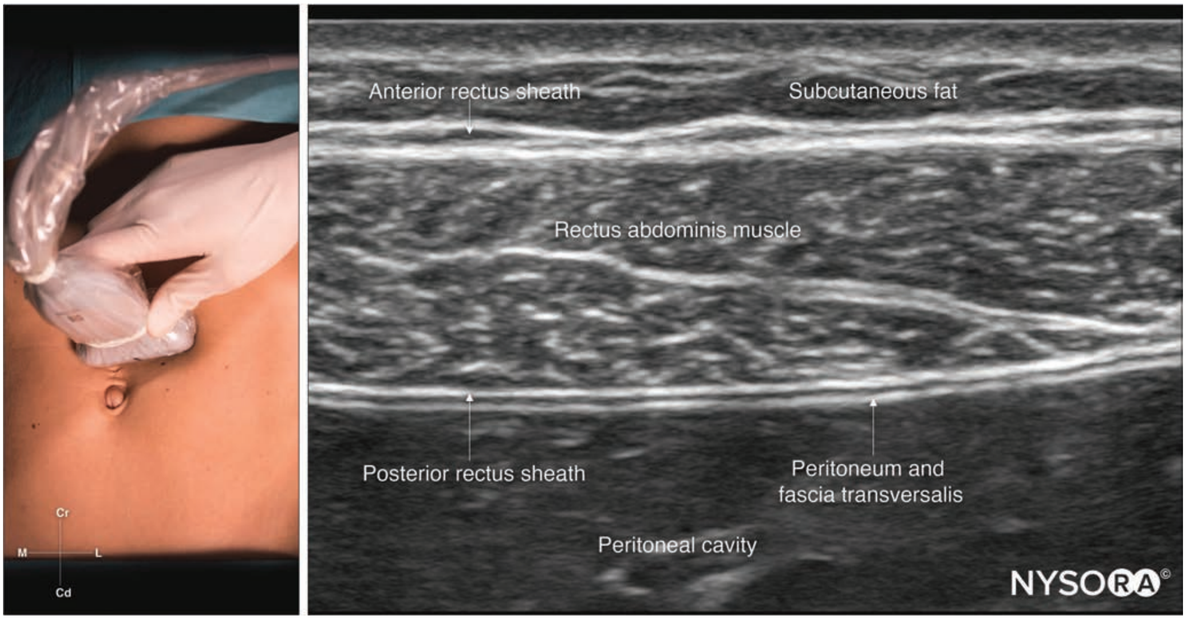

FIGURE 39-4. Transducer position and sonoanatomy to perform a rectus sheath block.

Problem-Solving Tips

- When injection of the LA spreads within the rectus abdominis muscle, the needle is further advanced and its position checked by injection of another 1 to 2 mL of LA (hydro dissection).
- When a large volume of LA is planned (e.g., in combining bilateral TAP and rectus abdominis sheath blocks), the 0.9% saline can be used for hydro dissection to decrease the dose of the LA.
- An out-of-plane technique can also be used. Small boluses of LA are injected as the needle is advanced toward the posterior rectus sheath, confirming the correct position of the needle tip.

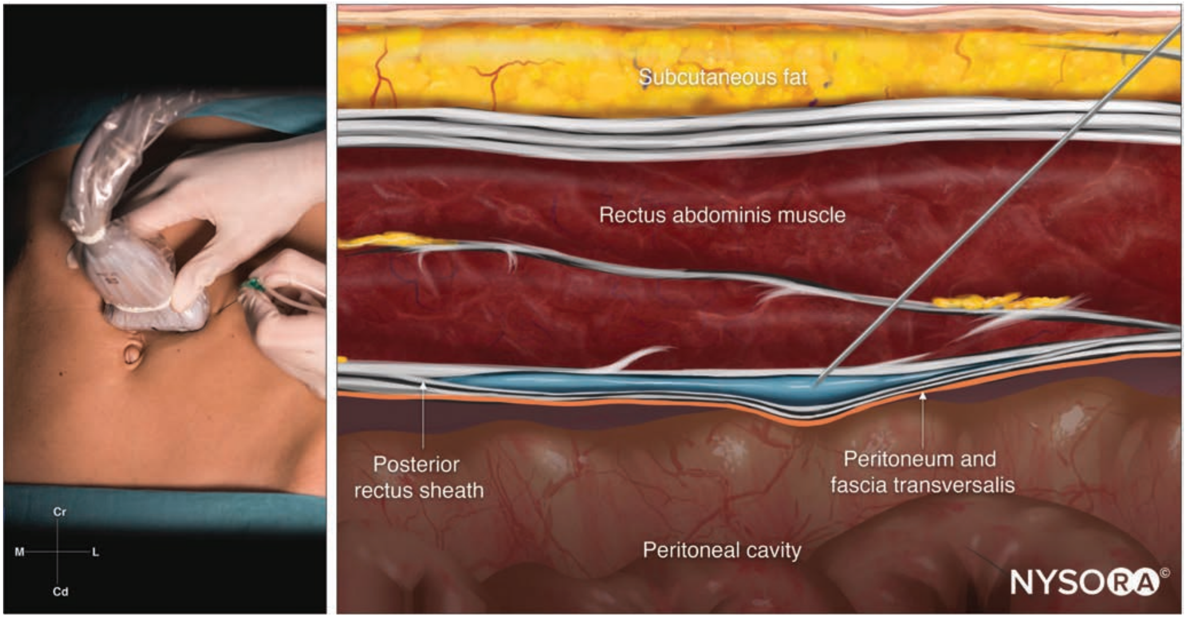

FIGURE 39-5. Rectus sheath block; reverse ultrasound anatomy showing needle insertion in-plane.

Flowchart

Rectus Sheath Block Technique Algorithm

Patient position
Supine

↓

Transducer position
Transverse, superior to the umbilicus, paramedial.

Initial settings
- Linear transducer
- Depth: 3-4 cm

↓

Goal #1:
Visualize the rectus abdominis (RA) muscle and the posterior rectus sheath.

↓

Scanning
Slide the transducer cranio-caudally between the xyphoid process and umbilicus to settle on the best image of the posterior rectus sheath.

- The RA appears as an oval hypoechoic structure surrounded by its hyperechoic sheath (epimysium).
- The posterior rectus sheath appears as an additional hyperechoic fascial layer located between the epimysium of the muscle and the parietal peritoneum.

↓

Goal #2:
Identify the fascial plane between the RA muscle and the posterior sheath.

↓

Insert the needle in-plane or out-of-plane through the RA to reach the space between the muscle and the posterior rectus sheath.

↓

Adequate spread will lift the RA muscle and push down the posterior rectus sheath.

↓

Complete the block with 10 mL of local anesthetic per side.
The block is done bilaterally.

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40 Quadratus Lumborum Blocks

BLOCK AT A GLANCE

Comprises a group of interfascial plane injections of local anesthetic at different locations around the quadratus lumborum muscle.

- **Indications:** Analgesia for the anterolateral abdominal wall and parietal peritoneum
- **Goal:** Local anesthetic spread either lateral (QL1), posterior (QL2), or anterior (QL3) to the quadratus lumborum muscle to block the anterior rami of spinal nerves T10-L1 (and, eventually, the paravertebral sympathetic chain)
- **Local anesthetic volume:** 15 to 30 mL

General Considerations

The ultrasound-guided quadratus lumborum (QL) block was developed from the transversus abdominis plane (TAP) block to achieve a more consistent and extended block of the anterior rami of spinal nerves supplying the abdominal wall. The various QL block techniques (i.e., QL1, QL2, QL3) aim to improve the analgesia after surgeries involving the abdominal wall. Several technique variations have been devised to enhance the spread of local anesthetic (LA) to reach the thoracic paravertebral space, and eventually the sympathetic chain. Other variations aim to extend the block to the lumbar plexus and provide analgesia to the lower extremity. New modifications continue to be implemented: the transverse oblique paramedian (TOP) and the supra-iliac anterior QL3, for instance, are thought to result in a more cranial and caudal spread of the LA, respectively. However, the available evidence so far is insufficient to draw conclusions.

Mechanisms of action of QL block variants are mainly related to the anatomical injection site but inconsistent. As an example, the spread of the LA with an anterior QL block (QL3) may reach the paravertebral space, lumbar nerve roots, and sympathetic chain, and result in weakness of the lower extremities, as has been reported. For safety and efficacy of QL blocks, adequate ultrasound (US) images are crucial, yet often challenging to obtain. Without adequate images, the QL blocks are associated with variable success rates and risks of iatrogenic injury to the kidney, liver, and/or spleen.

Limitations

Similar to many interfascial plane blocks, the duration, extent, and quality of the analgesia between the different QL blocks vary. The block characteristics depend on the injection site, anatomical characteristics of the fascial planes, the volume of the LA injected, and whether the injectate reaches the intended target nerves.

Anatomy

The QL muscle originates from the posterior part of the iliac crest and the iliolumbar ligament and inserts on the 12th rib and the transverse processes of vertebrae L1-L4. The QL muscle is located between the psoas muscle (anterior) and the erector spinae muscles (posterior). Both the QL and psoas muscles pass posterior to the medial and lateral arcuate ligaments of the diaphragm to insert in the transverse processes (Figure 40-1). To understand the potential mechanisms of action of the QL block, it is essential to understand the anatomy of the fasciae that surround the muscles at this level.

The ***thoracolumbar fascia (TLF)*** is a complex arrangement of multilayered fascial planes and aponeurotic sheaths that form the retinaculum around the paraspinal muscles of the lower back and sacral region. Anatomical variations of TLF are common, but it is usually described as a fascial structure consisting of anterior, middle, and posterior layers. The posterior TLF layer surrounds the erector spinae muscles, the middle layer separates the QL from the erector

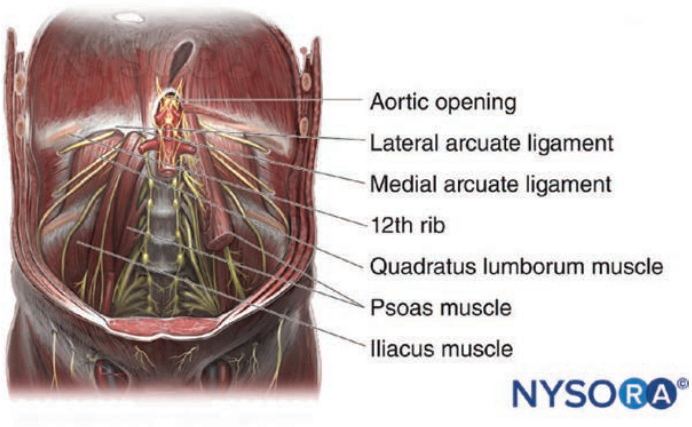


FIGURE 40-1. Anatomy of the quadratus lumborum.

spinae muscles, and the anterior layer covers the anterior aspect of the QL muscle (Figure 40-2). Cranially, these fascia layers follow the QL and psoas muscles through the arcuate ligaments and the aortic hiatus of the diaphragm, and continue with the endothoracic fascia, providing a potential pathway for the spread of injectate toward the thoracic paravertebral space.

The ***lateral raphe*** is a dense connective tissue layer formed where the aponeurosis of the transversus abdominis and internal oblique muscles join the fused posterior and middle TLF at the lateral border of the erector spinae muscles. The **lumbar interfascial triangle (LIFT)** is a fat-filled space along the lateral border of the erector spinae muscles from the 12th rib to the iliac crest.

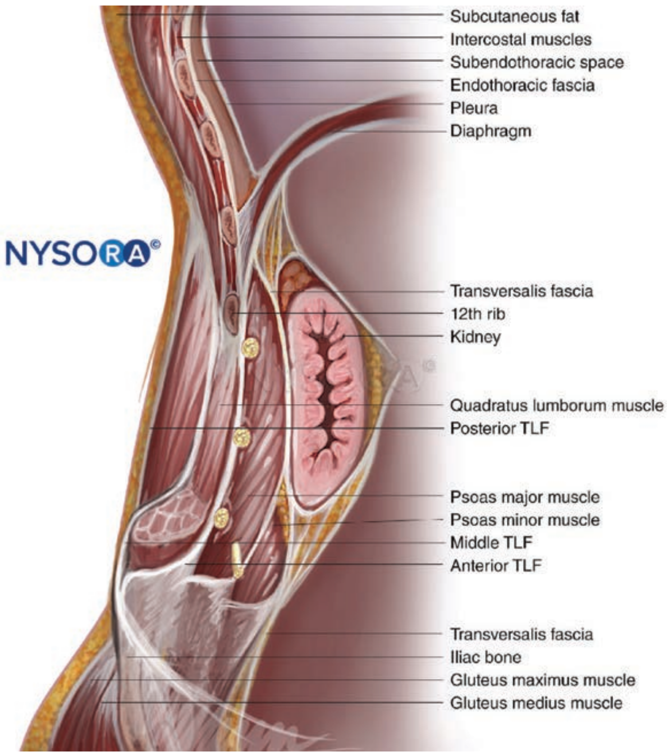


FIGURE 40-2. Anatomy of the fasciae surrounding the quadratus lumborum muscle showing the thoracolumbar fascia (TLF) and its posterior, middle, and anterior layers.

The ***transversalis fascia (TF)*** is the innermost layer of the parietal fascia of the abdomen. It is part of the endo-abdominal fascia investing the abdominal cavity and covering the deep surface of the transversus abdominis, QL, and psoas major muscles. It communicates with the endothoracic fascia posterior to the diaphragm with a possibility of LA spread into the thoracic paravertebral space, and it extends caudally as well, communicating with the fascia iliaca over the psoas major and iliacus muscle, resulting in a potential spread of LA to the branches of the lumbar plexus.

Cross-Sectional Anatomy and Ultrasound View

A cross-section at the level of the L3 vertebra shows a transverse view of the paraspinal muscles and surrounding fascial planes, along with the anterior branches of the spinal nerves (Figure 40-3). The subcostal (T12), iliohypogastric, and ilioinguinal (L1) nerves travel between the psoas major muscle and the QL muscle to enter the transversus abdominus plane. The lumbar plexus elements can be seen between the intervertebral foramen and the psoas muscle compartment.

With the transducer placed over the flank of the patient, and oriented medially, the transverse process of the L4 vertebra appears as a hyperechoic structure with an acoustic shadow behind. The psoas major, QL, and erector spinae muscles appear as hypoechoic structures, surrounded by hyperechoic fasciae, located anterior, superficial, and posterior to the transverse process respectively. This arrangement of the muscles produces a sonographic pattern often referred to as the "shamrock sign" (Figure 40-4). The tiny nerves cannot be seen.

Distribution of Analgesia

The distribution patterns of somatic analgesia with QL blocks depend on the site of injection among other factors. The extent of sensory blocks in Figure 40-5 are only orientative.

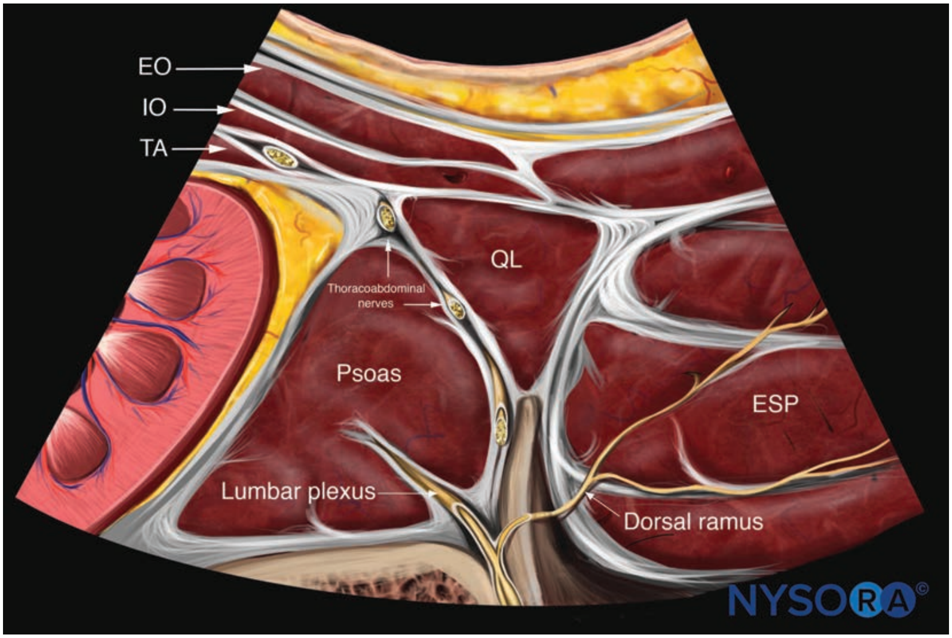


FIGURE 40-3. Cross-section anatomy of the quadratus lumborum (QL) muscle at the level of the L3 vertebra. EO, external oblique muscle; IO, internal oblique muscle; TA, transversus abdominis muscle; ESP, erector spinae muscles.

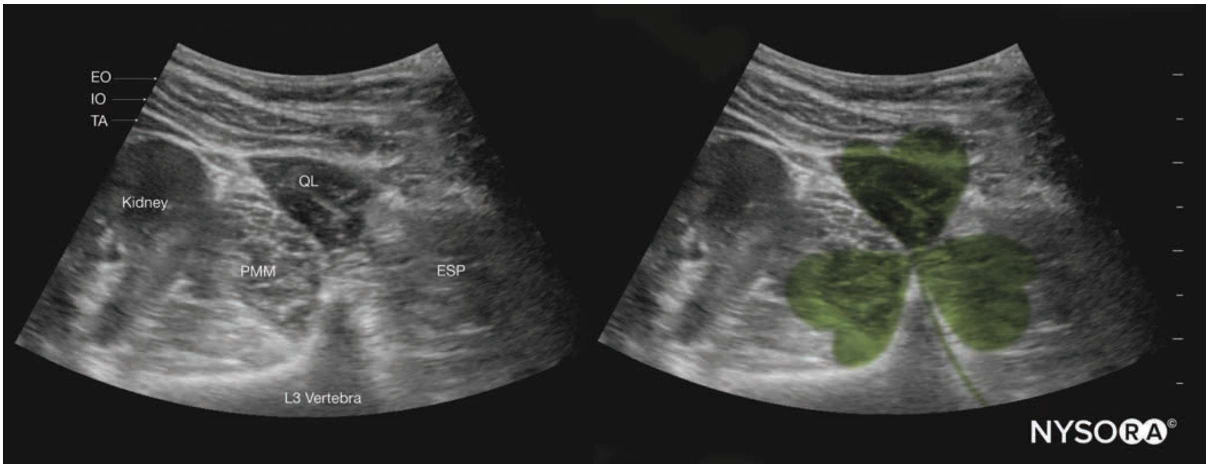


FIGURE 40-4. Sonoanatomy of the shamrock sign: psoas major (PMM) located anteriorly, quadratus lumborum (QL) located superficial, and erector spinae muscles (ESP) located posterior to the transverse process. EO, external oblique muscle; IO, internal oblique muscle; TA, transversus abdominis muscle.

Block Preparation

Equipment

- Transducer: High-frequency linear transducer for QL1, and low-frequency curved transducer for QL2 and QL3
- Needle: 80- to 100-mm, 22- to 25-gauge needle

Local Anesthetic

QL blocks typically require 15 to 30 mL of LA (0.2-0.4 mL/kg). Low concentrations (i.e., 0.125-0.375%) of long-acting LAs such as bupivacaine, levobupivacaine, or ropivacaine should be used.

Patient Positioning

For QL blocks the lateral decubitus or sitting positions may be used. The lateral decubitus position may allow for better ergonomics and imaging of the relevant US structures and neuraxis (Figure 40-6). The supine position is suitable only for lateral QL blocks (QL1 and QL2), although visualization of the neuraxial and paravertebral structures will be impaired. For the TOP QL3, the patient should be in a lateral or sitting position.

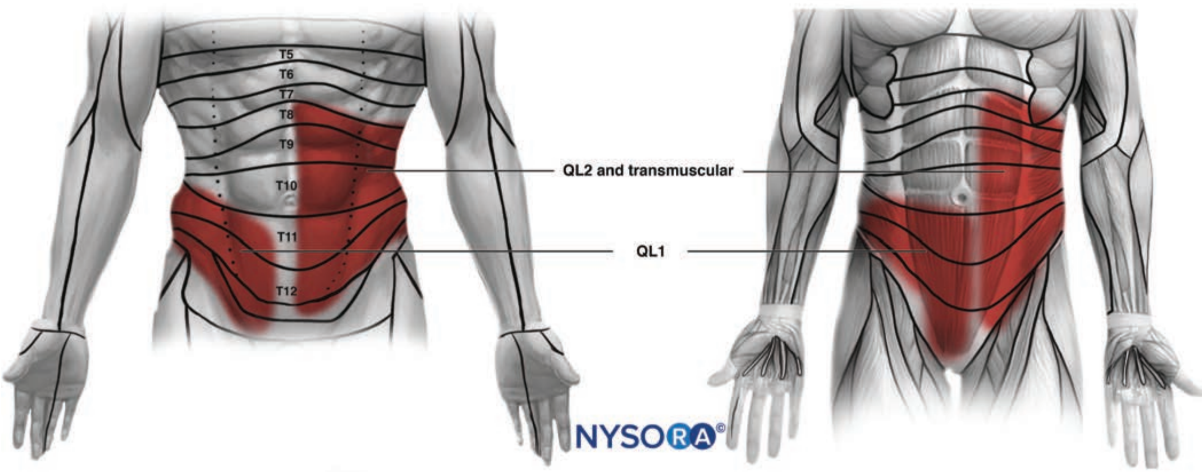


FIGURE 40-5. Sensory distribution after the performance of different QL blocks.

FIGURE 40-6. Patient position to perform QL block.

TECHNIQUES

For all QL block techniques, the external landmarks are the iliac crest, costal margin, and the posterior and midaxillary lines.

Lateral Quadratus Lumborum Block (QL1)

Initial Probe Position and Scanning Technique

With the linear transducer, the technique is similar to the posterior TAP block (see Chapter 38 for TAP blocks). The curvilinear transducer is placed in transverse orientation at the midaxillary line, between the iliac crest and the costal margin. The goal is to visualize the abdominal wall muscles (Figure 40-7).

The transducer is then slid posteriorly until the posterior aponeurosis of the transversus abdominus, internal oblique, and the QL muscles are identified. The target is just deep to the TAP aponeurosis but superficial to the TF at the lateral margin of the QL muscle. Applying some pressure and tilting the transducer may improve imaging of the fascial planes.

Needle Approach and Trajectory

The needle is inserted in-plane, from either the anterior or the posterior end of the transducer, until the tip pierces the posterior aponeurosis of the TA muscle, lateral to the QL muscle. The injection of 1 to 2 mL of LA should result in a visible spread along the lateral side of the QL muscle between the TA aponeurosis and the transversalis fascia (Figure 40-8).

Posterior Quadratus Lumborum Block (QL2)

Initial Probe Position and Scanning Technique

The transducer is placed in transverse orientation at the midaxillary line and slid posteriorly (similar to the QL1 block). The goal is to visualize the fascial plane between the posterior aspect of the QL muscle and the middle layer of the TLF (Figure 40-7).

Needle Approach and Trajectory

The needle is inserted in-plane, from either the anterior or posterior end of the transducer, toward the posterior aspect of the QL muscle and the middle layer of the TLF. The injection of 1 to 2 mL of LA should result in the pooling of LA along the posterior aspect of the QL muscle, posterior to the LIFT (Figure 40-8).

Anterior or Transmuscular Quadratus Lumborum Block (QL3)

Initial Probe Position and Scanning Technique

The transducer is placed in a transverse orientation over the patient's flank just cranial to the iliac crest and tilted caudally. The goal is to visualize the acoustic shadow of the L4 transverse process, the erector spinae muscles posteriorly, the QL muscle laterally, and psoas major muscle anteriorly (i.e., the shamrock sign) (Figure 40-7).

Needle Approach and Trajectory

The needle is inserted in-plane from the posterior side, and through the erector spinae and QL muscles until the tip reaches the plane between the QL and psoas muscle. The injection of 1 to 2 mL of LA should spread along this fascial plane (Figure 40-9).

Local Anesthetic Distribution

After confirmation of the correct needle tip position, the block is completed with the injection of 20 mL of LA while observing the spread along the corresponding fascial plane.

Variations of the Anterior QL3 Block

Several variations of the QL3 block have been described:

- The *transverse oblique paramedian (TOP QL)* is similar to QL3 but performed at the level of L2.
- The *supra-iliac anterior QL block technique* is performed at the level of the L5 transverse process.

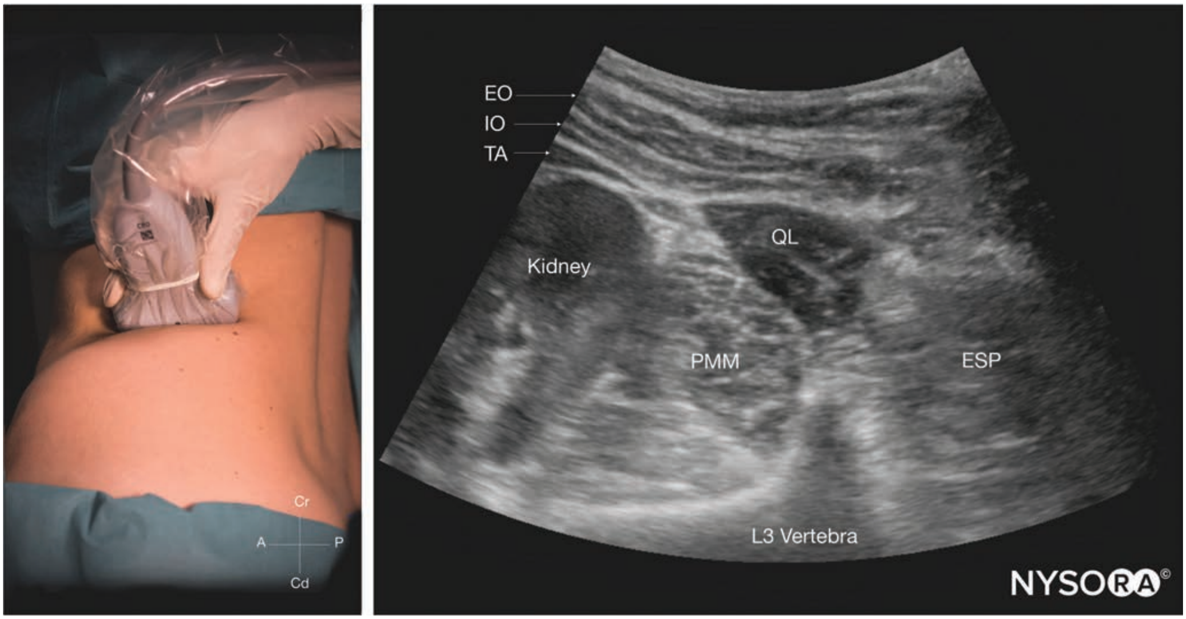


FIGURE 40-7. Transducer position and sonoanatomy to perform either a QL2 or a QL3 block. EO, external oblique muscle; IO, internal oblique muscle; TA, transversus abdominis muscle; QL, quadratus lumborum; PMM, psoas major muscle; ESP, erector spinae muscles.

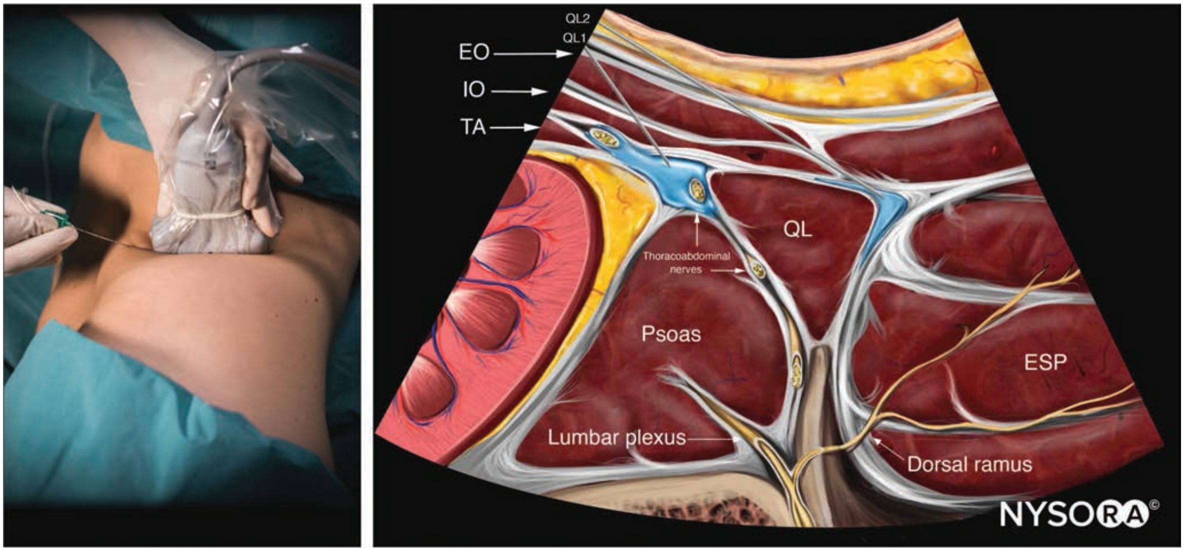


FIGURE 40-8. Reverse ultrasound anatomy of a QL1 or a QL2 block with needle insertion in-plane. EO, external oblique muscle; IO, internal oblique muscle; TA, transversus abdominis muscle; QL, quadratus lumborum; ESP, erector spinae muscles.

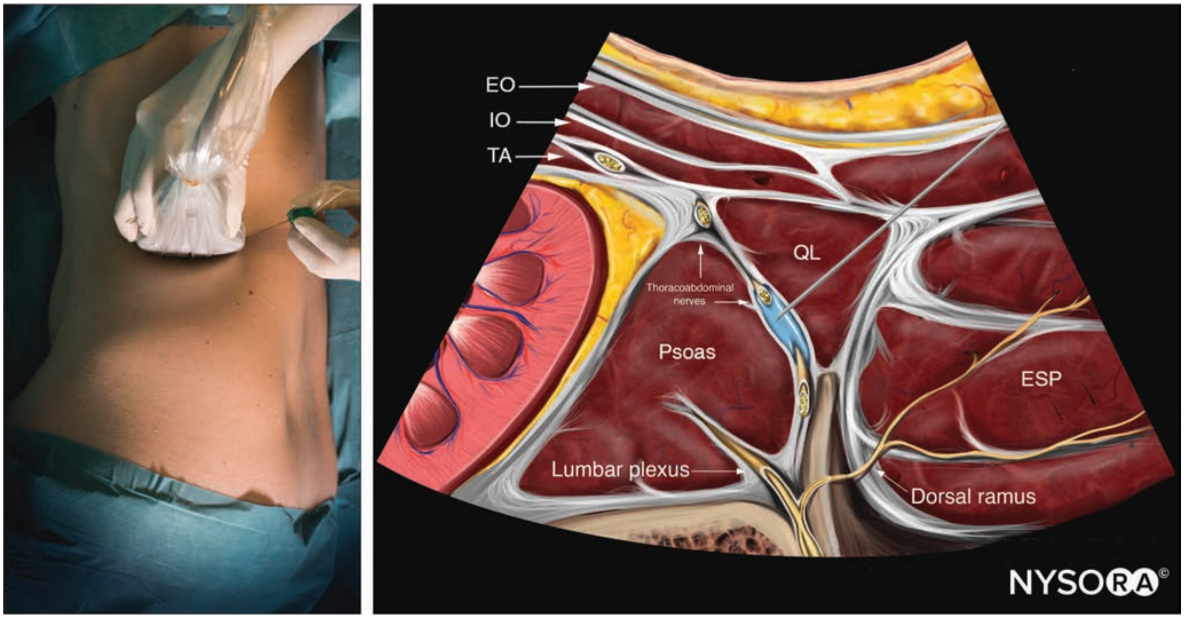


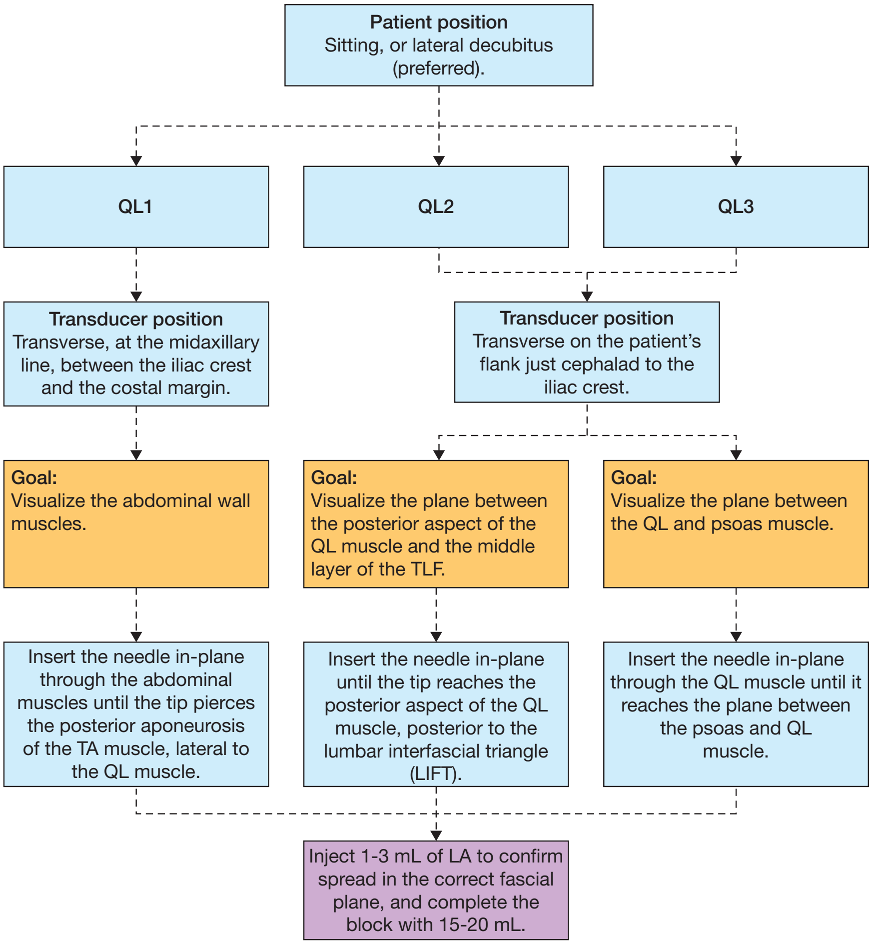
FIGURE 40-9. Reverse ultrasound anatomy of a QL3 block with needle insertion in-plane. EO, external oblique muscle; IO, internal oblique muscle; TA, transversus abdominis muscle; QL, quadratus lumborum; ESP, erector spinae muscles.

Problem-Solving Tips

- Close to the transverse process, the QL muscle is thin and best imaged from the anteroposterior aspect. When imaged from the flank, the muscle appears broader.
- Color Doppler imaging is recommended before insertion of the needle to rule out lumbar arteries on the posterior aspect of the QL muscle.
- The QL muscle is generally hypoechoic and posterior to the transversus abdominis muscle. The latissimus dorsi and erector spinae muscles are superficial and more hyperechoic.
- If you cannot identify the QL muscle easily, try to abduct and laterally flex the ipsilateral hip joint toward the same side of the block to contract the QL muscle.
- The kidneys, spleen, and liver are in the vicinity and exposed to iatrogenic injury, particularly when US imaging is suboptimal. Therefore, the use of QL blocks should entail risk/benefit assessment.

Flowchart

Ultrasound-guided Quadratus Lumborum Block Technique Algorithm



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