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Neurosensory Deficit Complications in Implant Dentistry

Randolph R. Resnik

Iatrogenic injury with resultant sensory impairment of the skin and mucosa innervated by branches of the trigeminal nerve is a major concern in association with dental implant surgery. With the increase in the number of implants being placed and more practitioners becoming involved with dental implant surgery, nerve damage will most likely be a continued problem in implant dentistry. The reported incidence of such nerve injuries following dental implant procedures is highly variable (0% to 44%) in the literature.[1] Studies have shown that approximately 73% of doctors who perform implant surgery have experienced postoperative nerve complications.[2] Libersa et al evaluated transient vs. permanent nerve injuries after implant placement and determined a 75% incidence of permanent injury (Fig. 9.1).[3]

When a nerve injury occurs, it is paramount the dental implant surgeon be able to recognize the type and extent of injury and provide the most appropriate postoperative care. Traumatic and iatrogenic nerve complications may involve total or partial nerve resection, crushing, thermal, stretching, or entrapment injuries. The resulting sensory deficits may range from a nonpainful, minor loss of sensation (hypoesthesia), to a more permanent and severe debilitating pain dysfunction (dysesthesia). Patients with neurosensory deficits often complain of symptoms that include interference with function, speaking, eating, kissing, facial soft tissue dysfunction, and inability to complete everyday tasks such as shaving and placing make-up. The sensory problems often result in an overall decreased quality of life and long-standing psychological problems.[4] Most patients find accepting and coping with even minimal nerve injuries difficult to live with. The clinician is usually affected by increased complaints from the patients, embarrassment, with significant medicolegal implications.

In the field of oral implantology today, the clinician must have a thorough understanding of the etiology, prevention, and treatment of neurosensory impairments. The authors have developed postoperative guidelines for diagnosis and possible management of neurosensory deficits following dental implant surgery that are dependent on the history, type, and nature of the injury.

ANATOMY

PERIPHERAL NERVE FIBER ANATOMY

The individual nerve fibers of peripheral nerves are situated in fascicles, which are bundles or groups of nerve fibers. For example, the inferior alveolar nerve is classified as polyfascicular, meaning that it contains more than 10 fascicles surrounded by an abundance of interfascicular connective tissue. Within the fascicles, there are approximately 7000–12,000 axons in various fascicular arrangements.[5] The number of fascicles varies along the intramandibular course of the inferior alveolar nerve because there are approximately 18–21 fascicles in the third molar region, decreasing to 12 fascicles in the mental foramen area.[6] Because of the polyfascicular nature of the inferior alveolar nerve, it is better able to regain sensation after injury via compensatory innervation from the uninjured fascicles. Surrounding the polyfascicular makeup of this nerve is the perineurium, which consists of dense, multilayered connective tissue. The perineurium functions to maintain intrafascicular pressure and acts as a diffusion barrier in the protection of the individual nerve fibers. Two types of connective tissue, the inner and outer epineurium, surround the fascicles. The inner epineurium is composed of loose connective tissue with longitudinal collagen bundles. This tissue protects the nerve fibers against compressive and stretching forces, thus maintaining the structural continuity of the nerve. The outer epineurium is continuous with the mesoneurium, which is the outer loose areolar tissue that suspends the nerve trunk within the soft tissue and contains the blood supply to the nerve. The mesoneurium allows the nerve to have longitudinal movement within the surrounding tissue.

If any of these extraneural tissues (epineurium, perineurium, endoneurium, or mesoneurium) is injured, impaired neural transmission by the individual nerve fibers may result in a sensory disturbance. The neurosensory impairment is dependent on the individual fiber type that is involved. The A-alpha fibers are the largest fibers; mediate position and fine touch through muscle spindle afferents and skeletal muscle efferents. The A-beta fibers are solely for proprioception, and the A-delta carries the initial pain impulses along with temperature information. Unmyelinated C-fibers are slow conducting and function for the perception of "second" or slow pain with an additional temperature component. For dental implant surgeons the primary concern is loss of sensory functions such as touch, pressure, pain, and temperature following trauma (Fig. 9.2).

TRIGEMINAL NERVE

The trigeminal nerve is the fifth cranial nerve and largest of the 12 cranial nerves. This nerve originates from the brainstem

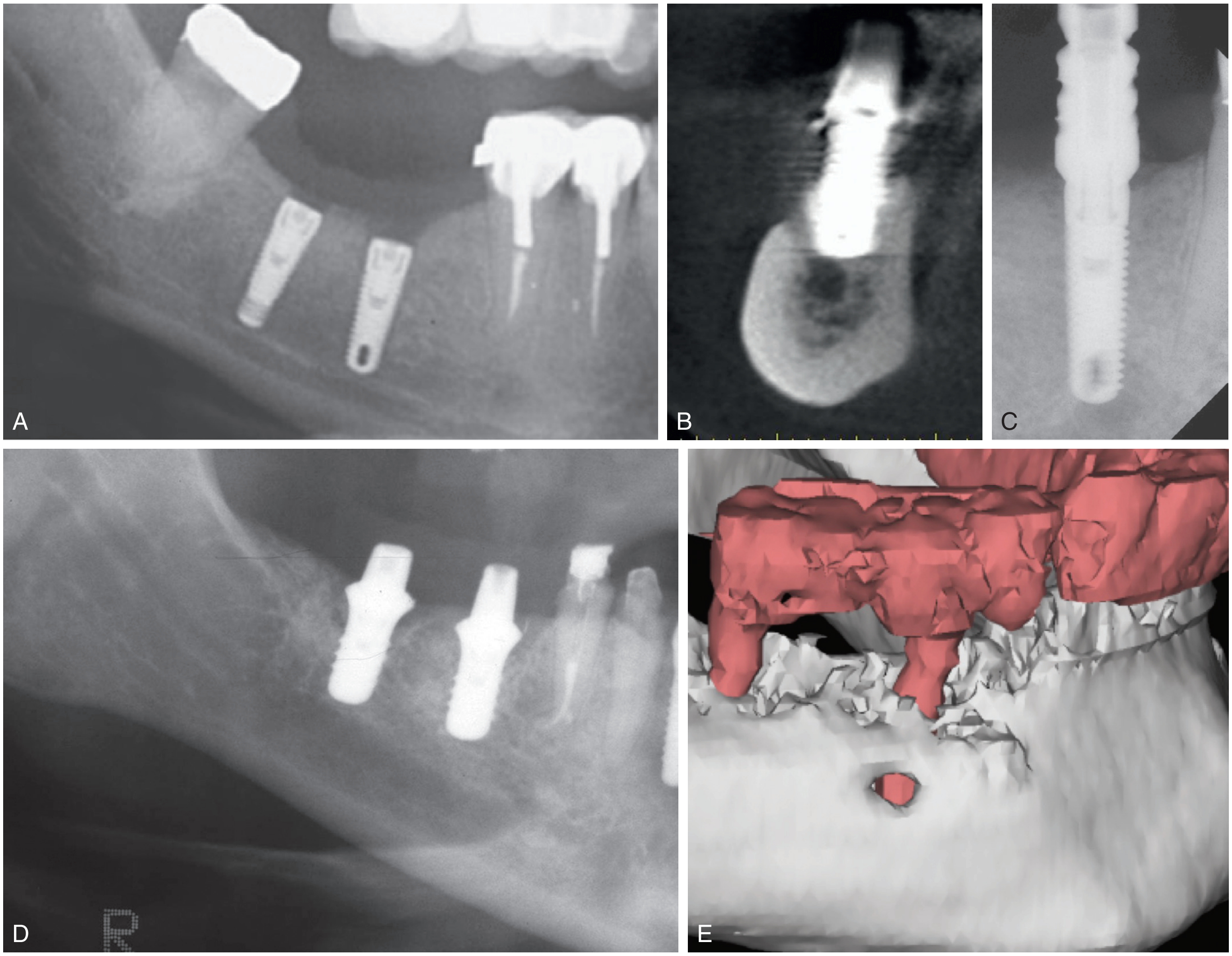


FIG 9.1 Neurosensory impairment of the inferior alveolar nerve. (A) Placement of two implants, completely transecting the mandibular canal. (B–C) Implant placement impinging on the mental foramen. (D) Immediate placement implant after premolar extraction causing nerve impairment. (E) CBCT image depicting implant placement through mandibular canal.

at the midlateral surface of the pons with its afferent fibers transmitting innervation from the face, oral and nasal cavity, as well as the scalp. The trigeminal nerve also has visceral efferent fibers for lacrimal, salivary, and nasal mucosa glands. Somatic efferent fibers are present that innervate the masticatory muscles. The trigeminal nerve has three main branches: V_1 (ophthalmic); V_2 (maxillary); and V_3 (mandibular).

V_1: Ophthalmic

The uppermost branch is the ophthalmic nerve, V_1, which is the smallest of the three divisions of the trigeminal nerve. It supplies sensory branches to the ciliary body, cornea, conjunctiva, lacrimal glands, and nasal mucosa as well as to the skin of the nose, eyelid, and forehead. The ophthalmic division structures are rarely involved in neurosensory disturbances associated with dental implant procedures.

V_2: Maxillary

The middle branch of the maxillary nerve (V_2) exits the middle cranial fossa through foramen rotundum and enters the pterygopalatine fossa, where it gives off branches to the maxillary teeth and gingiva, maxillary sinus, upper lip, lateral surface of the nose, the lower eyelid, the skin of the cheek and side of the forehead, nasal cavity, and mucosa of the hard and soft palate (Fig. 9.3).

Nasopalatine Nerve. The incisive canals fuse and form a common Y-shaped canal that exits lingual to the central incisor teeth (incisive foramen or incisive fossa). The nasopalatine nerve passes through these canals and provides sensation to the anterior palate. These nerves (also termed *incisive nerves*) terminate at the nasal floor and enter the oral cavity via the incisive canal, which is underneath the incisive papilla. To prevent trauma to these nerves, ideal presurgical planning of implant placement in the maxillary incisor region should be carefully evaluated (Fig. 9.4).

Clinical significance. Removing the contents of the nasopalatine canal and grafting has been reported to have a high success rate.[7,8] Although this nerve is often affected by the placement of implants or bone grafting in the incisor region,

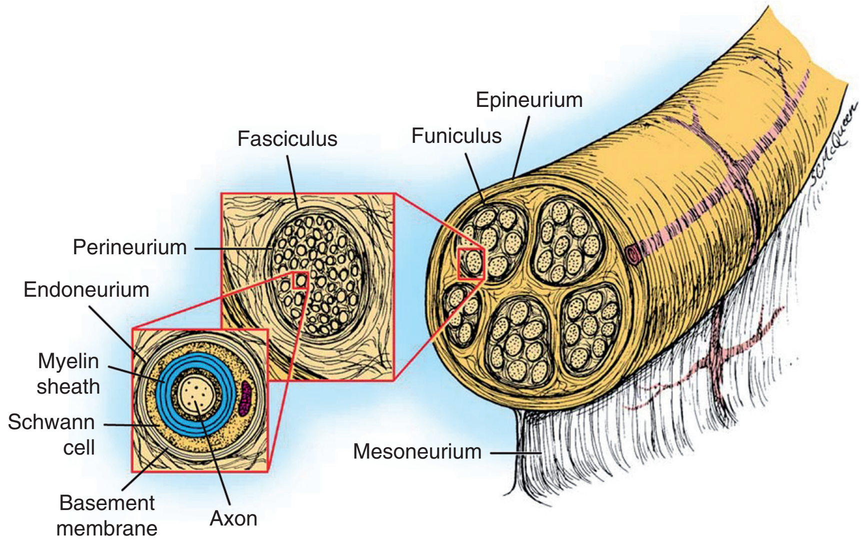


FIG 9.2 Nerve fiber anatomy showing polyfascicular nature of inferior alveolar nerve. (From Canale ST, Beaty JH editors: *Campbell's operative orthopaedics*, ed 11, Philadelphia, 2008, Mosby.)

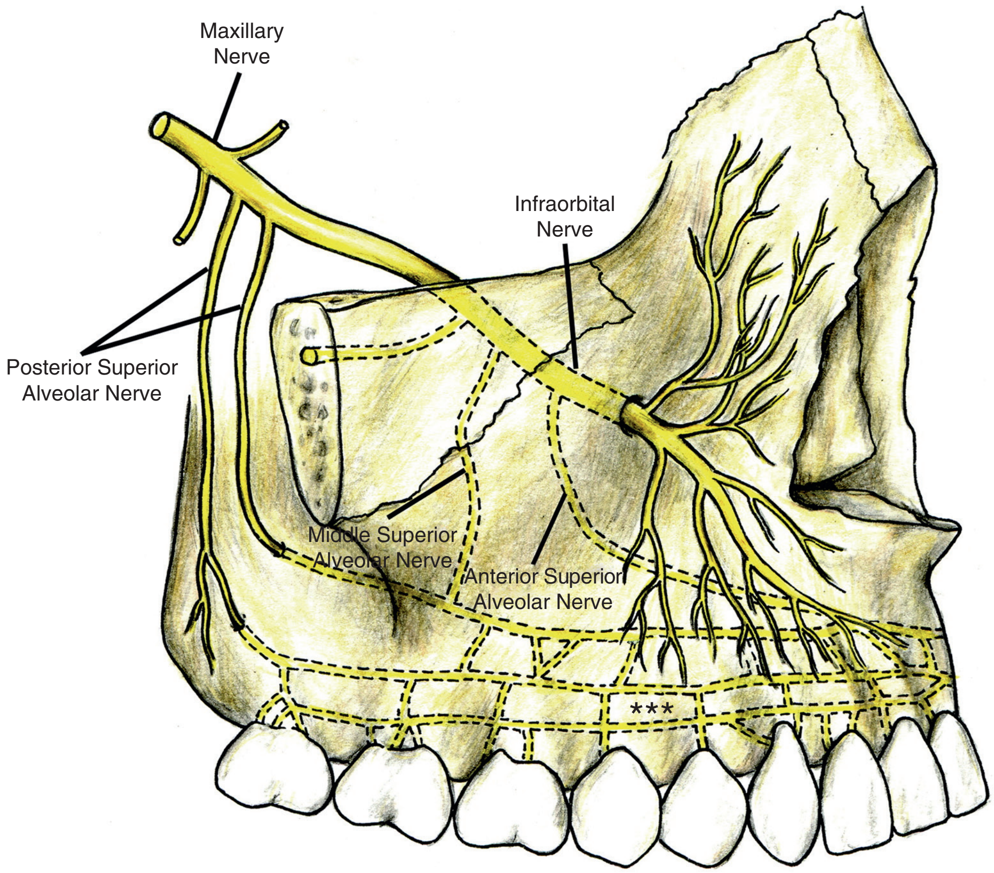


FIG 9.3 Maxillary nerve (V_2) and its associated branches: infraorbital nerve, posterior, middle, and anterior superior alveolar nerves. (From Rodella LF, Buffoli B, Labanca M, et al: A review of the mandibular and maxillary nerve supplies and their clinical relevance. *Arch Oral Biol* 57:323–334, 2012.)

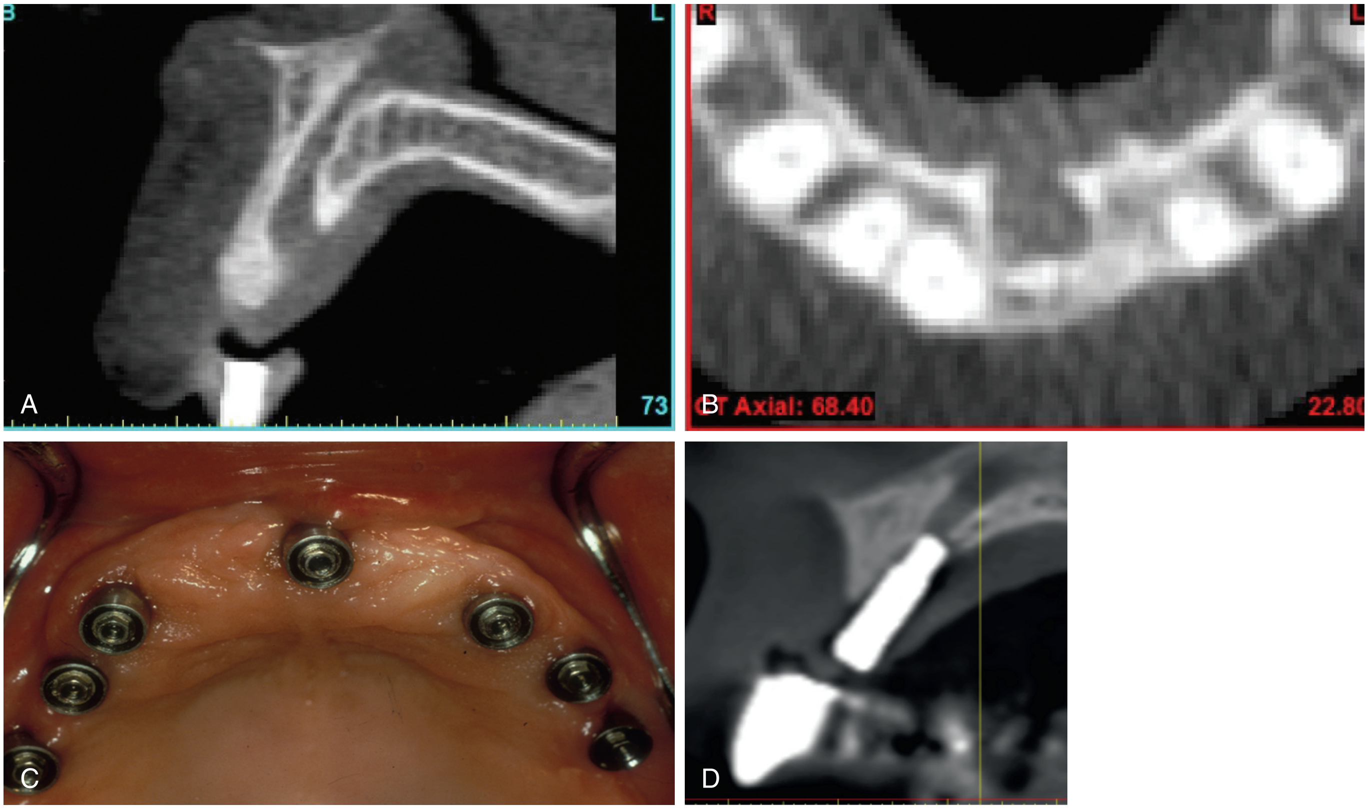


FIG 9.4 Nasopalatine nerve and canal. (A) Cross-sectional image depicting large nasopalatine canal. (B) Axial CBCT image. (C–D) Placement of implant into the nasopalatine canal after removal of soft tissue contents.

sensory disturbances are rare. Nerve damage reported in the literature caused by complete removal[9] or flap surgery[10] is of short duration. This is most likely due to cross innervation of the greater palatine nerve on the anterior palatal area.

Infraorbital Nerve. The infraorbital nerve emerges from the infraorbital foramen and gives off four branches: the inferior palpebral, external nasal, internal nasal, and the superior labial branches, which are sensory to the lower eyelid, cheek, and upper lip. The inferior palpebral branches supply the skin and conjunctiva of the lower eyelid. The nasal branches supply the lateral nose soft tissue and the movable part of the nasal septum, and the superior labial branches supply the skin of the cheek and upper lip. Normally, the average distance of the inferior border of the orbital rim to the infraorbital foramen is 4.6 mm to 10.4 mm (Fig. 9.5).

Clinical significance. Impairment of the infraorbital nerve may be very traumatic to patients. Damage to branches of the infraorbital nerve usually will result from retraction-related trauma (neuropraxia). Procedures involving the maxillary cuspid-bicuspid area are most susceptible to injuries. Anatomic variants of the infraorbital foramen have been shown to be up to 14 mm from the orbital rim. This is most likely seen in elderly female patients with extensive alveolar atrophy.

Anterior Superior Alveolar Nerve. The anterior superior alveolar nerve branches from the infraorbital canal on the lateral face. This small canal may be seen lingual to the cuspid and is denoted as the *canalis sinuosus*. The canal runs forward and downward to the inferior wall of the orbit and, after reaching the edge of the anterior nasal aperture in the inferior turbinate, it follows the lower margin of the nasal aperture and opens to the side of the nasal septum.[11] Studies have shown that in approximately 15% of the population, this area is described as foramina that are 1–2 mm in diameter. The canals present as a direct extension of the canalis sinuousus and may be clinically relevant when greater than 2.0 mm[12] (Fig. 9.6).

Clinical relevance. Because the canine pillar region is a common area for dental implants, care should be taken to check for the presence of neurovascular bundles of the infraorbital canal. Insertion of implants in approximation to the canal may be problematic. Impingement into the canal may lead to a soft tissue interface and failure of the implant and temporary or permanent sensory dysfunction and possible bleeding issues.[13] However, significant sensory impairments are rare because of cross innervation. Many clinicians are unaware of the canalia sinuosus and may misdiagnose this radiolucency as apical pathology of the maxillary cuspid.

V_3: Mandible

The mandibular nerve is the largest of the trigeminal branches and is the most common branch involved with neurosensory disturbances following dental implant surgery. The mandibular nerve is the lowest branch of the trigeminal nerve, which runs along the floor of the cranium, exiting through the foramen ovale into the infratemporal fossa. It has two

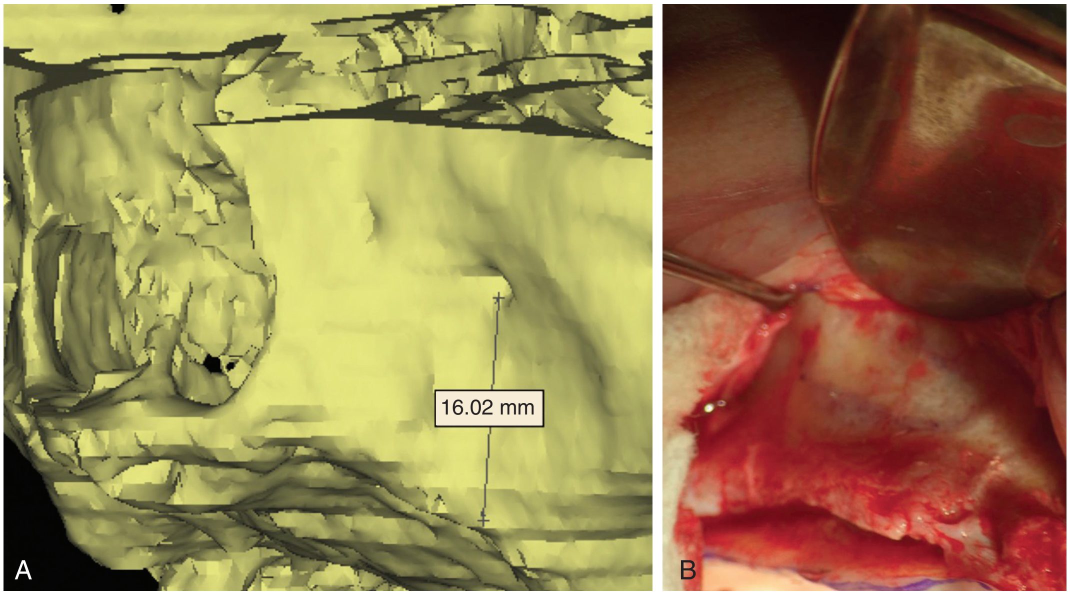


FIG 9.5 Infraorbital nerve. (A) Anatomic variants showing close proximity to the residual ridge. (B) Minnesota retractor in close proximity to the infraorbital nerve.

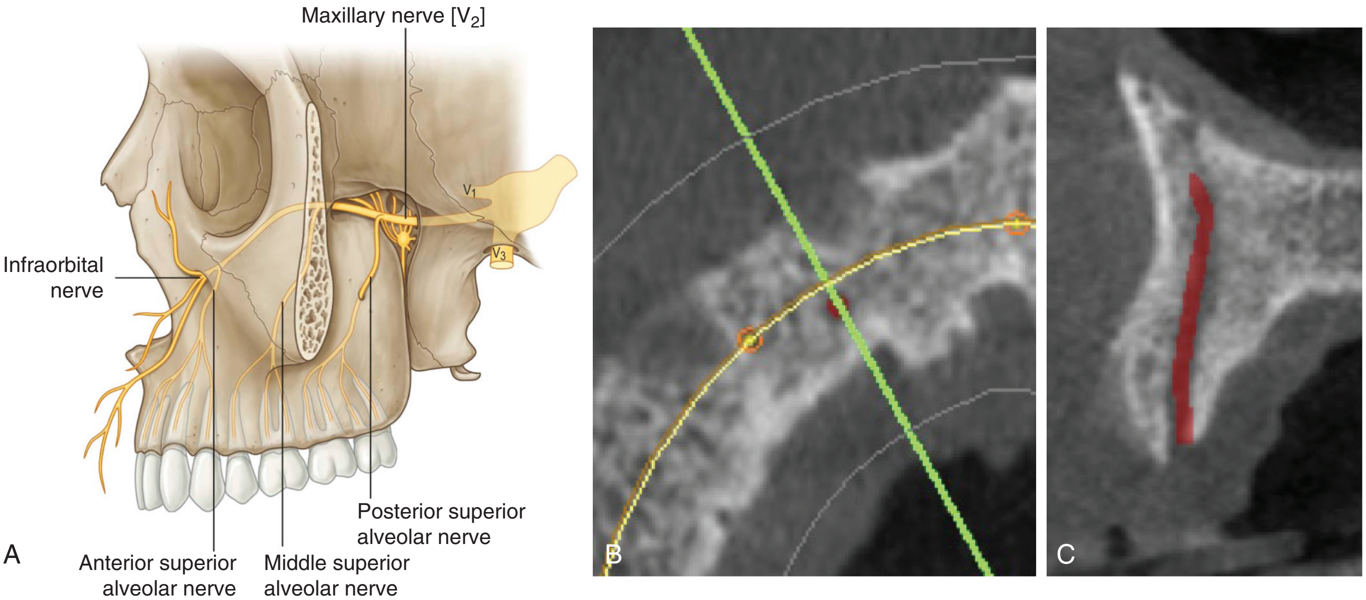
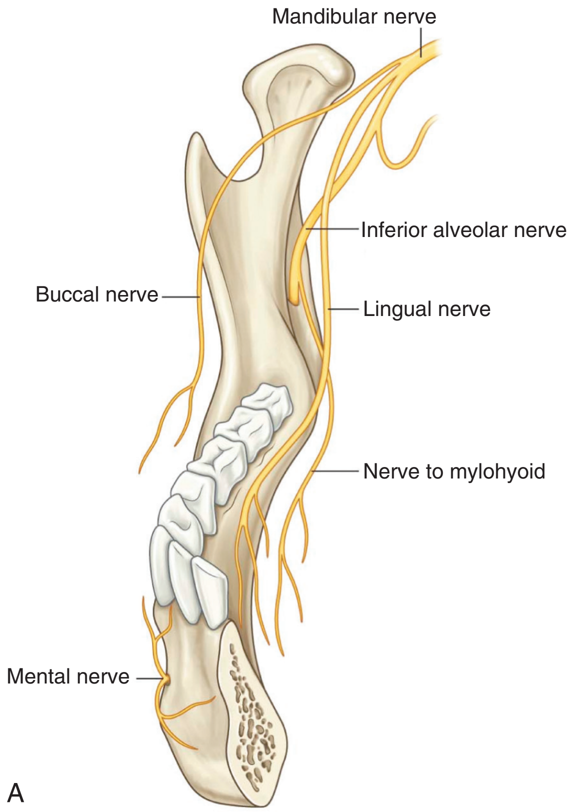


FIG 9.6 (A) Anterior superior alveolar nerve. (B) Canalia sinuosus is an anatomic variant leading to placement of implants into the canal leading to a soft tissue interface. Axial CBCT image showing location in center of residual ridge. (C) Cross-sectional CBCT image depicting the canalia sinuosus. (A, From Wells M: *Local and regional anaesthesia in the emergency department made easy*, Edinburgh, 2010, Churchill Livingstone.)

branches, the first being a smaller anterior branch containing the buccal and masseteric nerve. A larger posterior component divides the mandibular nerve into three main branches, the auriculotemporal, inferior alveolar (IAN), and lingual nerves (LN).

This nerve innervates the temporomandibular joint, skin above the ears, auricle, tongue and its adjacent gingiva, floor of the mouth, mandibular teeth and associated gingiva, mucosa and skin of the cheek, lower lip and the chin and the muscles of mastication.

Inferior Alveolar Nerve. The inferior alveolar nerve is the largest branch of the mandibular nerve. Before entering the mandibular foramen on the lingual surface of the mandible, the mylohyoid nerve branches, giving innervation to the mylohyoid and anterior belly of digastric muscles. In the mandibular canal it runs downward and forward before dividing, in approximately the first molar region, into two terminal branches; the incisive and mental nerves.[14] The mental nerve courses anteriorly until it exits through the mental foramen, which is sensory to the soft tissues of



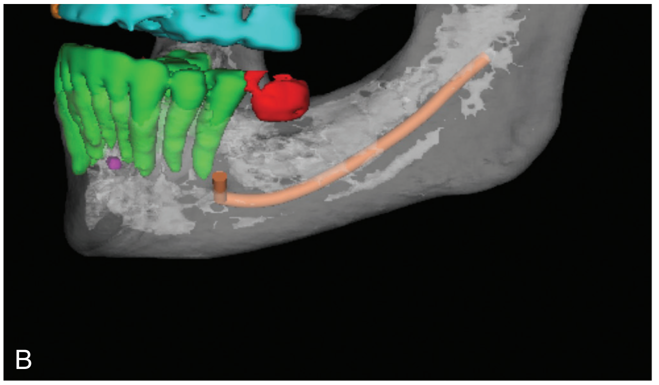


FIG 9.7 (A) Mandibular nerve and its branches. (B) 3-D image of the intraosseous course of the mandibular nerve. (A, From Wells M: *Local and regional anaesthesia in the emergency department made easy*, Edinburgh, 2010, Churchill Livingstone.)

the chin, lip, and anterior gingiva. The incisive nerve continues anterior and innervates the mandibular anterior teeth. Accurately determining the exact location of the inferior alveolar nerve as it courses through the body of the mandible is imperative to avoid neurosensory disturbances secondary to implant placement (Fig. 9.7).

Histologically, this IAN consists of connective tissue and neural components in which the smallest functional unit is the individual nerve fiber. The IAN fibers may be either myelinated or unmyelinated. The myelinated nerve fibers are the most abundant; they consist of a single axon encased individually by a single Schwann cell. The individual nerve fibers and Schwann cells are surrounded by the endoneurium, which acts as a protective cushion made up of a basal lamina, collagen fibers, and endoneurial capillaries.

Clinical relevance. Nerve impairment to the inferior alveolar nerve (mental nerve) is a common clinical complication with major medicolegal implications. Because of its anatomic location, the mental nerve is the most common nerve to be damaged via implants or bone graft procedures. Trauma usually occurs from placement of implants directly into the foramen or into the inferior alveolar canal in the posterior mandible. Sensory nerve injury may result in altered sensation, complete numbness, and/or pain, which may interfere with speech, eating, drinking, shaving, or make-up application and lead to social embarrassment.

Lingual Nerve. Within the infratemporal fossa, the lingual nerve divides from the posterior division of the mandibular nerve (V_3) as a terminal branch. As the lingual nerve proceeds anteriorly, it lies against the medial pterygoid muscle and medial to the mandibular ramus. It then passes inferiorly to the superior constrictor attachment and courses anteroinferiorly to the lateral surface of the tongue. As it runs forward deep to the submandibular gland, it terminates as the sublingual nerve.

The lingual nerve is sensory to the anterior two thirds of the tongue, floor of the mouth, and lingual gingiva. It also contains visceral afferent and efferent fibers from cranial nerve seven (facial nerve) and from the chorda tympani, which relays taste information. With the prevalence of second molar implants, care should be taken to note the possible position of the lingual nerve on the medial ridge of the retromolar triangle, where it courses anteriorly along the superior lingual alveolar crest, which is slightly lingual to the teeth (Fig. 9.8).[15]

Clinical relevance. Due to the lingual nerve's variable anatomic location, it may be iatrogenically traumatized during various implant surgical procedures. Usually the lingual nerve is not damaged from the actual osteotomy preparation of implants unless the lingual plate is perforated. This sensory nerve is most likely traumatized during soft tissue reflection during implant placement in the second molar area or incision/reflection over the retromolar pad for bone graft procedures. Additionally, the lingual nerve can suffer damage from lingual flap retraction and inferior alveolar nerve blocks. Studies have shown that lingual nerve impairment after nerve blocks occurs twice as often as inferior alveolar nerve damage.[16] This is most likely due to the fact the lingual nerve is most commonly unifascular at the site of the injection. Sensory damage to the lingual nerve may cause a wide spectrum of complications ranging from complete anesthesia to paraesthesia, dysesthesia, drooling, tongue biting, change in taste perception, and change in speech pattern.

NERVE INJURIES

ETIOLOGY

Most implant-related nerve impairments are the direct result of poor treatment planning and inadequate radiographic

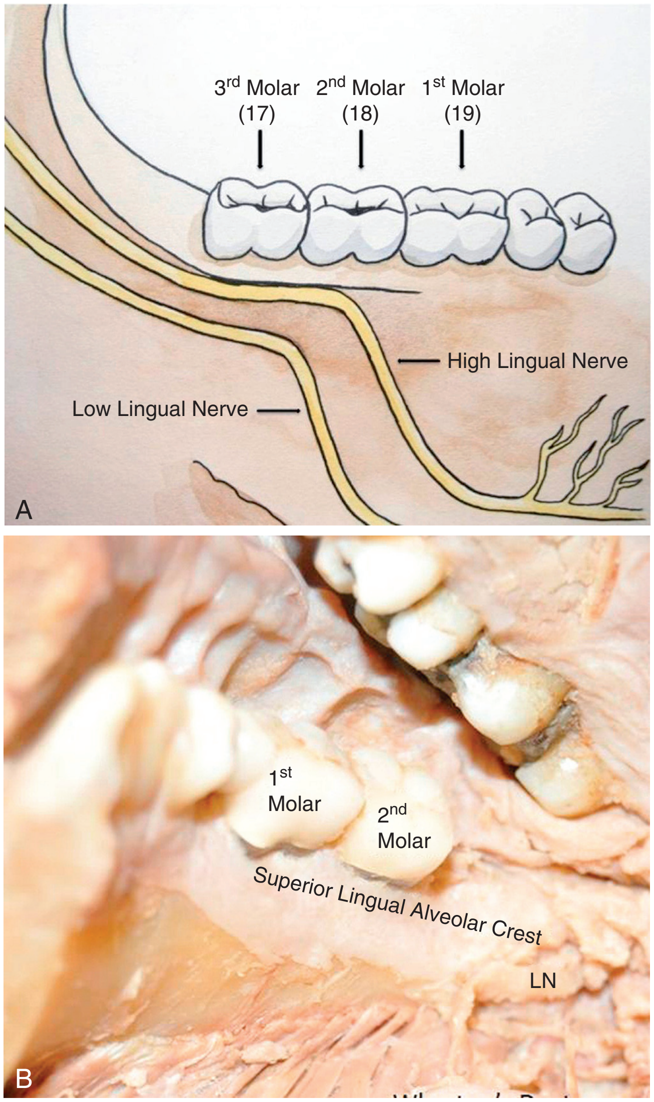


FIG 9.8 (A–B) Lingual nerve anatomy and variant positions. Note the proximity to the crest of the ridge in the "high" variant position. A lingually placed incision or excessive retraction may cause damage to the lingual nerve. (From Benninger B, Kloenne J, Horn JL: Clinical anatomy of the lingual nerve and identification with ultrasonography, *Brit J Oral Maxillofac Surg* 51:541–544, 2013.)

evaluation. Nerve trauma occurs when the implant clinician is not aware of the amount of bone or does not know the location of nerve canals or foramens. Preoperative planning is crucial to determine the amount of available bone in approximation to a nerve structure, location of vital structures, bone density, and location for proper placement of implants. A cone beam computed tomography (CBCT) examination is most commonly used for the three-dimensional planning in these areas.

Nerve injuries may result from various intraoperative and postoperative complications. Nerves may be mechanically injured by indirect or direct trauma via retraction, laceration, pressure, stretching, and transection. Thermal trauma may cause inflammation and secondary ischemia injuries with associated degeneration. And lastly, peripheral nerves have been shown to be susceptible to chemical injuries, where the nerve is directly traumatized by chemical solutions.

Administration of Local Anesthesia

Adequate local anesthesia is paramount for successful dental implant surgery and stress reduction protocol. However, although rare, the use of nerve blocks may result in trauma to various branches of the trigeminal nerve. The exact etiology of local anesthesia nerve damage is unclear, and various theories such as injection needle trauma, hematoma formation, and local anesthetic toxicity have been discussed. Although the true incidence is difficult to quantify, studies have shown permanent injury occurs in approximately 1 in 25,000 inferior nerve blocks. Most patients do recover fully without deficits, with full recovery in 85% of patients with complete remission in 8–10 weeks.[17]

Needle. Complications resulting from needle trauma are likely the most common theory on why nerve injury results after administering nerve blocks. First, it is not uncommon for the tip of the needle to become barbed (damaged) when contacting bone. Stace et al showed that 78% of needles became barbed after initial injection, increasing the possibility of damaging the nerve. Two-thirds of the needles developed outward-facing barbs, which have been shown to rupture the perineurium, damage the endoneurium, and cause transection of nerve fibers.[18] The lingual nerve has been associated with the highest percentage of nerve impairment cases as a result of an anesthetic injection (~70%)[19]. Because of the lingual nerve's anatomic location, it is predisposed to nerve injuries because it is commonly contacted when using the pterygomandibular raphe as an injection landmark due to the nerve being positioned shallow in the tissue (~3–5 mm from the mucosa).[20]

Hematoma. The anesthetic needle may also cause damage to the epineurial blood vessels, which may result in hemorrhage-related compression on the nerve fibers. The accumulation of blood may lead to fibrosis and scar formation, which may cause pressure-related trauma.[21] The extent of impairment to the nerve is directly related to the amount of pressure exerted by the hematoma and recovery time of the axonal and connective tissue damage.

Anesthetic Toxicity. If the anesthetic is injected within the fascicular space, chemical irritation and damage may occur. Studies have shown articaine to comprise 54% of mandibular nerve block injuries,[22] and it is 21 times more likely to cause injury in comparison to other nerve injuries.[23] Theories concerning articaine toxicity include the high concentration of articaine solution[24] and the increased resultant inflammatory reaction.[25] Lidocaine has been shown to be the least toxic anesthetic followed by articaine, mepivacaine, and bupivacaine.[26] Chemical trauma from local anesthetics has been shown to cause demyelination and axon degeneration of nerve fibers.[27]

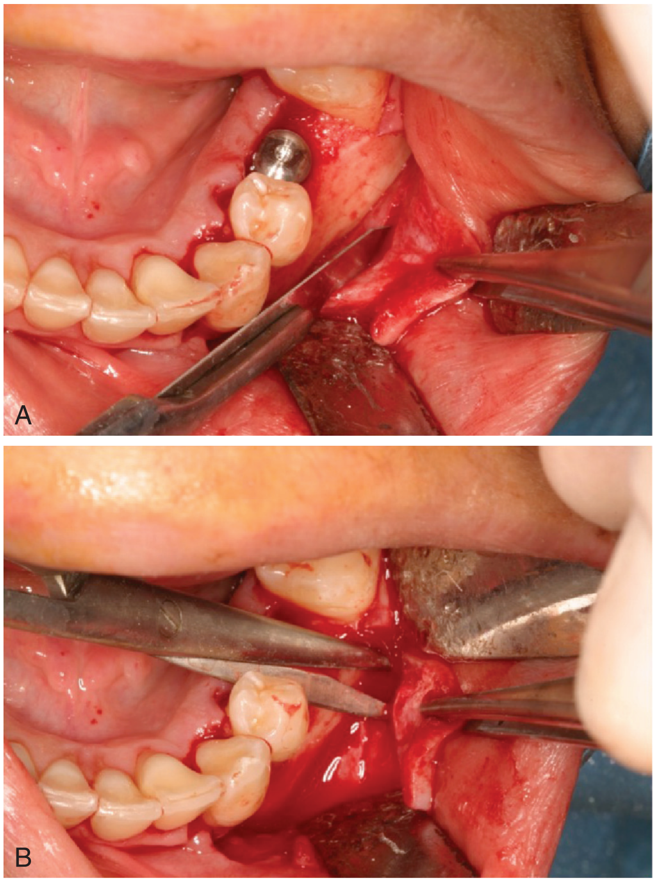


FIG 9.9 Periosteal release of the tissue to obtain tension-free closure. (A) The use of a #15 blade to release the periosteal fibers. (B) Blunt dissection to release tissue with Metzenbaum scissors.

Soft Tissue Reflection

Injury to nerves and nerve fibers may occur during the reflection, retraction, or suturing of the soft tissue. This is most noted when the mental nerve is dehiscenced or exposed on the mandibular ridge. Special caution should be exercised when making incisions over these areas because complete transection injuries may occur from incisions through the nerve or foramen. Stretching injuries (neuropraxia) may occur from excessive retraction, so care should be noted as to the proximity of neural vital structures within the retracted tissue. Complete transection of the nerve results from stretching the tissue to reduce tension over the flap without regard to the anatomic location of the nerve (Fig. 9.9).

Implant Drill Trauma

Neurosensory impairment may result from direct or indirect trauma from the osteotomy sites. Direct trauma may occur from overpreparation of the osteotomy site or lack of knowledge of the true bur length. The implant clinician must know and understand the true length of the surgical burs used in the osteotomy site preparation. The marked millimeter gauge lines inscribed on the shank of the drills most often do not include the cutting edge of the drill and do not correspond to the actual depth of the drill. Most drills have a sharp, V-shaped apical portion to improve their cutting efficiency. The V-shaped apical portion of the drill (termed the "Y" dimension in engineering) is often not included in the depth measurements of the commercial drills and may measure as much as 1.5 mm longer than the intended depth.

When the bone is less dense, slippage of the handpiece may occur, leading to overpenetration. The implant clinician should use the initial implant osteotomy twist drill as a gauge for bone density type and for an evaluation of the position of the surgical drill relative to the mandibular canal. In implant dentistry today the overzealous use of immediate implants has been associated with an increase of drilling-related trauma. To gain primary stability, most immediate implant osteotomy sites require drill preparation and implant placement apical to the extraction site. When placing implants in the mandibular premolar area, violation of the canal may occur, causing nerve damage. Therefore in this anatomic area, immediate implant placement is not recommended unless adequate bone is available below the root apex.

The following are the types of surgical drill trauma that may lead to a neurosensory impairment:

Drill Encroachment. The surgical drill may cause a nerve impairment from thermal damage even though the surgical drill does not violate the mandibular canal. Most commonly, this is the result of insufficient irrigation, which leads to overheating the bone. Thermal trauma may lead to nerve impairment via bone necrosis from overheating the bone during preparation. Nerve tissue has been shown to be more sensitive to thermal trauma than bone (osseous) tissue. Excessive temperatures have been shown to produce necrosis, fibrosis, degeneration, and increased osteoclastic involvement.[28] To minimize this complication the bone density should be evaluated preoperatively via CBCT examination, tactile evaluation, and by location.

Partial Penetration. The surgical drill may also cause direct trauma to the neurovascular bundle by penetrating the mandibular canal or mental foramen. The neurosensory impairment will be directly proportional to the specific nerve fascicles that are damaged. Normally, the vein and artery, which are positioned more superiorly than the nerve, will be damaged when penetration of the canal results. Indirect trauma may also cause nerve damage from the excessive bleeding (hematoma), as well as thermal and chemical injuries from the penetration into the canal.

Transection. The most severe type of nerve injury, with the lowest probability of regeneration, is when the implant drill transects the canal. Because the nerve is usually completely severed, repair and regeneration is highly variable. This type of injury will usually result in anesthesia-type symptoms and neuroma formation with possible dysesthesia symptoms (Fig. 9.10).

Implant Encroachment on the Mandibular Canal. Injuries to vital nerve structures due to implant positioning are most

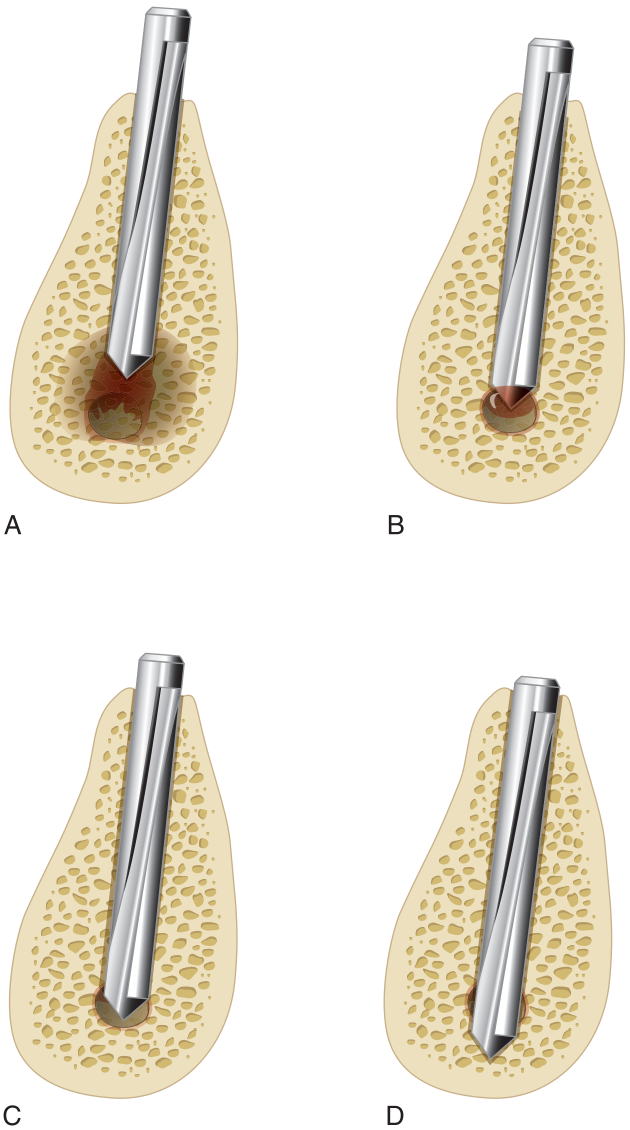


FIG 9.10 Drill impingement trauma. (A) Encroachment: even though surgical drill is short of canal, thermal damage and bone necrosis (brown/green) result in nerve damage. (B) Partial penetration (hematoma): the surgical drill partially penetrates the superior aspect of the canal resulting in bleeding and hematoma formation. (C) Partial penetration (laceration): the surgical drill penetrates deeper into the canal, which results in laceration of nerve fibers. (D) Transection: the surgical drill may penetrate the entire canal leading to complete transection of the nerve fibers.

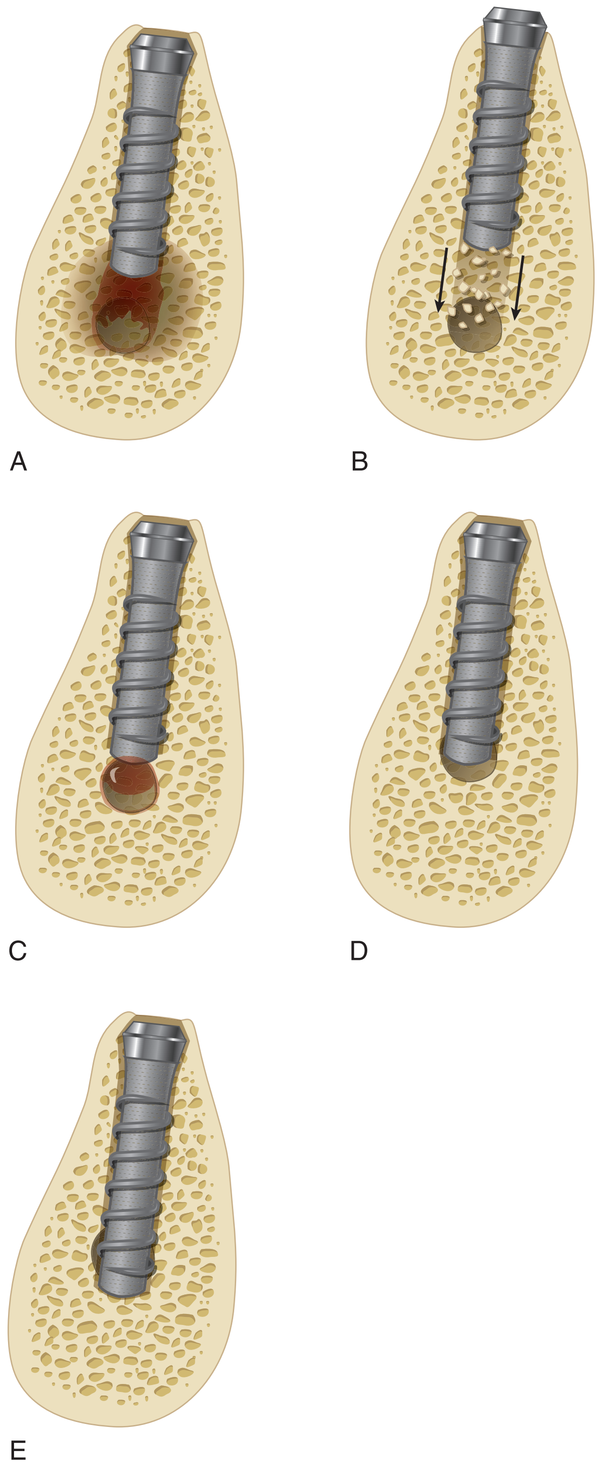


FIG 9.11 Implant impingement trauma. (A) Encroachment: even though the implant body is short of the canal, thermal damage may occur from overheating the bone. (B) Bone fragments (trabeculae) may be pushed apically resulting in a pressure necrosis nerve injury. (C) Partial penetration (hematoma): the implant body may partially penetrate the superior aspect of the canal resulting in bleeding and hematoma formation. (D) Partial penetration (laceration): the implant body may penetrate deeper into the canal, which results in laceration of nerve fibers. (E) Transection: the implant body may penetrate the entire canal leading to complete transection of the nerve fibers.

common in the posterior mandible. These may be caused by direct trauma (mechanical) and indirect trauma or infection (pressure). Placement of an implant into or near the mandibular canal is associated with many types of neurosensory impairments (Fig. 9.11).

Placement of an implant close to the mandibular canal may cause trauma due to compression or secondary ischemia. A 2.0-mm safety zone of the implant in proximity to the canal should always be adhered to. Studies have shown that implant pressure on the canal occurs with increasing stress as the bone density decreases.[29] Khaja and Renton showed that placement of an implant too close to the canal may cause hemorrhage or deposition of debris into the canal, causing ischemia of the nerve. Even removing the implant or repositioning may not alleviate and decrease pressure-related symptoms. Additional studies have shown the presence of postoperative severe pain after implant placement in close approximation to the canal resulting in chronic stimulation and debilitating chronic neuropathy.[30]

Partial Penetration Into Mandibular Canal. Placement of the implant body into the mandibular canal is associated with a high degree of morbidity. The sensory nerve fascicles are usually inferior to blood vessels within the canal, and the type and extent of injury is proportional to the fibers that are damaged. This is why in some cases the implant is directly within the canal; however, no neurosensory symptoms exist. Additionally, implant placement into the canal may cause hematoma formation (severing of the inferior alveolar artery or vein), leading to a nerve impairment.

Perforation Through the Entire Canal. Complete transection of the nerve occurs when surgical error involves the preparation of an osteotomy too deep due to inaccurate measurements or slippage of the handpiece. This type of injury results in the most severe of response, a total nerve impairment (anesthesia) and neuroma formation. Usually this type of nerve injury results in a complete anesthesia and retrograde degeneration resulting in future dysesthesia.[27] The extent of neurosensory impairment is proportional to the extent of fascicle injury and is dependent upon the time the implant is left to irritate the nerve fibers.

Infection. Placement of implants in approximation to the canal may cause neurosensory impairments via periimplant infections. Infectious processes after implant placement may result from heat generation, contamination, or prior existence of bone pathology. This may lead to spread of infection that may extend into the neural anatomy. Case reports have shown nerve impairment issues resulting from an implant infected by chronic peri-implantitis.[31]

Mandibular Socket Grafting. After mandibular tooth extractions, grafting into the socket may effectively expose the inferior alveolar nerve to socket medicaments. This may lead to chemical neuritis and, if the irritation persists, an irreversible neuropathy may occur (Fig. 9.12). Additionally, care should be exercised when removing pathology and granulation tissue from extraction sockets in close proximity to the nerve canal (type 1 nerve).[32] Overzealous curretting of the socket apex may lead to direct traumatic injury of the canal.

Delayed Nerve Damage (Canal Narrowing). Nerve damage may result even when ideal implant placement is performed (>2.0 mm from the nerve canal). Shamloo et al reported an implant placement case in which the implant body caused compression and bone to be forced into the superior aspect of the mandibular canal (canal narrowing). This led to delayed healing and remodeling within the canal and resulted

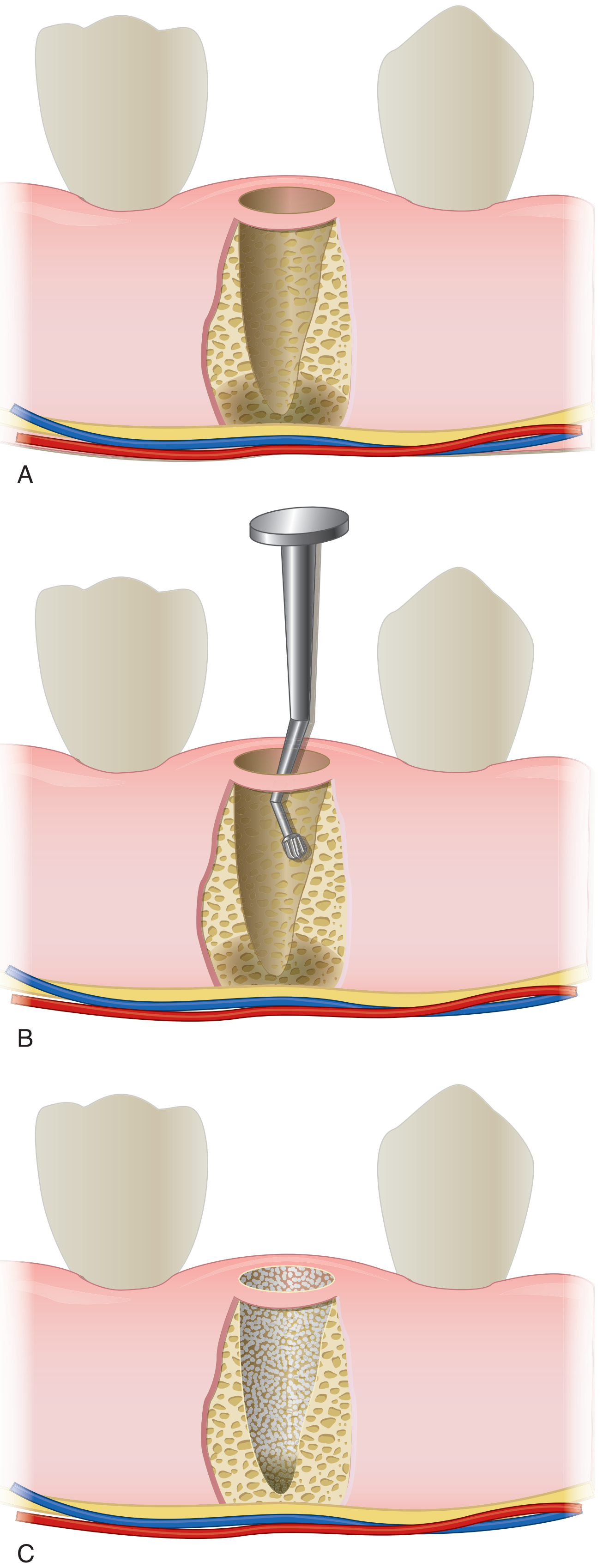


FIG 9.12 Postextraction site. (A) Care should be taken when grafting an extraction site in close approximation to the inferior alveolar nerve. (B) A curette should be used with caution because direct damage to the nerve may occur. (C) Grafting in close approximation to the canal may lead to nerve trauma.

in excessive narrowing of the canal with compression of the nerve fibers. The narrowed aspect of the canal was shown to be approximately 0.2 mm, with an average diameter in the nonaffected sites being approximately 3.2 mm.[33] The nerve impairment (paresthesia and anesthesia) occurred 2 years after implant placement surgery.

PHYSIOLOGIC RESPONSE

The incidence of nerve impairment has been shown to be patient specific. Studies have shown that females and older patients are at greater risk of nerve deficits. As patients age, neural cell body regeneration has been shown to be much slower.[34] Women have been shown to have greater associated pain and nerve impairment in comparison to men because of lower pain thresholds, greater chance of seeking treatment in comparison to men, and an increased tendency to communicate their problems.[35]

There are many local and host-related factors that determine the neurologic response to a nerve injury. Older individuals exhibit slower and less dramatic cell body regeneration in comparison to younger individuals. The type of injury is the most significant local factor relating to the neurologic response after trauma. Injuries that occur at the proximal site of the peripheral nerve are usually more significant in comparison to those that occur at distal sites.[9] In the event any of the extraneural tissues (epineurium, perineurium, endoneurium, or mesoneurium) are injured or traumatized, impaired neural transmission may result in a sensory disturbance. The resultant neurosensory impairment is dependent on the varying functional units of the individual fiber type involved. A-alpha fibers are the largest fibers and mediate position and fine touch by way of muscle spindle afferents and skeletal muscle efferents. The A-beta fibers are mainly proprioceptive in nature, and A-delta fibers mediate initial pain impulses along with temperature information. The C-fibers are unmyelinated and slow conducting, which allow the perception of pain and temperature.[4]

When complete transection of a nerve occurs, within 96 hours the proximal end of the nerve fiber shrinks approximately 20% to 50% in diameter and usually will not recover more than 80% of its original size.[10] Shortly thereafter, axonal nerve sprouts will seek and extend out to the degenerating distal branch. Each axon may contain up to 50 collateral sprouts and advance approximately 1–3 mm per day and eventually attempt to reinnervate the target tissue. If the nerve sprouts are unable to reconnect, forward progress is stopped and Wallerian degeneration will occur. Wallerian degeneration is the process resulting from a damaged nerve fiber in which part of the axon is separated from the neurons cell body. This may also be known as anterograde or orthograde degeneration.[35a] Wallerian degeneration usually results in neuroma (benign growth) formation, which is associated with increased mechanical and chemical sensitivity, resulting in chronic neurosensory deficits.[11]

Quick, immediate treatment is highly recommended in neurosensory impairment cases. Nerve fiber atrophy has been shown to occur with trauma over 6 hours.[36] After 3 months, permanent central and peripheral changes occur that make it unlikely the nerve will respond to surgical treatment intervention.[37] Injuries older than 6 months rarely respond to any treatment and are usually permanent.[38]

Nerve Healing

After nerve injury, there exist two phases of healing, degeneration and regeneration.

Degeneration. There are two types of nerve degeneration: segmental degeneration and Wallerian degeneration. Segmental demyelination occurs when the myelin sheath is damaged and causes a slowing of the conduction velocity, which may prevent the transmission of nerve impulses. The resulting effects will clinically be paresthesia, dysesthesia, or hyperesthesia. The second type of degeneration is termed *Wallerian degeneration,* in which the axons and myelin sheath distal (away from central nervous system [CNS]) to the injury undergo complete disintegration (Fig. 9.13). The axons proximal to the site of injury (towards the CNS) undergo less degeneration, but many nodes of Ranvier (periodic gaps in the myelin sheaths of axons that facilitate the rapid conduction of nerve impulses) are affected. Wallerian degeneration usually occurs after complete transection of the nerve and results in dysesthesia type of symptoms.

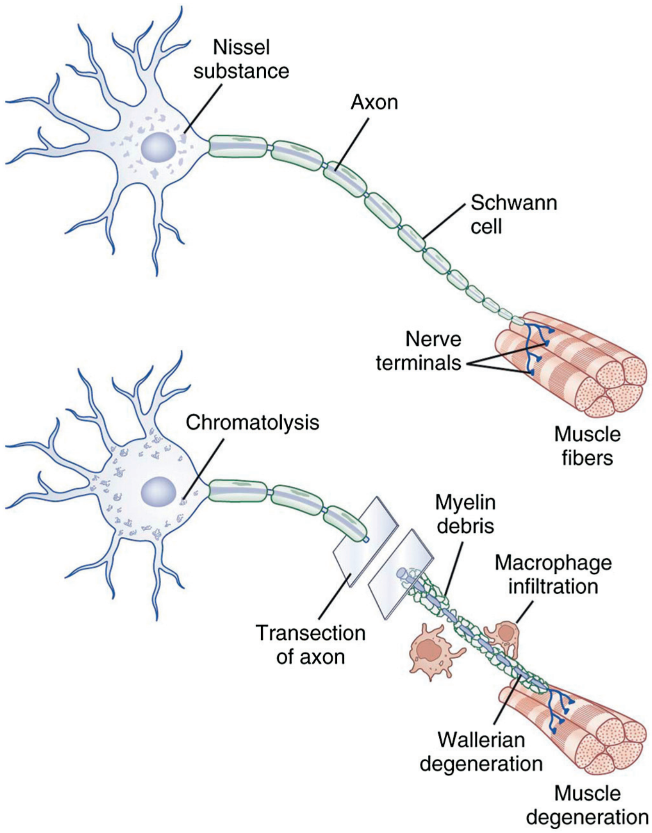


FIG 9.13 Wallerian degeneration resulting with inadequate nerve repair. (From Daroff RB, Jankovic J, Mazziotta JC, et al editors: *Bradley's neurology in clinical practice*, ed 7, London, 2016, Elsevier.)

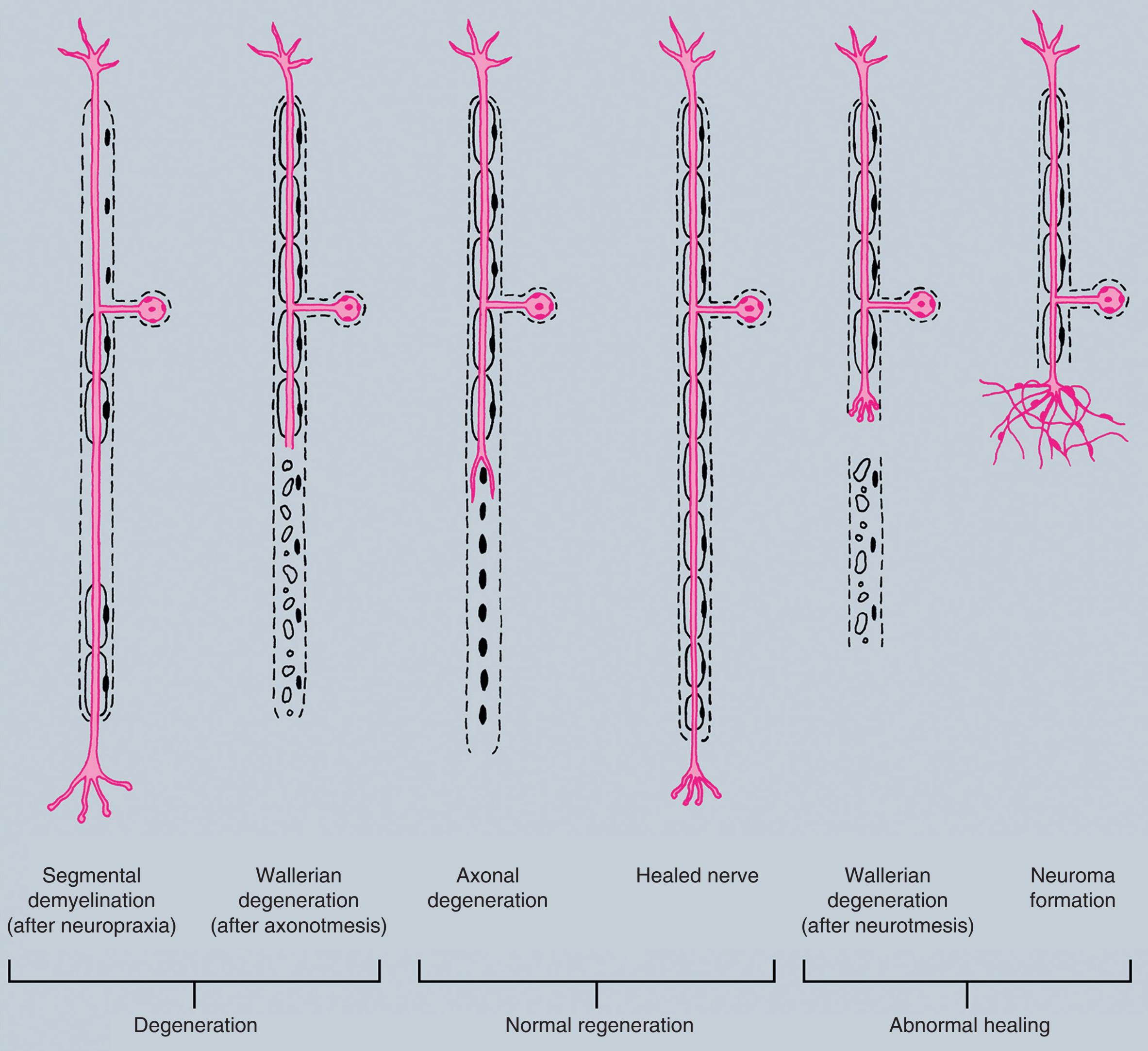


FIG 9.14 Normal and abnormal nerve responses (degeneration, regeneration) to nerve injury. (From Hupp JR, Tucker MR, Ellis E: *Contemporary oral and maxillofacial surgery*, ed 6, St. Louis, 2014, Mosby.)

Regeneration. Usually, regeneration occurs immediately after nerve injury. The proximal nerve area sprouts out new fibers that grow at a rate of 1.0–1.5 mm per day. This will continue until the site innervated by the nerve is reached or blocked by fibrous connective tissue, bone, or object (e.g., dental implant). During the regeneration process, new myelin sheaths form as axons increase in size. In some situations the continuity of the Schwann cells is disrupted, and connective tissue may enter the area. The growth may find an alternative path, or it may form a traumatic neuroma, which is usually characterized by significant pain. Studies have shown that the administration of steroids may minimize the formation of neuromas, especially the administration of high doses within the first week of nerve injury (Fig. 9.14).[2]

Neurosensory Deficit Classification

There are two widely accepted classifications of nerve injuries. In 1943 Seddon postulated a three-stage classification, which was later reclassified by Sunderland in 1951 into five different subclassifications. These nerve injury classifications are described by the resultant morphophysiologic type of injury, which is based on the time course and amount of sensory recovery (Fig. 9.15).

Neuropraxia, or first-degree injury, is characterized by a conduction block with no degeneration of the axon or visible damage of the epineurium. Usually, this type of injury is consistent with stretching or manipulation (reflection of tissue) of the nerve fibers, which results in injury to the endoneurial capillaries. The degree of trauma to the endoneurial capillaries will determine the magnitude of intrafascicular edema, which results in various degrees of conduction block. Usually, resolution of sensation and function will occur within hours to weeks.

Axonotmesis (second-, third-, or fourth-degree injury) consists of degeneration or regeneration axonal injuries. The injury classification depends on the severity of axonal damage.

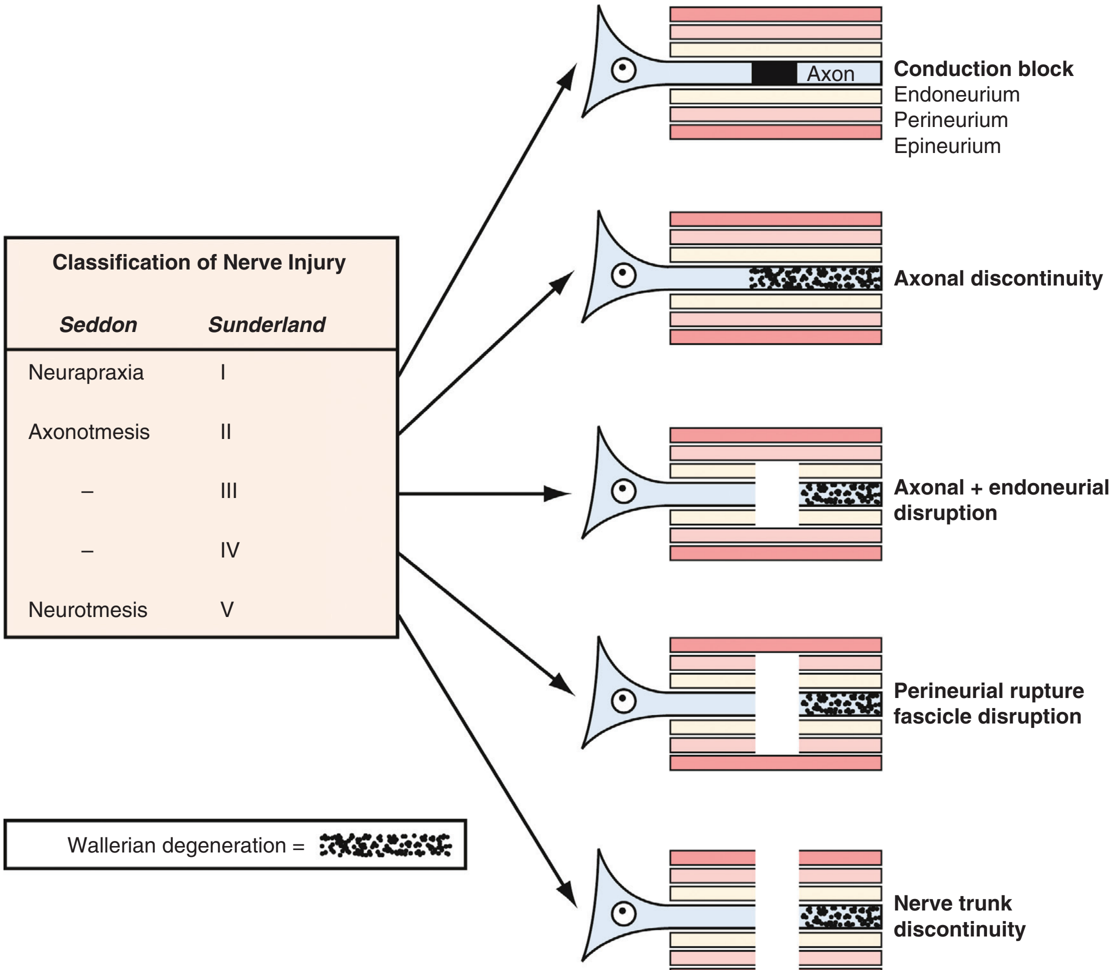


FIG 9.15 Seddon/Sunderland Neurosensory Impairment Classification with description of nerve damage. (From Ellenbogen RG, Sekhar LN, editors: *Principles of neurological surgery*, ed 3, Philadelphia, 2012, Saunders.)

This type of injury involves the endoneurium, with minimum disruption to the perineurium and epineurium. The most common type of injuries are traction, stretching, and compression, which can lead to severe ischemia, intrafascicular edema, or demyelination of the nerve fibers. Initially, complete anesthesia is most common, which is followed by paresthesia as recovery begins. Improvement of the related sensory deficits occurs within approximately 2–4 months with complete recovery usually within 12 months. In some cases, painful dysesthesias are possible with resulting neuroma formation.

Neurotmesis (fifth-degree injury) is the most severe type of injury, resulting from severe traction, compression, or complete transection injuries. Initially, patients exhibit anesthesia, followed by paresthesia with possible dysesthesia. A very low probability of neurosensory recovery exists, with immediate referral for a neurosurgical evaluation recommended.[39,40] The axon and encapsulating connective tissue will lose their continuity. There is usually complete loss of motor, sensory and autonomic function. Neuroma formation is common if transection has occurred.

Classification of Sensory Symptoms

The literature involving peripheral nerve injuries is vast, with a significant variation in the nomenclature used to describe the associated clinical signs and symptoms. Neurosensory impairments are classified from complete numbness to severe pain of the facial soft tissues to the intraoral anatomy. Because of these deficits, severe complications result for the patient and the clinician. A thorough understanding of the associated classifications and definitions is necessary (Tables 9.1 and 9.2).

To standardize the nomenclature concerning nerve injuries, the International Association for the Study of Pain reduced sensory impairment into three categories: anesthesia, paresthesia, and dysesthesia.[40a] *Anesthesia* is characterized by the complete lack of "feeling," which is usually consistent with complete transection of the nerve. This type of altered sensation is most severe because anesthesias are the most difficult and unpredictable to treat with a high incidence of neuroma formation. *Paresthesia* is defined as an altered sensation that is not unpleasant. It is usually characterized as a "pins and needles" feeling. Within the paraesthesia category,

TABLE 9.1 Neurosensory Impairment Classification and Injury Response[5,6]

Sunderland	Seddon	Description	Causes	Responses	Recovery Rate
I	Neurapraxia	Temporary interruption of nerve transmission (Conduction Block)	Nerve Compression Edema Hematoma Minor Stretching Thermal	• Neuritis • Paresthesia	Complete (Fast—days to weeks)
II	Axonotmesis	Endoneurium, perineurium, and epineurium remain intact. Some axon degeneration may occur	Nerve Compression Traction Hematoma Partial Crush Edema Stretching	• Paresthesia • Episodic • Dysesthesia	Complete (Slow—weeks)
III		Disruption of axon and connective tissue (endoneurium) causing disorganized regeneration. Wallerian degeneration occurs	Crush Puncture Severe Hematoma Stretching	• Paresthesia • Dysesthesia	Variable (Slow—weeks to months)
IV		Damage involves entire fascicle. Axonal, endoneurium, and perineurium changes occur. The epineurium is intact. Scar tissue formation.	Full Crush Extreme Strecthing High Thermal Direct Chemical Trauma	• Hypoesthesia • Dysesthesia • Neuroma formation	Unlikely
V	Neurotmesis	Complete transaction or tear of the nerve with amputation neuroma forming at injury site	Complete Transection (overpreparation with implant drill)	• Anesthesia • Intractable Pain • Neuroma Formation	None

TABLE 9.2 Description of Neurosensory Impairment Deficits[7]

Anesthesia	Total Loss of Feeling or Sensation
Dysesthesia	Abnormal sensation that is unpleasant
Allodynia	Pain due to a stimulus that does not normally provoke pain
Hyperpathia	Abnormally painful reaction to a stimulus
Causalgia	Persistent burning pain
Anesthetic Dolorosa	Pain in an area that is anesthetic
Hyperesthesia	Increased sensitivity to stimulation
Hyperalgesia	Increased response to a stimulus that is normally painful
Paresthesia	Abnormal sensation that is not unpleasant
Hypoesthesia	Decreased sensitivity to stimulation
Hypoalgesia	Decreased response to a stimulus that is normally painful
Synesthesia	Sensation felt in an area when another area is stimulated

many subcategories exist including hypoesthesia (decreased sensitivity to stimulation), hypoalgesia (decreased response to a stimulus that is normally painful), and synesthesia (sensation in an area when another is stimulated). *Dysesthesias* are classified as an altered sensation that is unpleasant. Usually pain is associated with this type of impairment, which may be spontaneous or mechanically evoked. Subcategories include hyperalgesia (painful response to nonpainful stimuli), hyperpathia (delayed or prolonged painful response), anesthetic dolorosa (pain in an area that is anesthetized), causalgia (persistent burning pain), and allodynia (pain in response to a stimulus that usually does not provoke pain).

TREATMENT

Nerve Impairment at Time of Surgery

During surgery, if known traction or compression of the nerve trunk has occurred, the topical application of Dexamethasone may be used to minimize deficits. Upon removal of an encroaching implant on the mandibular canal, 1–2 mL of the intravenous form of Dexamethasone (4 mg/mL) is topically applied (Fig. 9.16). This direct steroid application will reduce neural inflammation and may enhance recovery from neurosensory deficits. Studies have shown no morbidity associated with the topical application of glucocorticoids at the injury site and postsurgical recovery has also been shown to improve significantly.[12] No bone grafting or implant should be placed that may lead to irritation of the traumatized nerve fibers.

Nerve Impairment Postoperatively

When a neurosensory deficit occurs postoperatively, a comprehensive sensory evaluation must be completed. This initial examination is used to determine whether a sensory deficit

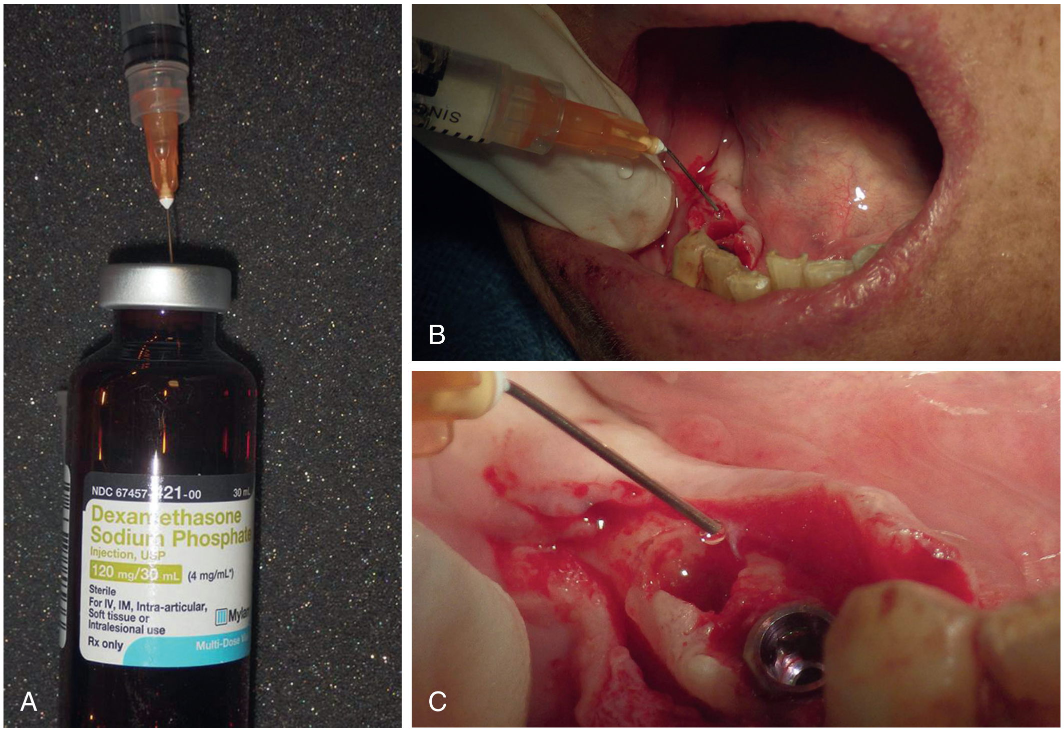


FIG 9.16 (A) Dexamethasone 4 mg/mL. (B–C) 1–2 mL of dexamethasone placed into osteotomy site.

exists, to quantify the extent of injury, document a baseline for recovery, and to determine if referral for microneurosurgery is indicated.

Step 1: Clinical Assessment. The implant clinician must first determine if a neurosensory deficit exists by mapping the area of deficit. This diagnostic examination consists of objective and subjective findings to determine the extent of impairment, to use as a baseline for future evaluation, and to determine when referral for surgical intervention is required.

The subjective clinical sensory tests involve nociceptive and mechanoceptive examinations. Nociceptive tests trigger a variety of autonomic responses that result in the subjective experience of pain. Mechanoceptive tests utilize mechanical stimuli to trigger sensory neurons that elicit various responses such as touch, position and motion (Table 9.3 and Fig. 9.17).

Clinical examination complications. There exist many inherent problems with relying on the credibility of the patient's subjective responses. Because there may exist a high degree of false-positive and false-negative results, clinicians should utilize clear and concise instructions when administering these tests. For instance, when administering the "directional movement" test, the clinician should complete this test on the contralateral side first so the patient understands the technique and response. The results of the subjective clinical examination will depend on good communication between the implant clinician and the patient, with the outcome of the results related to the patient's perceived interpretation and how to relate their perceptions. Additionally, the tests should be administered with the patient's eyes closed, so as to minimize the possibility of incorrect responses.

Step 2: Radiographic Evaluation/Removal or Repositioning of the Implant. A thorough and comprehensive radiographic examination should be completed including (ideally) a CBCT radiograph. If the implant (or bone screw) is in close approximation of the nerve bundle, removal or repositioning should be completed. Care should be exercised in "backing" the implant out (repositioning farther from the nerve) because trauma to the nerve may still be present from hematoma formation or pressure from cancellous bone crushed into the neural space. Additionally, backing the implant out may lead to the implant being positioned undesirably because of lack of interocclusal space for the restoration (i.e., too coronally positioned). In these cases, the implant should be removed and the osteotomy site irrigated with 4% Dexamethasone (1–2 mL). No graft materials should be added to the osteotomy site because they may interfere with the reinnervation and repair of the nerve trunk.[41]

Step 3: Pharmacologic Intervention. Immediately after the nerve is traumatized, the inflammatory process begins with the activation of cytokines and inflammatory mediators. These inflammatory mediators will contribute to the development of nerve trauma by activating the neurons and their nociceptors.[42]

With any type of nerve impairment, corticosteroids or nonsteroidal antiinflammatory agents should be used immediately. Studies have shown that the use of systemic adrenocorticosteroids (e.g., Dexamethasone) minimizes neuropathic symptoms following nerve trauma if administered in high doses within 1 week of injury.[43] It has been advocated that a tapering dose of a corticosteroid for 5–7 days following trigeminal nerve injury is beneficial.[44] Dexamethasone (~8 mg)

TABLE 9.3 Nociceptive and Mechanoceptive Diagnostic Tests

Diagnostic Test	Description
Nociceptive	
Pin pressure (A-Delta, C-Fiber)	Determination of feeling from pin pressure using a blunted explorer. A normal response (distinct sharp pain) is a positive sign of feeling (in relation to an unaffected area) with no pain. If no feeling is present in comparison to an unaffected side, the area is termed *hypoalgesia*. If an exaggerated response is noted in relation to an unaffected side, the area is termed *hyperalgesia*.
Thermal discrimination (warm: A-Delta: cold: C-Fibers)	Ice chips or ethyl chloride spray and a heated mirror handle (warmed to 43°C) are used to determine the patient's ability to feel cold and hot.
Mechanoceptive	
Static light touch	Cotton tip applicator with the patient's eyes closed to test tactile stimulation by gently touching the skin and determining the threshold of the patient. (A-beta afferent axons.)
Directional movement	Soft brush is used to determine the patient's ability to detect both sensation (A-beta and A-alpha axons) and direction of movement. The soft brush is swiped from left to right, as well as in the reverse direction.
Two-point discrimination	With the patient's eyes closed, the patient's ability to discriminate varying (myelinated A-alpha fibers) distances between two points is determined using a caliper. The normal values vary significantly, with the average being approximately 5 mm.[71]

is specifically recommended because of its greater antiinflammatory effects in comparison to other corticosteroids such as methylprednisolone or prednisone. Additional pharmacologic agents include antidepressants, neurologic drugs, antisympathetic agents, and topical agents.

Additionally, cryotherapy (ice packs) should be applied to the paraneural tissues intensely for the first 24 hours and then episodically for the first week. Cryotherapy has been shown to be beneficial in minimizing secondary nerve injury from edema-induced compression, decreasing the metabolic degeneration rate of trigeminal ganglion cells and slowing potential neuroma formation.[45] Additional physiologic agents include transcutaneous electric nerve stimulation, acupuncture, and low-level laser therapy.

Step 4: Possible Referral. In certain situations, patients may need to be referred in a timely manner to a practitioner experienced in nerve injury assessment and repair. The decision and timing to refer should be based on the patient's symptoms and the type of injury, along with the experience of the implant dentist in treating nerve injuries. Usually, sufficient time is given for neurosensory recovery. In cases of dysesthesia, anesthesia, or known nerve transection, prompt surgical intervention may allow for the best chance of neurosensory recovery. Early, aggressive treatment has been shown to minimize possible transition to chronic refractory neuropathies (Table 9.4).[16]

Step 5: Follow-Up Care. Follow-up care should always be a component of the treatment of a nerve impairment patient. The interval between appointments is determined by the extent and type of nerve injury (see Table 9.4). Usually, after the one week postoperative, patients are seen every 2 weeks with mapping and documentation of the deficits noted.

Surgical Intervention

In some cases of neurosensory impairment, surgical repair is indicated. In general, early treatment is crucial to success and decreased morbidity. Microneurosurgical procedures include direct nerve repair via primary anastomoses of the two severed ends for transection injuries. For nerve splits, reestablishment and proper alignment of nerve stumps will allow for the best chance to correct regeneration of the damaged nerves (Fig. 9.18).

PREVENTION

Iatrogenic injuries to the third division of the trigeminal nerve pose a common and complex problem in implant dentistry today. Neurosensory impairment in the head and neck region may affect the patient's quality of life and can present potentially significant medicolegal problems for the clinician. To prevent damage to vital nerve structures, it is imperative for the implant dentist to have a comprehensive radiographic survey of the region, a thorough knowledge of the normal vs. variant anatomy, and awareness of intraoperative surgical techniques to minimize the possibility of nerve impairment.

Radiographic Considerations

Understand Disadvantages and Limitations of Two-Dimensional Radiography. Today, the sole use of two-dimensional radiography is becoming less common for treatment planning of dental implant patients. Two-dimensional radiographs, mainly panoramic, have many inherent disadvantages in evaluating potential implant sites. All panoramic (2-D) radiographs exhibit some degree of distortion, nonuniform magnification, and image superimposition, which can potentially lead to incorrect measurement

FIG 9.17 Sensory testing. (A) Mapping out deficit with eyeliner. (B) Light touch with cotton applicator. (C) Directional test with brush. (D) Two-point discrimination utilizing calipers. (E) Thermal test with mirror handle. (F) Pin-point tests with explorer or dull needle.

and assessment of neural structures. Studies have shown periapical and panoramic radiography to be unreliable in assessing the true location of the inferior alveolar canal and the mental foramen.[46] Extreme caution should be exercised when using two-dimensional radiography as the only modality for implant site evaluation (Fig. 9.19A–B).

Do Not Use Two-Dimensional Magnification Guides. Manufacturers have made available to implant dentists magnification guides and digital software programs for intraoral radiographs to assist in the placement of implants over vital structures. Caution should be noted that panoramic radiographs have variable magnification (i.e., not 25% as related by many implant and panoramic companies), and even calibrated intraoral software programs cannot accurately assess true distances because of their two-dimensional origin. Both periapical and panoramic radiography are associated with magnification that is inconsistent

TABLE 9.4 Neurosensory Deficit Treatment Algorithms

Postsurgery	Documentation	Pharmacologic Intervention	Treatment	Referral
≈48 hr	3-D radiographic examination (CBCT); neurosensory examination	Corticosteriods (Dexamethasone 4 mg) 2 tabs AM for 3 days 1 tab AM for 3 days	Implant evaluation: Removal or reposition if impingement within the mandibular canal No bone grafting Cryotherapy (1 week)	None, unless unfamiliar with neurosensory testing
1 week postoperative	Neurosensory examination (Testing should be continued every 2 weeks thereafter)	High-dose NSAIDs (600–800 mg ibuprofen TID)	Palliative	Refer to Oral Surgeon or Neurosurgeon if: • Known nerve transection • Dysesthesia • Complete anesthesia
8 weeks postoperative	Neurosensory examination	NSAIDs (PRN)	Palliative	IF NO SIGN OF IMPROVEMENT Refer to OMFS or microneurosurgeon

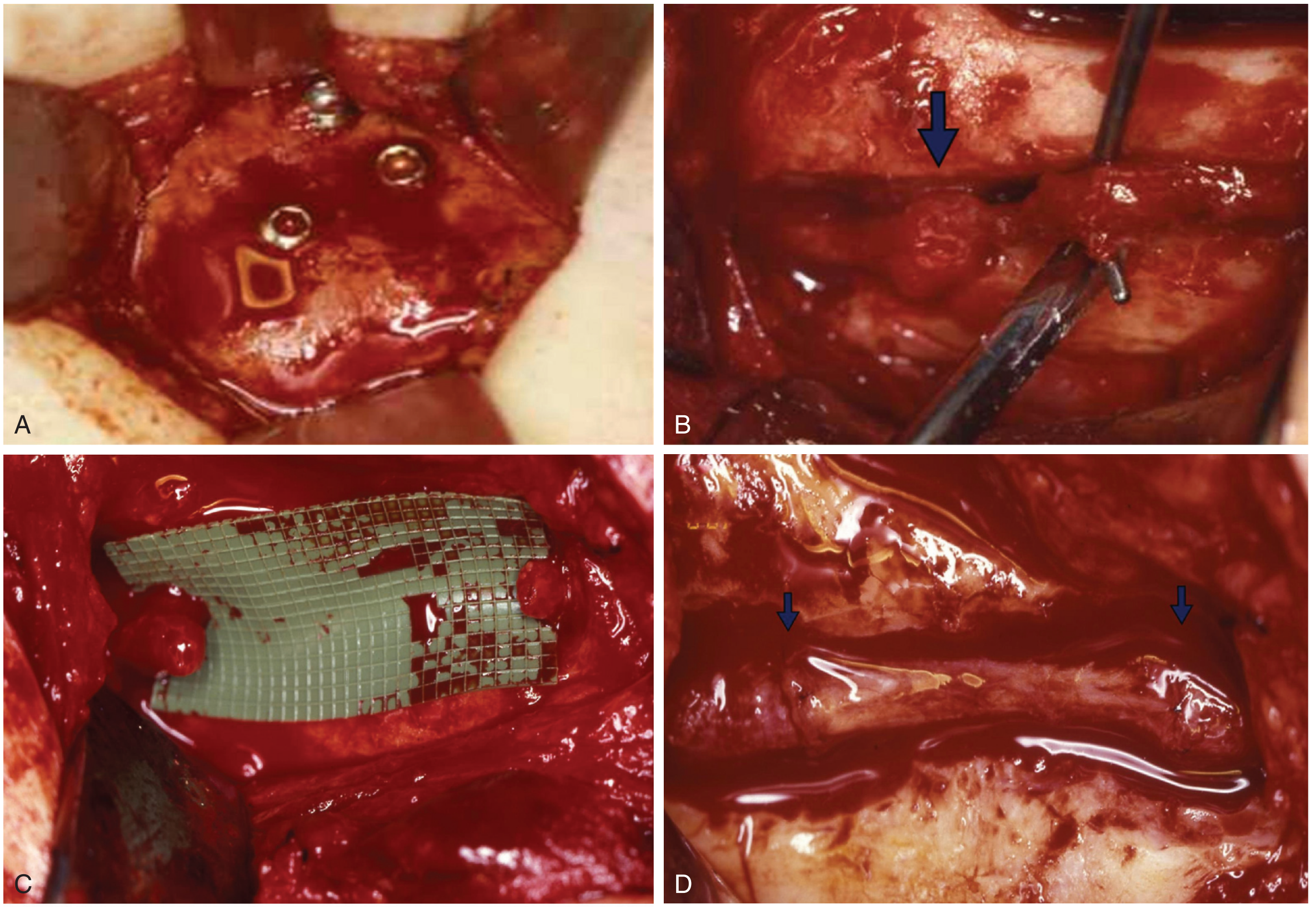


FIG 9.18 Nerve repair. (A) Mandibular internal fixation screws in a 29-year-old patient with right inferior alveolar nerve (IAN) sensory dysfunction after sagittal split ramus osteotomy. (B) The IAN was not directly contacted by any of the screws, but there is a proximal stump neuroma *(arrow)* and a thin stalk of scar tissue, containing no viable nerve tissue, which extends between the proximal and distal nerve (supported by nerve hook) stumps. (C) The proximal stump neuroma has been excised and the two nerve stumps have been prepared for microsurgical repair. (D) The right IAN has been reconstructed with an autogenous right great auricular nerve graft (*arrows* at sutured areas). (From Bagheri SC, Meyer RA, Khan HA, et al: Microsurgical repair of the peripheral trigeminal nerve after mandibular sagittal split ramus osteotomy, *J Oral Maxillofac Surg* 68:2770–2782, 2010.)

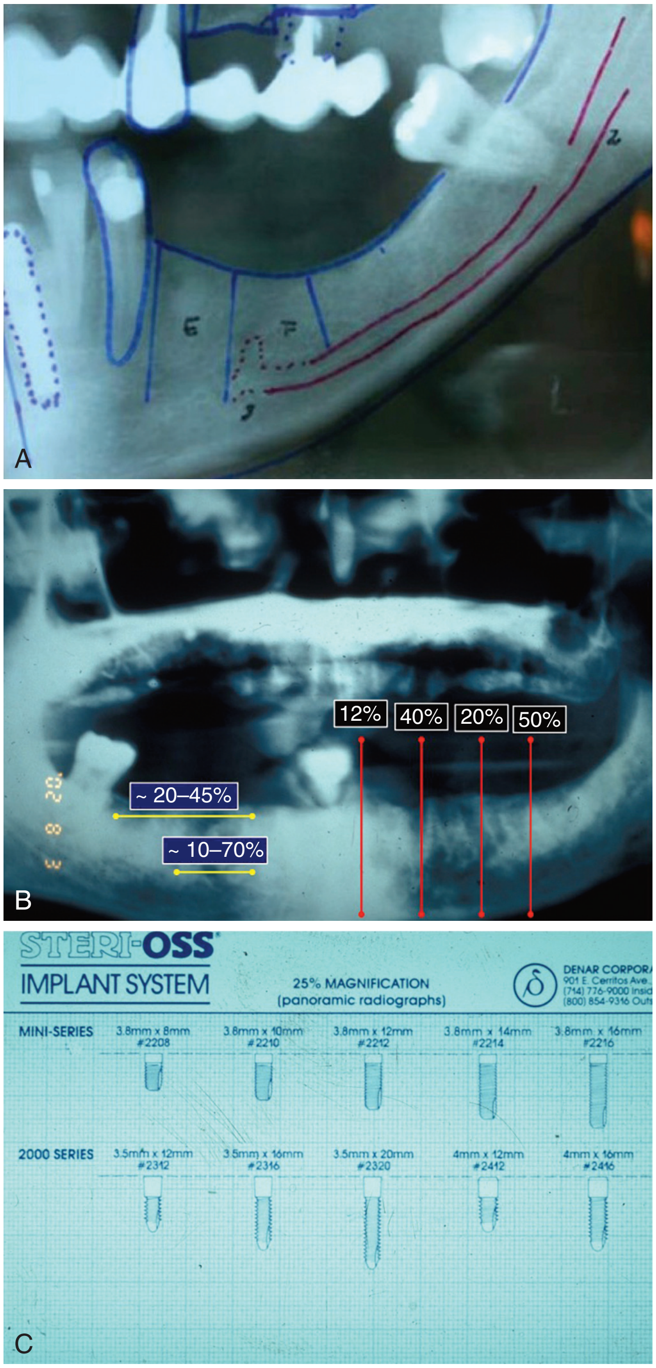


FIG 9.19 (A) 2-D panoramic radiographs exhibit many inherent inaccuracies and should never be solely relied upon in making measurements because they provide nonuniform magnification. (B) Magnification may be determined in the vertical plane. Horizontal magnification is completely unreliable and inaccurate. (C) Magnification (25%) guides are superimposed over two-dimensional radiographs, but they often lead to misrepresentation of available bone.

and difficult to determine. Schropp et al have shown that over 70% of cases in which implant size was initially determined via panoramic radiographs the size had to be altered after CBCT evaluation.[47] Magnification guides should never be used as the sole criteria for implant site evaluation because they may lead to overestimation of available bone dimensions (Fig. 9.19C).

Three-Dimensional Radiography Is the Most Accurate Type of Radiographic Modality. In most cases, a three-dimensional radiographic modality is recommended for evaluation of the mandibular arch and related nerve anatomy. To determine the ideal location and measurement parameters associated with the dental implant placement, the clinician must be able to accurately measure the distance between the alveolar crest and the superior border of the mandibular canal, as well as the width of bone in the proposed implant site. Medical slice computed tomography (MSCT) and CBCT images have been shown to be the most accurate radiographic modalities in the assessment of available bone and identification of the inferior alveolar nerve.[1,48] A thorough knowledge of the relative three-dimensional (3-D) position of the inferior alveolar nerve is crucial in preventing mandibular nerve impairment prior to implant placement (Fig. 9.20A).

Use Interactive Treatment Planning Software for Evaluation of the Posterior Mandible. Because MSCT and CBCT have been proven to be 1 : 1 (no magnification), the implant dentist has the ability to place implants, measure available bone, evaluate bone density, and order surgical templates directly from their computerized treatment plan. Interactive treatment planning software programs available today contain libraries of most implants systems, which allow the clinician to accurately access the size, type, and ideal placement of the implant in relation to anatomic structures. This virtual treatment plan may then be transferred to the patient's surgery by means of a surgical template or computer-assisted navigation system (Fig. 9.20B–C).

Use of Bone Models. For implant dentists early on their learning curve, the fabrication of a bone model can be an invaluable preoperative diagnostic tool. Bone models are made directly from the CT Dicom data, which involves a third-party vendor fabrication through some type of 3-D printer, such as stereolithography. The clinician is able to evaluate the exact osseous morphology (width of bone, undercuts, bony landmarks) and location of vital structures (color coded within the model) prior to the actual surgery. Implant osteotomies may be performed in a laboratory setting to allow the implant dentist to complete the procedure prior to surgery.

Use of Surgical Templates. Neurosensory impairment issues are most frequently an inadvertent sequela of improper diagnosis, treatment planning, or surgical technique. Many of these complications can be overcome by using three-dimensional surgical guides for the ideal positioning and placement of implants. Basically, the surgical guide is the conduit for transferring the interactive treatment plan from the computer to the patient's actual surgical procedure. This allows the implant dentist to be able to place the implants in the exact location as per the treatment plan. Surgical guides

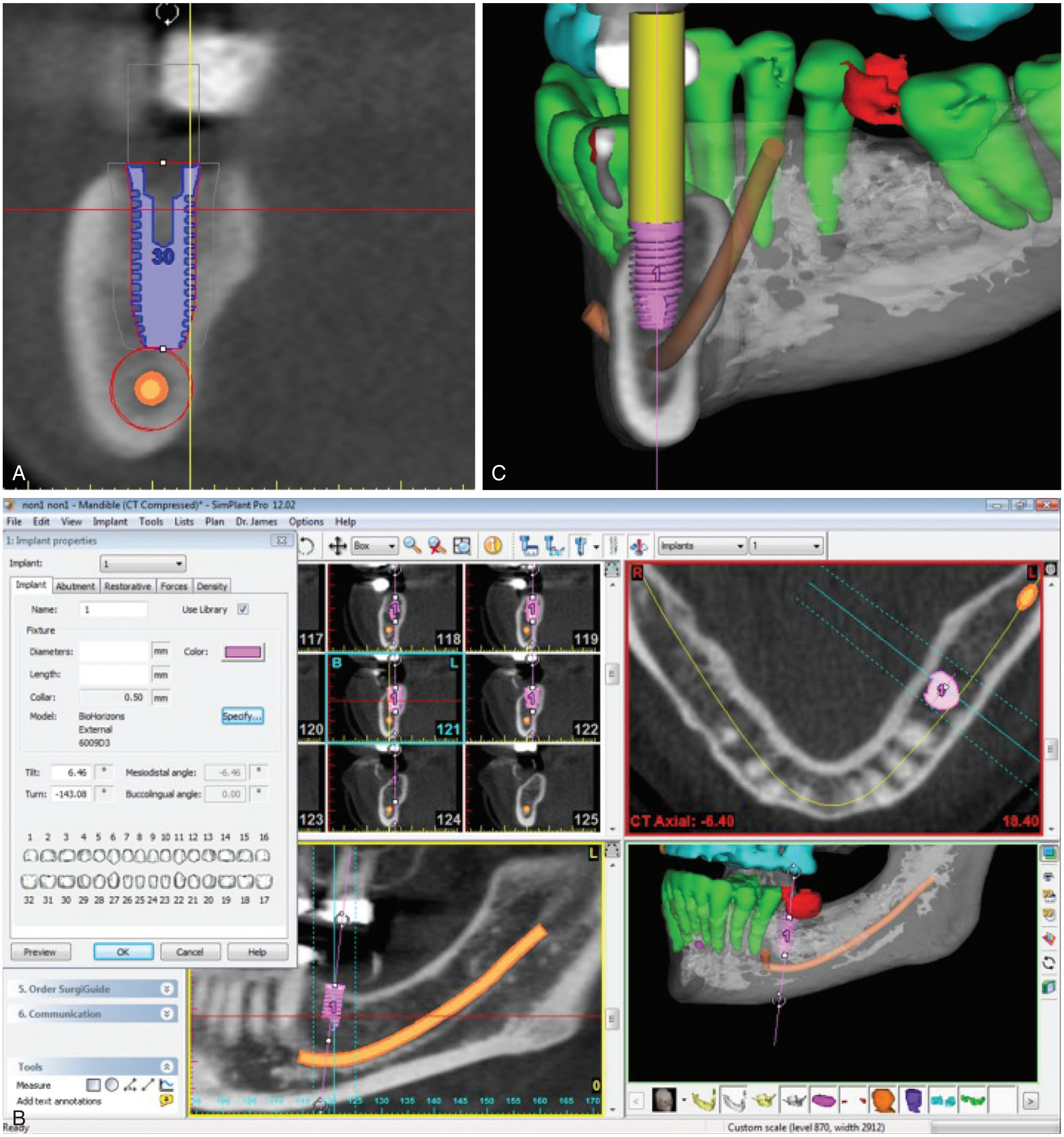


FIG 9.20 (A) CBCT images have no magnification and are 1 : 1 and can be relied upon for measurements that approximate vital structures. (B–C) Third-party interactive software programs showing implant placement via integrated software program.

are categorized based on method of retainment: tooth, bone, or mucosa supported. SIMPLANT Safe Guide (DENTSPLY Implants) gives the practitioner the ability to place the implant via an interactive treatment plan in the mesiodistal, buccal-lingual, and apicocoronal dimensions via three types of guides. Guided surgery with surgical templates has been reported to improve the accuracy of implant placement in clinical situations in comparison to conventional surgical methods (Fig. 9.21).[49] Nickenig et al showed that implants placed with surgical templates were within 0.9 mm of the planned positions, whereas free-hand placement resulted in deviations of approximately 2–3 mm.[49a]

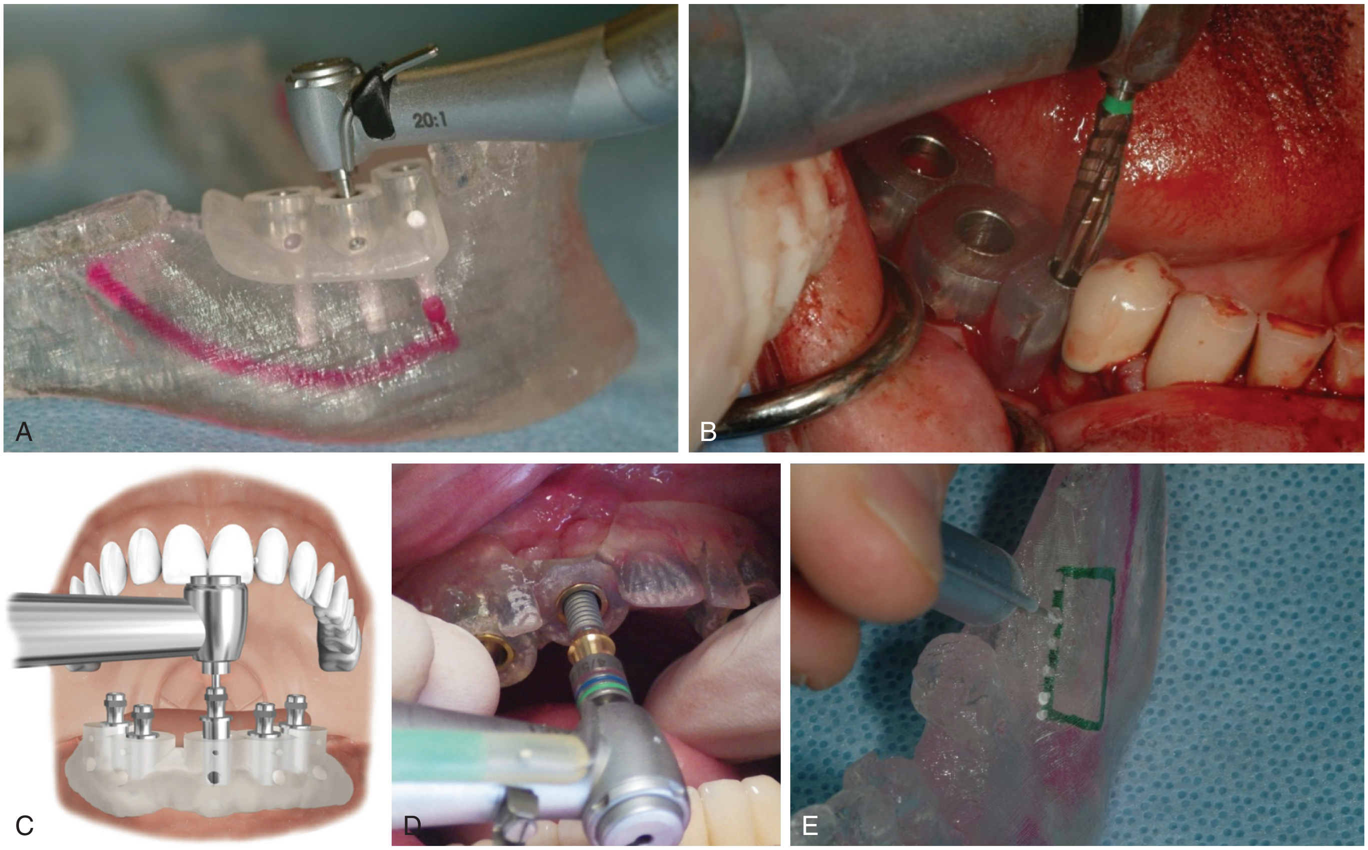


FIG 9.21 Stereolithographic bone models. (A) Depicting exact location of IAN canal and mental foramen for implant placement. (B) Bone-supported SurgiGuide (Materialise Dental) placing posterior mandibular implant. (C–D) Simplant Safe Guide; implant being placed through guide. (E) Bone model showing ramus bone graft with the IAN depicted in red. (C, Courtesy Dentsply Sirona Implants, Waltham, MA.)

Anatomic Considerations: Mandible

The Position of the IAN is Variable and Not Consistent in the Vertical (Inferior-Superior) Plane. There is a common belief that the vertical position of the inferior alveolar nerve is relatively constant within the mandible. Normally, the IAN runs a concave path from posterior to anterior, with anterior segments exiting the mental foramen and a branch that ascends to the midline of the mandible. However, studies have confirmed the inferior-superior (vertical) positions of the inferior alveolar nerve are not consistent.[50,51] An early classification of the vertical positions of the course of the alveolar nerve was reported by Carter and Keen.[52] They described three distinct types: (1) in close approximation to the apices of the teeth, (2) a large nerve approximately in the middle of the mandible with individual nerves supplying the mandibular teeth, and (3) a nerve trunk close to the inferior cortical plate with large plexuses to the mandibular teeth. In type 1 nerves, impairment is very common because of the close proximity to the nerve bundle. Three percent of patients can have the IAN directly contacting one or both of the roots of the mandibular first molar.[53] It is highly recommended that a comprehensive radiographic survey be completed to evaluate the IAN in a vertical plane, especially with type 1 and 2 nerves (Fig. 9.22).

The Position of the IAN is Variable and Not Consistent in the Buccal-Lingual Plane. Studies have shown the buccal-lingual location of the IAN as it progresses anteriorly is not constant. The nerve paths have been described in a buccal-lingual direction with a high degree of variability and are dependent on the amount of bone resorption as well as age and race variables.[54] Additionally, older and Caucasian patient groups have shown less distance between the buccal aspect of the nerve and the inferior border of the mandible.[55] Other studies have shown the most common area for the IAN to be in the middle of the buccal and lingual cortical plates is the first molar region.[56] Thus, in the buccal-lingual plane, three-dimensional cross-sectional images should be utilized to determine the true position of the nerve (Fig. 9.23).

Understand the Variations of the Mental Foramen Location. Determining the exact location of the mental foramen is crucial when placing implants in the posterior mandible. Although the foramen has been shown to be symmetrical to the contralateral side in most patients, the location has been shown to be highly variable.[57] The mental nerve passes through the mental foramen with three nerve branches. One innervates the skin of the mental area, and the other two proceed to innervate the skin of the lower lip, mucous membranes, and the gingiva as far posteriorly as the second

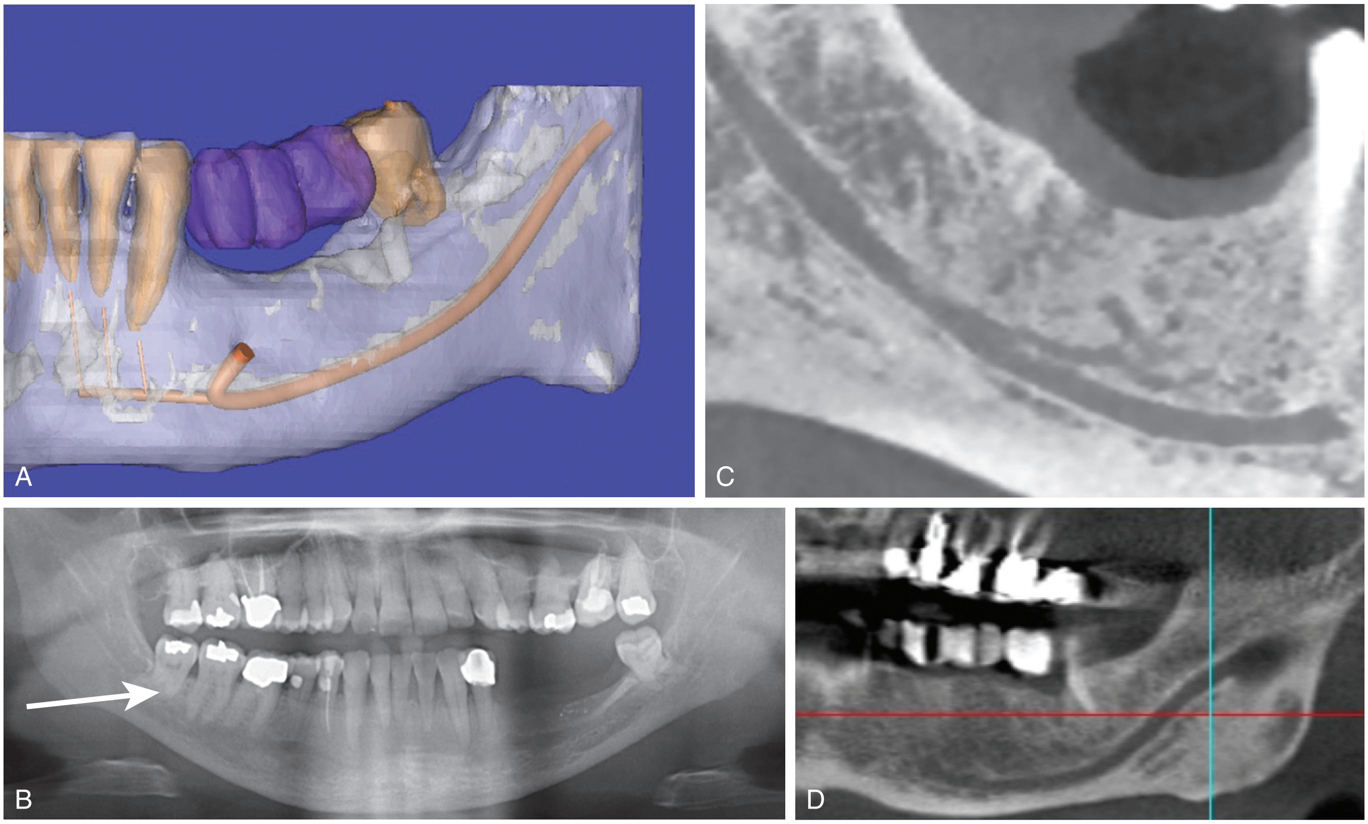


FIG 9.22 (A) Inferior alveolar nerve. (B) Type 1 nerve *(arrow)*. (C) Type 2 nerve. (D) Type 3 nerve.

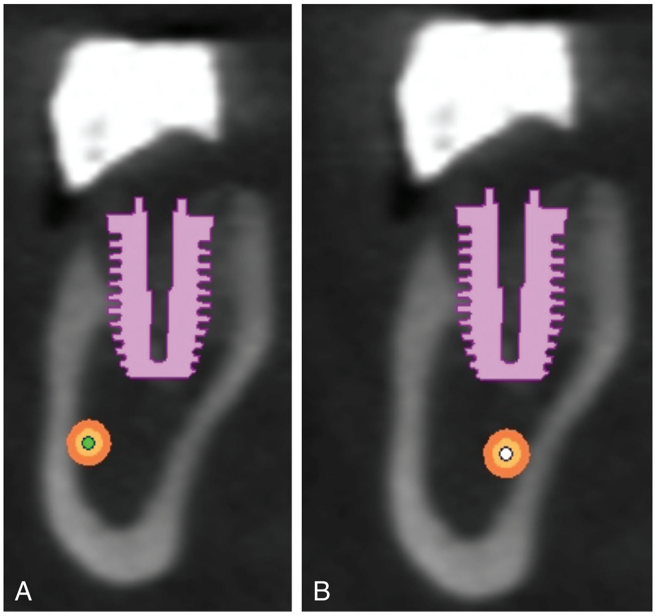


FIG 9.23 Cross-sectional image showing variability of the IAN in buccal-lingual position. (A) Buccal orientation. (B) Lingual orientation.

premolar. Any trauma to this nerve will result in neurosensory impairment in this area. Clinically, there are many different techniques in identifying the foramen with a wide variation of predictability.

Palpation. In rare cases, the implant dentist may be able to palpate the location of the mental foramen. Most notably, when bone resorption has caused the nerve to be exposed on the residual ridge, the concavity formed by the exposure of the nerve can be determined. In these cases, the location of the mental foramen may be marked with a surgical pen. When the nerve is located on the buccal surface of the mandible, the palpation method of identification has very low utility (Fig. 9.24A).

Anatomic landmarks. In the literature, many authors have postulated that landmarks such as teeth and mandibular bony areas may help identify the location of the mental foramen. With respect to teeth, the location cannot conclusively be associated with a particular tooth (e.g., first premolar, second premolar, between apices of the premolars) because studies have shown the location to be dependent on gender, age, and race.[58] Certain bony landmarks (e.g., alveolar ridge, mandibular symphysis, infraorbital foramen) have been associated with a general location of the foramen, although these measurements are extremely variable and dependent on the extent of bone resorption, skeletal relationships, and anatomic variants (Fig. 9.24B–C).

Two-dimensional radiographs. Studies have shown that in over 50% of periapical and panoramic radiographs, the mental foramen is not in the location depicted on the two-dimensional image.[46] Conventional two-dimensional radiography should never be used as the sole diagnostic modality in evaluating the foramen position.

Three-dimensional radiography. The literature has shown that 3-D imaging is the most accurate tool to ascertain the exact location of the mental foramen. CBCT panoramic

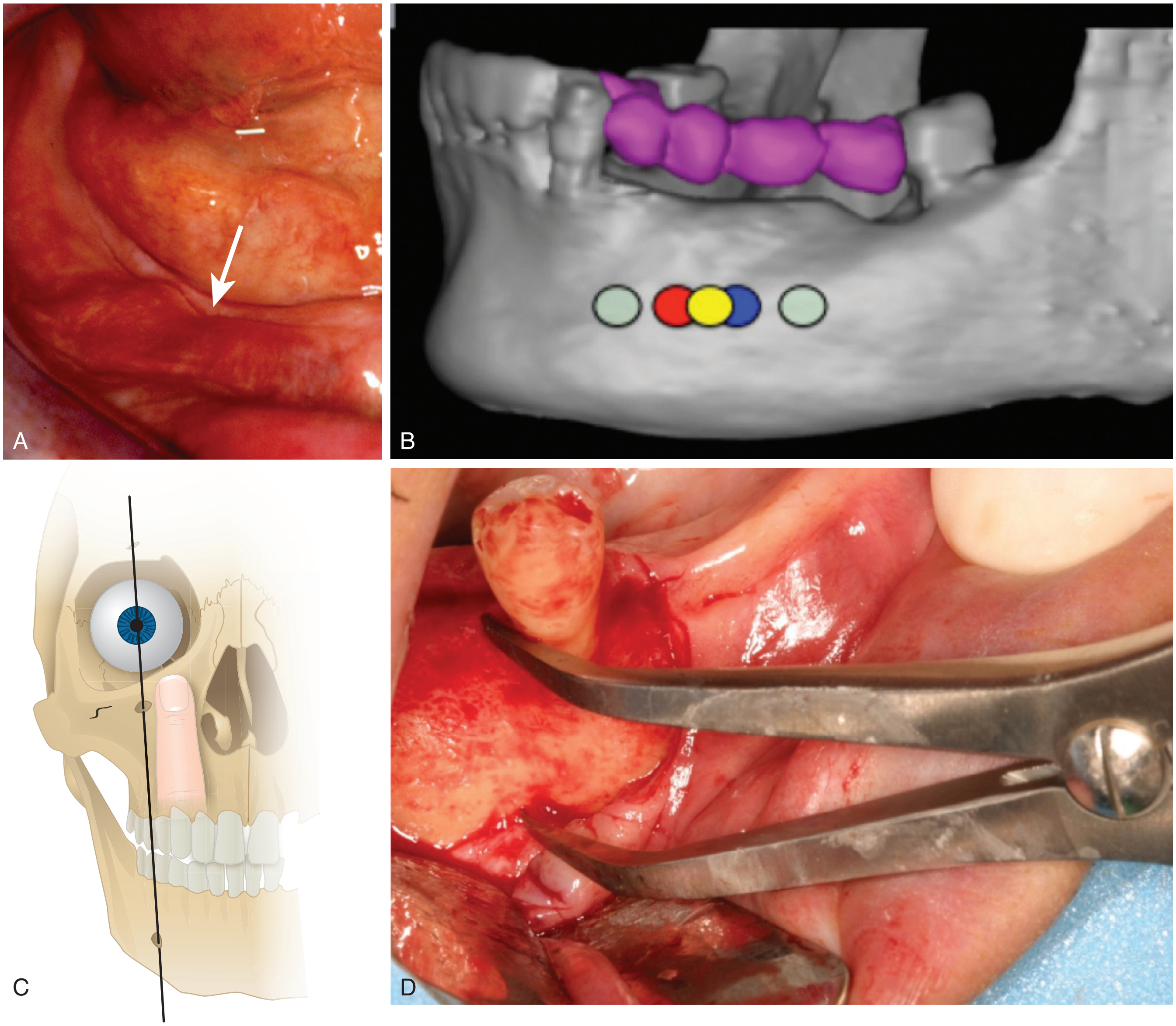


FIG 9.24 Location of the mental foramen. (A) Palpation can be misleading and should not be used as the sole technique of mental foramen identification. (B) Anatomic location with respect to the teeth apices is highly variable—cuspid/molar position *(green circles)*; first premolar *(red circle)*; first/second premolar *(yellow circle)*; second premolar *(blue circle)*—and is dependent on gender, age, and race. (C) Anatomic location: a vertical line through pupils of eyes and infraorbital foramen or a finger width lateral to ala of the nose. (D) Direct exposure of the foramen with the use of calipers to measure distance.

images and 3-D images are the easiest and most accurate technique in determining the exact foramen location.

Direct evaluation. The most precise technique available today to find the exact location of the mental foramen is by direct evaluation. Exposing the mental foramen may be intimidating to some clinicians, especially early on their learning curve. This can be accomplished with very low morbidity; however, the technique's success depends on the implant dentist's training and experience (Fig. 9.24D).

3-D ultrasound. The most promising imaging technique for the future is ultrasound. Ultrasound has the advantage of no ionizing radiation and the ability to reconstruct 3D images of bone surfaces to within an accuracy level of 24 μm. At this time, ultrasound units are not available specifically for dental use.

Always Evaluate for an Accessory (Double) Foramen. Studies have shown that in approximately 10% of patients, an accessory (double) foramen is present.[58] In the majority of cases, small accessory foramina usually contain a small branch of the mental nerve and are not problematic because of cross innervation or actually contain nutrient branches. However, in a small percentage of cases, a larger branch of the mental nerve (equal or larger size foramen) may exit the

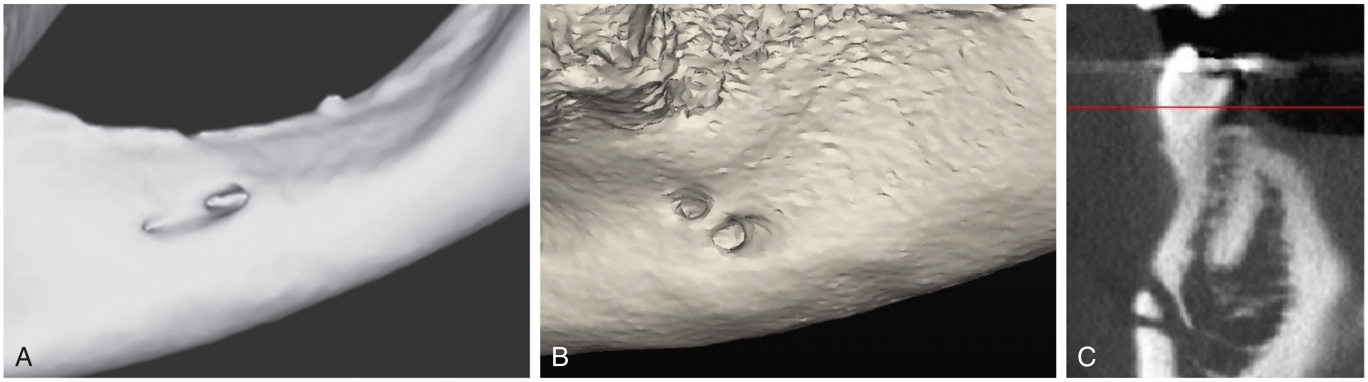


FIG 9.25 (A) Accessory nerve anterior to main foramen. (B) Double foramens showing two large foramens. (C) Coronal image showing two nerve foramina.

second mental foramen. Special care should be extended in this situations because it may contain components of one of the three branches of the mental nerve. Accessory foramina are believed to be the result of early branching of the inferior alveolar nerve, prior to exiting the mental foramen during the 12th week of gestation.[59] Double foramens are easily seen in the 3-D or the coronal CBCT images (Fig. 9.25).

Evaluate for Anterior Loops of the Mental Nerve. As the mental nerve proceeds anteriorly in the mandible, it sometimes runs below the lower border and the anterior wall of the mental foramen. This anterior and caudal component of the mental nerve will curve cranially back to the mental foramen. This anterior and caudal part of the mental nerve is termed the *anterior loop*.[59] Recently, studies have shown a higher percentage (70%) prevalence of anterior loops with a mean of 1.16 mm distance anteriorly. The anterior loop may be depicted most predictably on axial CBCT images, with 2-D radiographs being totally unreliable.

Determining the presence of an anterior loop is critical when placing implants anterior to the mental foramen. Inability to ascertain the presence of an anterior loop may result in damage to the mental nerve (Fig. 9.26). The anterior loop measurement should be added to the safe zone to avoid damaging the mental nerve.

Do Not Confuse the Incisive Nerve Branch as an Anterior Loop. The incisive nerve branch, a continuation and terminal branch of the IAN, supplies the mandibular canine and incisor teeth. Because there is no sensory innervation with this nerve, implants may be placed in proximity to it without nerve impairment. Studies have shown incisive canals have a mean diameter of 1.8 mm and location 9.7 mm from the lower cortical border.[60] The incisive nerve has been recognized as an important anatomic structure that must be taken into consideration when performing surgery in this area. It is frequently mistaken as an anterior loop in the mandible. Excessive bleeding has been reported as a significant intraoperative complication in this area when it is perforated during osteotomy preparation (Fig. 9.27).

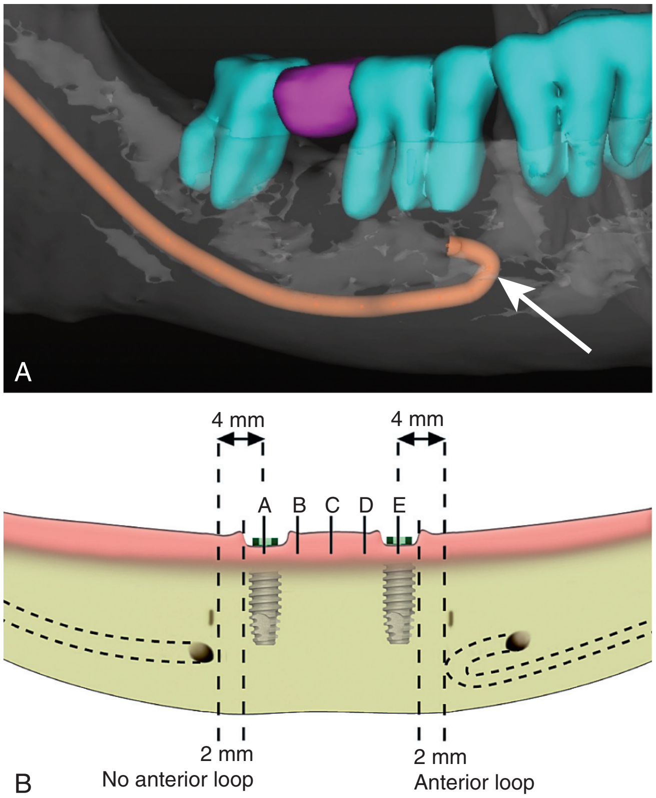


FIG 9.26 (A) An anterior loop showing nerve anterior to foramen. (B) Modification of safe zone with consideration of anterior loop. The anterior loop measurement is added to the 2-mm safe zone.

Intraoperative Considerations

Utilize the Misch “Zone of Safety” Principle. To determine the ideal position of implants with respect to the inferior alveolar or mental nerve, Misch, in 1990, identified the “zone of safety” concept. With this technique the mental foramen is directly identified and a measurement from the superior aspect of the foramen to the residual ridge is determined. Research has shown that implants can be placed at this height measurement 100% of the time posterior to the middle half of mandibular first molar and 97.5% of the time to the distal of the first molar. The corresponding safety height measurement extends posterior to the mesial half of the second molar 43% of the time.[61]

Maintain a Safety Zone of 2 mm Upon Osteotomy Preparation and Final Implant Positioning. A 2-mm safety zone with osteotomy preparation and final implant placement is paramount in preventing neurosensory impairments.[41] Compression-related injuries (neuropraxia) can occur by encroaching on the IA nerve without actual contact. Nerve impairments have been reported when implants are placed less than 2 mm from the canal without invasion of the canal. Bleeding and resultant hematomas have been shown to cause nerve damage because of final positioning too close to the neurovascular canal.[62] Additionally, the IAN superior to cortical bone can be compressed, causing pressure necrosis with resultant nerve impairment.[63] Interactive treatment-planning software programs allow the implant clinician to accurately assess the ideal placement with respect to this vital structure (Fig. 9.28).

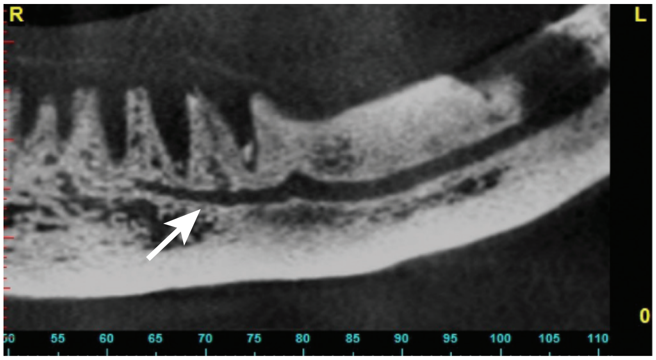


FIG 9.27 CBCT panoramic image depicting incisive branch of IAN *(arrow)*.

Understand the "True" Implant Bur Drilling Depths. Care should always be exercised when performing osteotomies over vital structures, especially in the posterior mandible. The implant clinician should double-check the marking depth on the burs prior to initiating the osteotomy. The principle of "MEASURE TWICE, DRILL ONCE" should be followed to prevent iatrogenic overpreparation of the implant site. Additionally, the "Y" dimension of the implant system being used must be known. As noted earlier, the depth of the millimeter lines inscribed on surgical drills do not always coincide with the actual depth of the drill. Most drills contain a V-shaped apical portion designed for cutting efficiency ("Y" dimension). Usually, the wider the drill, the greater the "Y" dimension. The implant clinician should always evaluate the manufacturer's drill length with respect to the length of the implant prior to performing the osteotomy. If this concept is not adhered to, overpreparation of the site may occur, resulting in nerve damage (Fig. 9.29).

Use Drill Stop Burs to Prevent Overpreparation. An additional technique to prevent overpreparation of the osteotomy site is the use of stop drills. These drills have a predetermined depth marking that prevents overpreparation. Stop drills are very beneficial in the mandibular posterior area, especially when visibility and access is compromised. Generic drill stop kits are also available that may be used with most implant surgical systems (Salvin Dental Corp.). These autoclaveable,

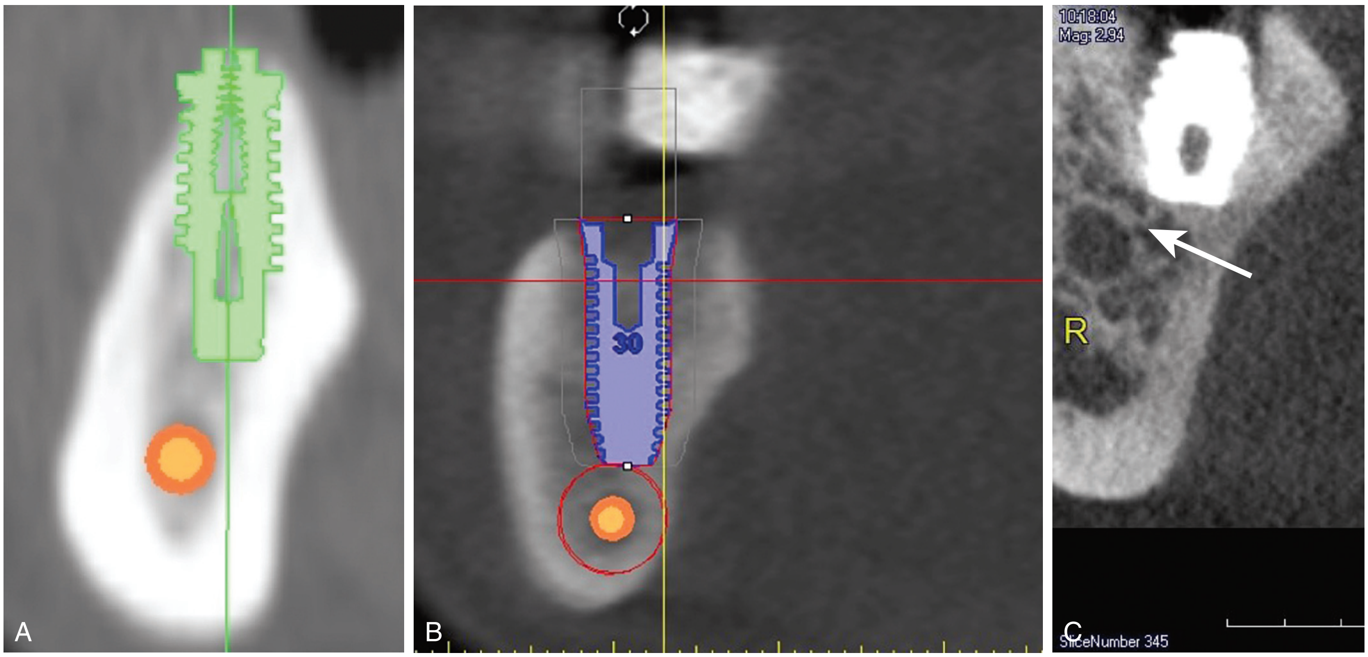


FIG 9.28 (A) Ideal placement >2.0 mm from nerve. (B) Simplant Software with 2.0-mm safety zone for interactive planning. (C) Nerve impairment can be caused from compression necrosis *(arrow)*.

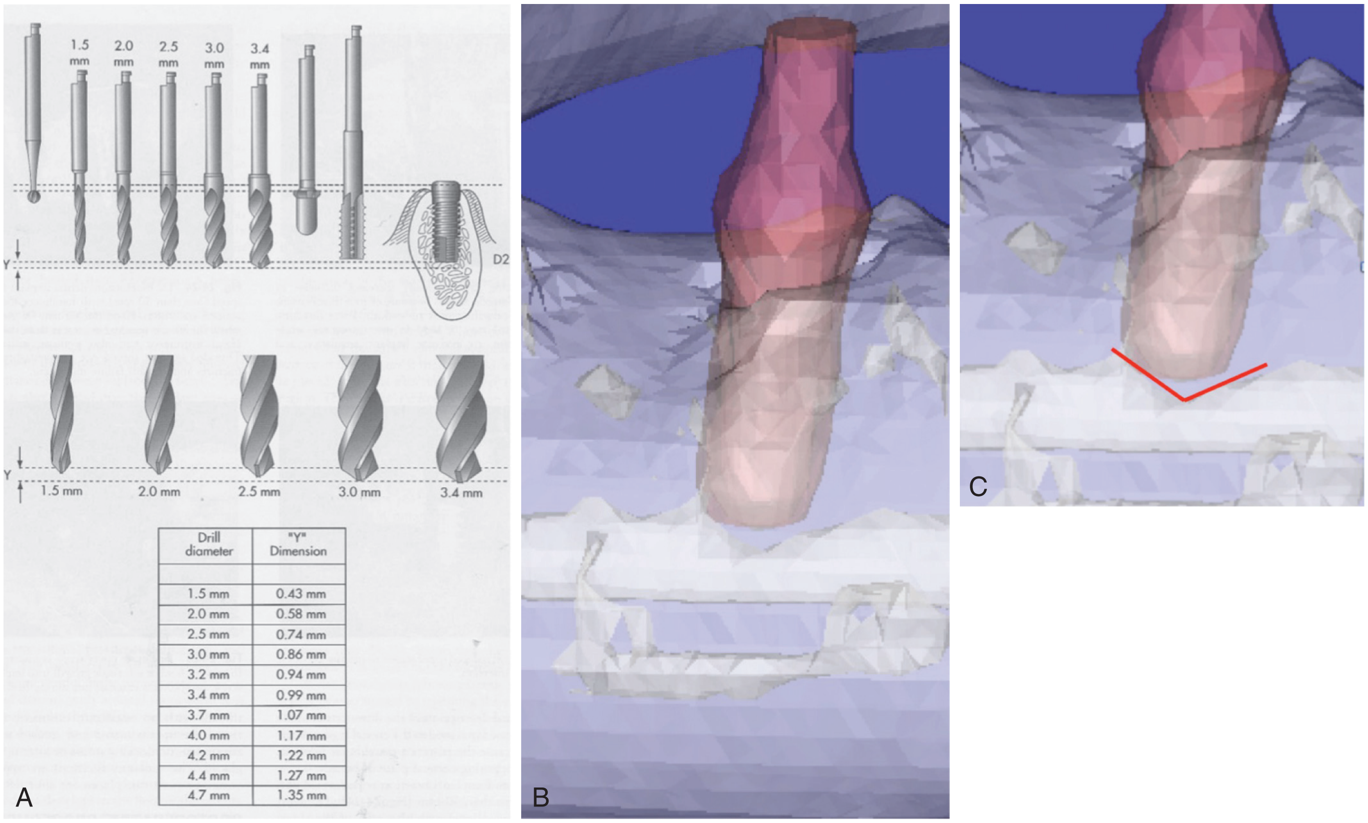


FIG 9.29 (A) Ideally, measure all burs before performing osteotomy. (B) "Y" diameter of surgical burs. (C) CBCT image showing penetration from "Y" dimension into mandibular canal. (A, From Misch CE, editor: *Contemporary implant dentistry*, St. Louis, 2008, Mosby.)

reusable kits may be used for any size length implant and corresponding drill (Fig. 9.30). Additionally, some surgical implant systems have specific depth burs that coincide with the actual implant depth (e.g., Hahn Implants, Glidewell Corp.).

Understand Bony Crest Anatomy. Due to resultant bone resorption after extraction, the alveolar ridge becomes compromised in width (Division B bone) at the expense of the buccal plate. When measuring available bone height, special consideration should be given to the final location of the superior aspect of the implant platform, not the crest of the ridge. It will often appear that there is adequate vertical height for implant placement; however, when the osteotomy is initiated, the thin crest will be lost and the implant will be placed inferior to where it was originally intended. This can lead to unexpected depth drilling and an implant that is placed too close to the vital structure. The clinician should either augment the ridge to maintain vertical height or reduce the height calculation by the amount of osteotomy induced osteoplasty (Fig. 9.31).

Maintain Total Control of the Handpiece. When performing osteotomies in the posterior mandible, special care should be noted to maintain complete control of the surgical handpiece. Large marrow spaces (i.e., where there is a lack of or thin trabecular bone) are often present, which may allow the osteotomy site to become deeper than intended. This will result in the implant being placed more apically, leading to neurosensory impairment. A MSCT or CBCT comprehensive evaluation allows the implant dentist to view the bone quality prior to surgery. Many third-party implant-planning programs allow the clinician to ascertain the density in the intended site. The implant clinician may also determine the bone density by tactile sensation when drilling. Additionally, when drilling the osteotomy near the mental foramen, care should be exercised not to bend the wrist. This can potentially redirect the drill or implant placement in an unwanted direction (e.g., near the mental foramen, into a tooth root). Surgical templates and guides are beneficial in preventing this malpositioning complication (Fig. 9.32).

Do Not Place Bone Graft Material in Close Approximation to Nerve. After tooth extractions, especially in the mandibular premolar areas, care should be exercised in placing bone graft material (autologous, allogenic, xenogenic) in direct contact with an exposed IAN. Whether socket grafting or in conjunction with implant placement, case studies have shown resultant neurosensory impairment from bone graft material causing compression, crushing, or chemical burn injuries.[64] When socket grafting in this area, excessive pressure should be avoided.

Use Copious Amounts of Irrigation. Overheating the bone during osteotomy preparation may produce thermal stimuli that may lead to periimplant necrosis and secondary

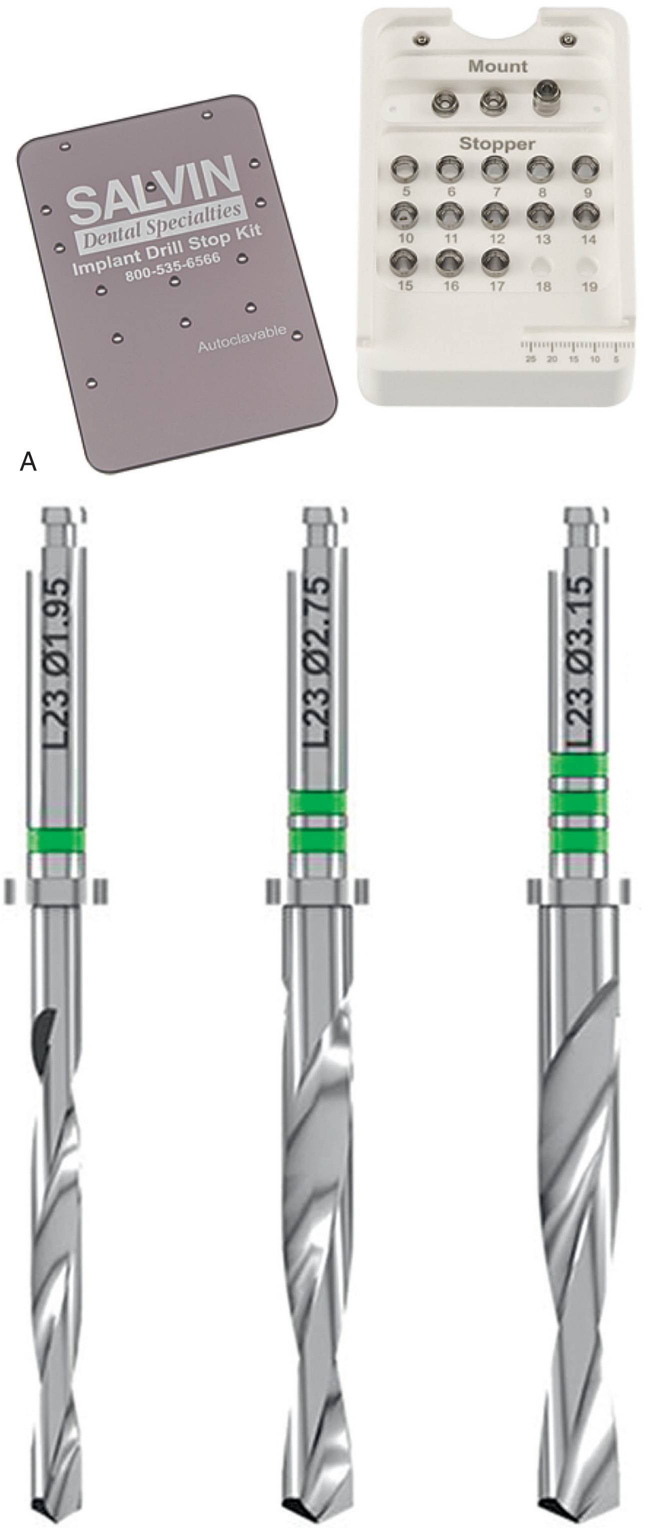


FIG 9.30 (A) Drill Stop Kit. (B) Sequential surgical drills with stops that prevent overpreparation. (A, Courtesy Salvin Dental Specialties, Inc., Charlotte, NC. B, Courtesy Dentsply Sirona Implants, Waltham, MA.)

postoperative nerve damage. Neural tissue is extremely sensitive and damaged by heat stimuli. The thickness of the necrotic area is proportional to the amount of heat generated during preparation.[65] The implant dentist must be cautious to not overheat the bone. This can be minimized by "bone dancing," which involves drilling in short intervals and allowing irrigation to enter the osteotomy, preventing heat generation. Additionally, new (sharp) and intermediate-sized drill burs may be used to reduce heat generation. This is more crucial with harder bone density (e.g., D1 or D2) or bone with compromised vascularity (Fig. 9.33).

Avoid Incision-Related Injuries. There should be an awareness when making incisions near the location of the mental foramen and associated nerve structures in the posterior mandible. In cases of severe bone atrophy, the presence of nerve dehiscence may inadvertently result in a transected nerve during the initial incision (i.e., making incision on the crest of the ridge). Anatomic landmarks, 3-D models, accurate measurements from CBCT scan, or palpation of the nerves are ways to avoid this complication. Additionally, incisions in the posterior of the oral cavity should never be made over the retromolar pad. This can result in possible injury to the lingual nerve, which in 10% of cases transects this area (Fig. 9.34).

Avoid Flap/Retraction-Related Injuries. Neurosensory impairments may also occur from overzealous use or incorrect placement of retractors. Broad base (not sharp) retractors should be used to retract tissue that is not directly over the mental foramen because excessive stretching of the nerve trunk may cause irreversible damage. It is imperative that the mental foramen and associated branches of the mental nerve be identified in this area when placing retractors. Retractors should always be placed and held on the bone to prevent slippage or excessive soft tissue pressure, which can lead to a neuropraxia type of nerve damage (Fig. 9.35). Excessive stretching of the tissue may also lead to neurosensory impairments. It has been shown the perineurium protects the fascicles; however, if greater than 30% elongation of the nerve occurs, structural damage will occur to the nerve fibers.[65a]

Use Special Care When Releasing Periosteum Over Mental Foramen. It is a common procedure during closure after implant placement or bone grafting to stretch the periosteal tissue to allow primary and "tension-free" closure. Various techniques are used to "release" the tissue to improve vascularization of the incision line and adhesion of the margins to prevent incision line opening. The submucosal technique developed by Misch in 1988 is an effective method to expand the tissue. This procedure involves the use of a #15 scalpel blade and soft tissue scissors (i.e., Metzenbaum) to create a blunt dissection. Knowledge of the location of the three mental nerve branches is necessary because inadvertent incisions over the mental nerve branches may result in neurotmesis (transection) type of nerve injuries.

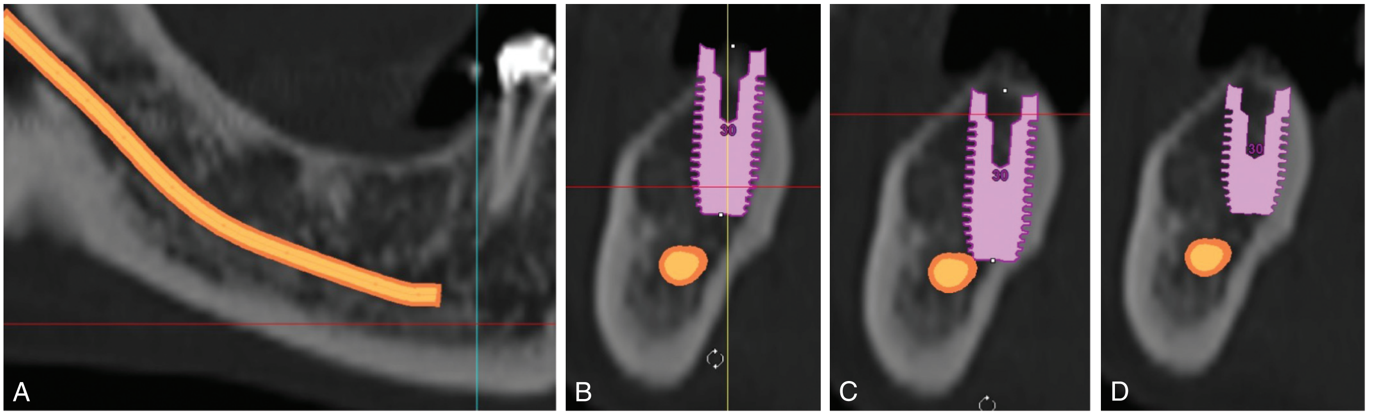


FIG 9.31 (A) Panoramic showing available bone above the IAN canal; however, it does not depict the width of bone. (B) If ridge is Division B (compromised in width) after osteotomy the crestal bone will be removed. (C) Implant placed at position that has adequate width; however, it will impinge on the vital structure. (D) Ideal selection of implant (decreased length) to maintain 2-mm safety zone.

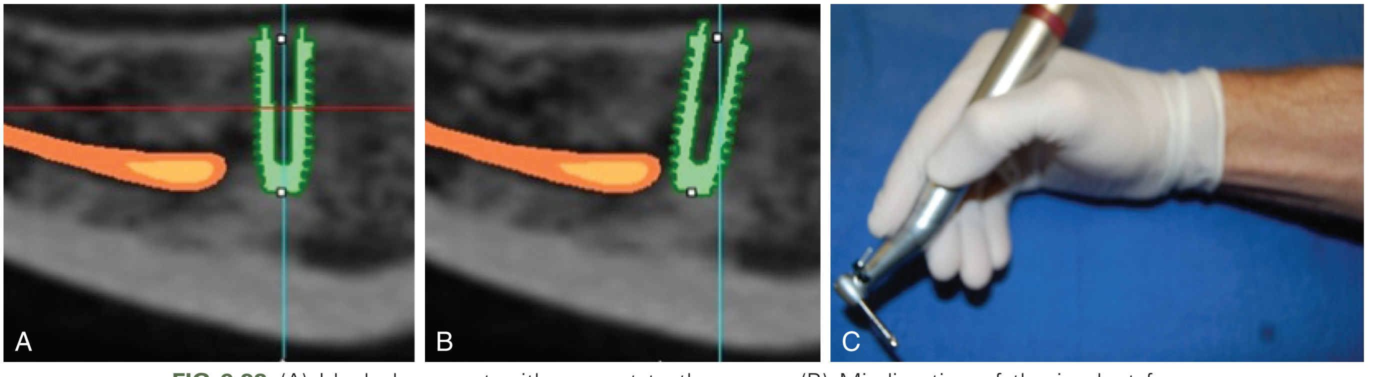


FIG 9.32 (A) Ideal placement with respect to the nerve. (B) Misdirection of the implant from improper drilling technique. (C) When drilling osteotomy, wrist should never be bent.

Careful Suturing. When the mental nerve is exposed, care should be exercised to prevent nerve tissue from being entrapped within the sutures. The mental nerve emerges from the mental foramen and divides into three branches below the depressor anguli oris muscle. Caution must be exercised to prevent any of the mental nerve branches from becoming entrapped within in the suture material, potentially causing a neuropraxia (compression) type of nerve injury. Additionally, nerve fibers may be damaged from the passage of the extremely sharp suture needle through the tissue (Fig. 9.36).

Verify Correct Positioning of CBCT SurgiGuides. Studies have shown that the most precise and accurate surgical templates are tooth supported. When using bone- or tissue-supported surgical guides, care must be exercised to correctly position the guide because an error in placement may result in direct damage to the IA nerve. Tooth-supported guides should always be the first choice if possible because they are clinically proven to give rise to the fewest positioning errors. The least accurate is the mucosa supported, which are most utilized for flapless surgery.[66] Studies have shown that flapless surgical guides consistently show deviations of implant positions from ideal locations. Perforations of the buccal plate can be found in over 50% of the flapless cases.[67] A very minor discrepancy (anterioposterior) in the placement of the guide can lead to impingement on vital structures (Fig. 9.37). Therefore, surgical templates should always be fixated and ideal position verified.

Miscellaneous Alternative Surgical Techniques

Avoid Immediate Implants in the Mandibular Premolar Area. Immediate implants have gained overwhelming popularity in implant dentistry today. Extreme caution must be exhibited when extracting and immediately placing implants in the mandibular premolar area. As noted, there are many variables that dictate the position of the mental foramen, with the foramen being highly variable. Studies have shown that 25% to 38% of the time the mental foramen is superior to the premolars apex.[58] Because most immediate implant osteotomy sites involve drilling the osteotomy site deeper for stability, chances of nerve trauma are greatly increased. Because of this the implant clinician must be very selective in cases involving extraction and immediate implant placement in this anatomic area (Fig. 9.38).

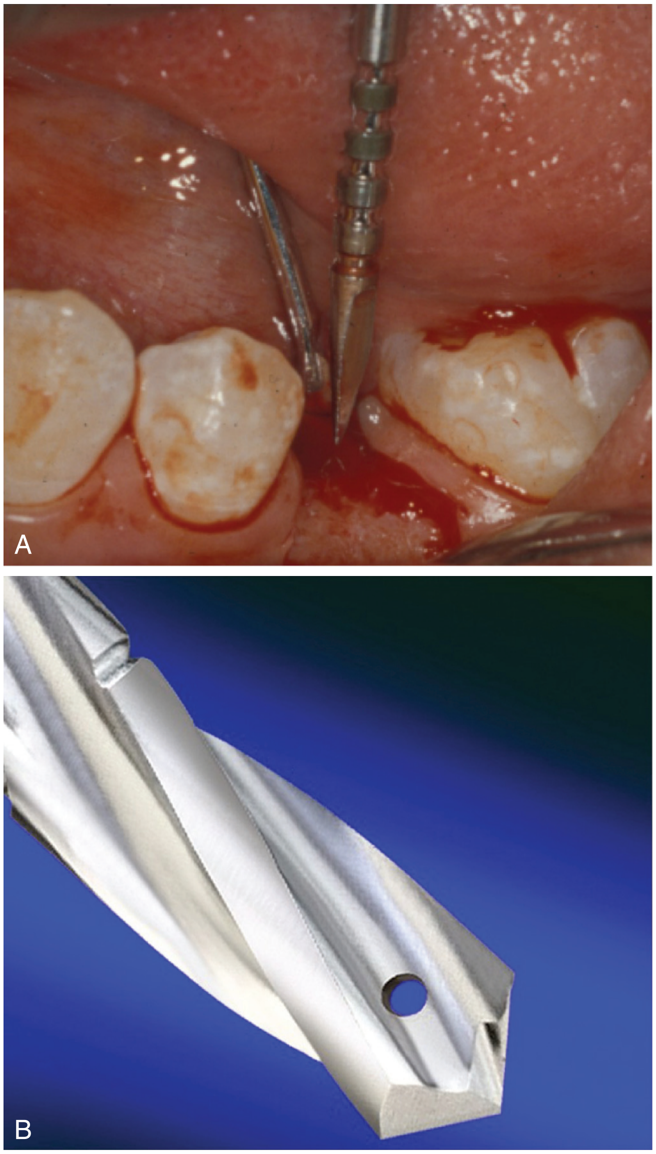


FIG 9.33 (A) During osteotomy preparation, copious amounts of irrigation must be used to decrease heat most commonly with the use of a SurgiGuide. (B) Internally cooled drill. (B, Courtesy FFDM PNEUMAT—Département Dentaire THOMAS, Bourges Cedex, France.)

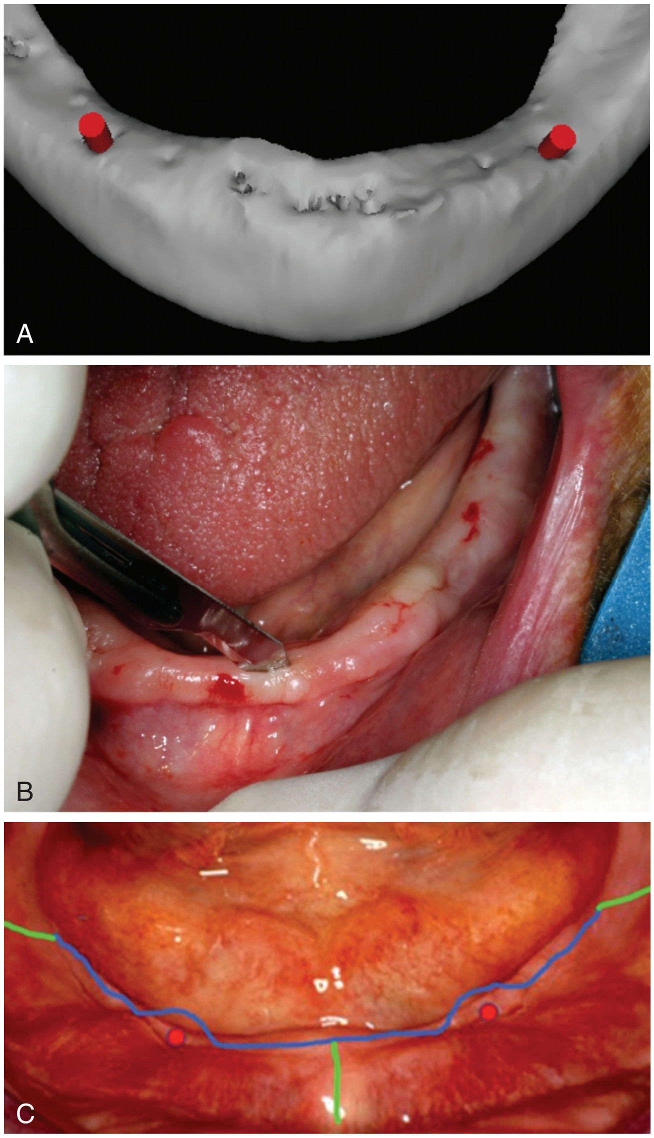


FIG 9.34 Incision-related injury. (A) Bilateral nerve dehiscence. (B) Incision needs to be modified to decrease chance of nerve damage as crestal incision will transect nerve. (C) Incision should be made lingual when nerve dehiscence is present.

"Drill Until the Superior Cortical Plate Is Felt." It has been advocated in the literature that the osteotomy depth maybe determined by "feeling" the superior cortical plate of the inferior alveolar canal. A 2-mm safety zone should always be adhered to because research has shown in approximately 28% of posterior mandibles, there is no superior cortical plate over the inferior alveolar canal.[68] Additionally, studies have shown it to be impossible to use tactile sense to ascertain the presence of superior cortical bone surrounding the mandibular canal.[58] Clinical reports have revealed hemorrhage into the canal or bone fragments may cause compression or ischemia of the nerve from engaging the superior cortical plate. Dependence on the ability to "feel" the superior cortical plate through tactile sense increases the likelihood of nerve complications (Fig. 9.39).

Infiltration Technique. An alternative technique in placing implants in the posterior mandible is not utilizing mandibular nerve block anesthesia. Instead, infiltration is accomplished in the soft tissue surrounding the osteotomy site, and the patient is asked to alert the implant clinician on the proximity of the drill to the nerve bundle.[69]

This alternative technique results in a very high degree of subjectivity concerning patient's responses due to varying degrees of pain thresholds. Additionally, disadvantages of this surgical method include inconsistent mandibular nerve anatomy

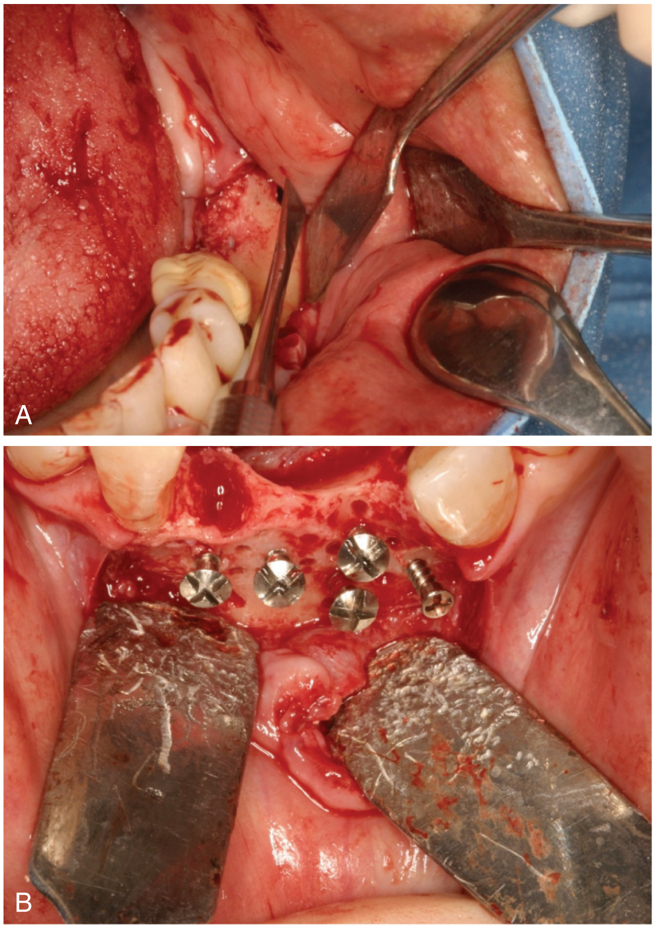


FIG 9.35 (A) Avoid direct pressure on mental foramen from retractor. (B) Be cautious when stretching tissue near the branches of the mental nerve. Note the sharp damaged retractors that may cause tissue damage.

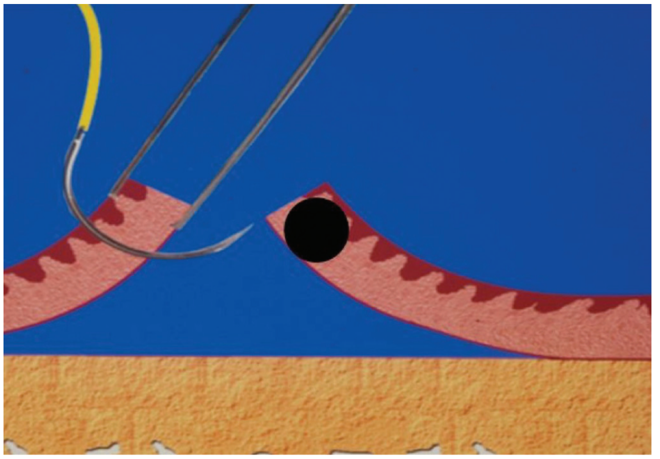


FIG 9.36 Placement of suture should be carefully assessed to prevent nerve tissue from becoming entrapped within suture line.

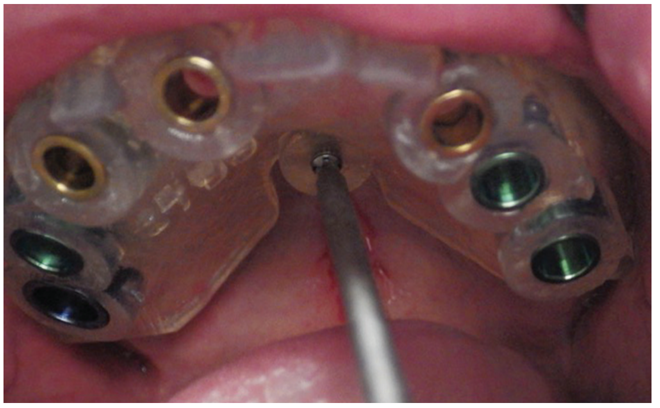


FIG 9.37 Tissue-borne surgical template fixated with palatal screw to prevent movement of the template.

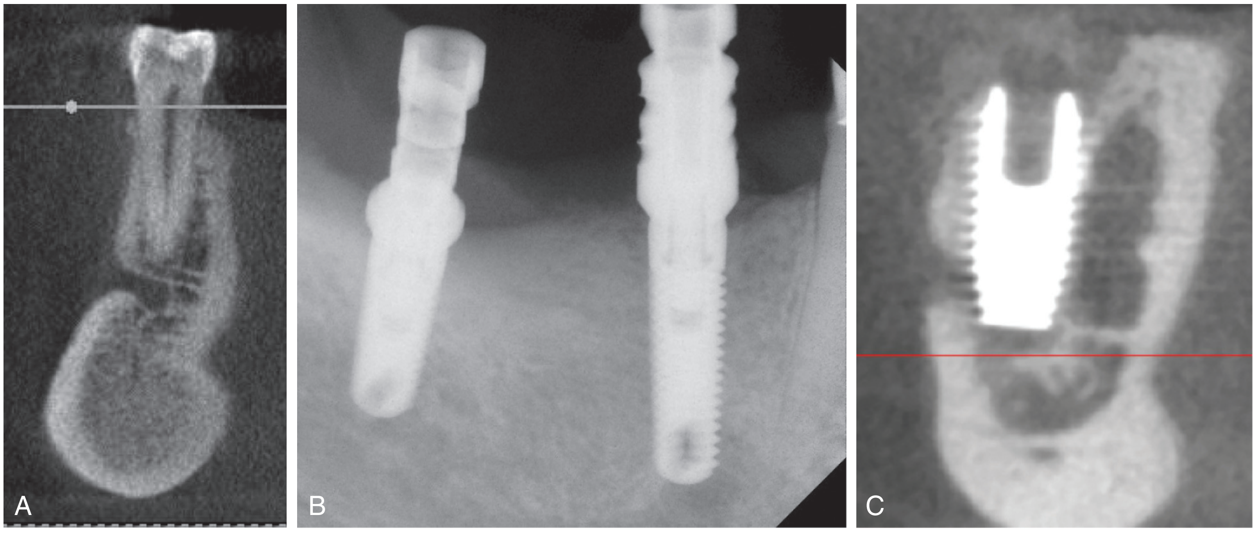


FIG 9.38 (A) CBCT revealing close proximity of root apex to mental foramen. The root apex is inferior to the mental foramen. (B) Complications arising from simultaneous extraction and implant placement in premolar area. (C) Implant placed into mental foramen location.

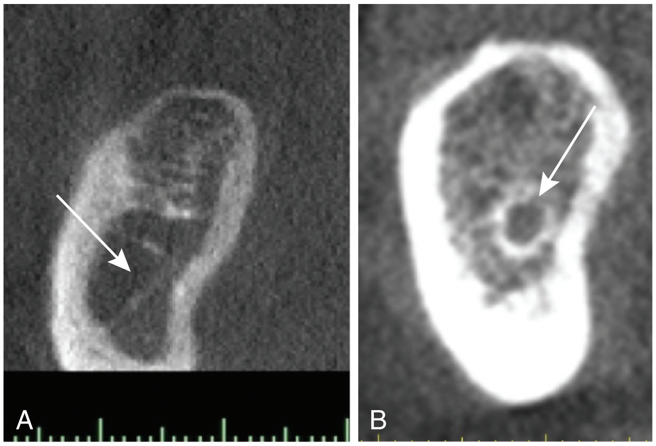


FIG 9.39 (A) In approximately 28% of patients, no superior cortical plate is present. (B) Even when present, cortical plate is very thin, which makes tactile sensitivity extremely difficult.

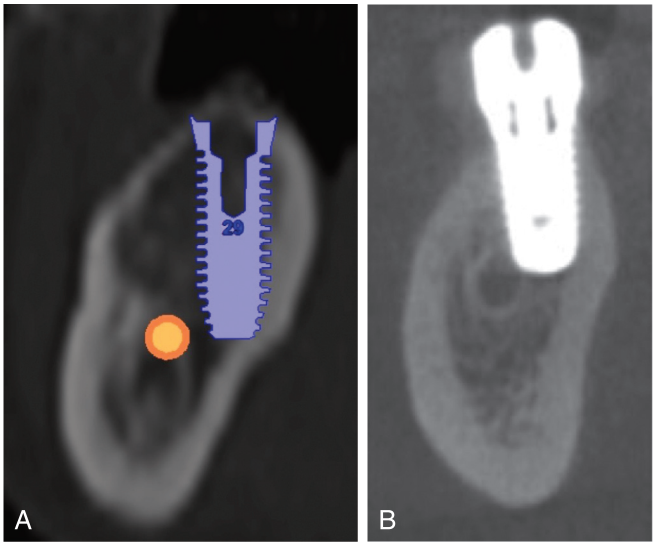


FIG 9.40 (A–B) Placing implants lingual increases chances of nerve impairment or perforation of the lingual cortical plate.

with varying locations of dental-alveolar nerve branches. With the success of CBCT radiography in implant dentistry today in determining the exact location of the inferior alveolar nerve, this technique should be avoided because of the high degree of false-negative and false-positive results from patients. Etoz et al showed this supraperiosteal infiltartion technique to be safe in 91% of cases. However, this results in approximately one patient in ten ending up with a neurosensory deficit.[70]

"Place Implants Buccal or Lingual to the IAN Canal or Foramen." Many authors have advocated placing implants buccal or lingual to the neurovascular bundle. (Kumar; Stellar) As stated previously, the buccal-lingual nerve position within the mandible is extremely variable along with the incidence and trajectory of lingual osseous concavities. Attempting to place implants buccal or lingual to the inferior alveolar canal or mental foramen is associated with a high degree of morbidity, even with the use of CBCT-guided surgery. Additionally, perforation of the cortical plate can occur, which may lead to sublingual bleeding or formation of a sublingual hematoma (Fig. 9.40).

"Place Implants at the Depth of the Adjacent Root Apexes." Many implant clinicians use the location and length of the adjacent teeth as a guide in determining the size (length) implant to be placed. Usually a panorex or periapical radiograph is utilized in determination of this length. When this technique is used in anatomic type 2 or 3 (i.e., more apically positioned in the vertical dimension) nerve courses, incidence of nerve impairment is low. However, in mandibles that exhibit a type 1 nerve course (close to root apex), close approximation of the implant to the canal is likely leading to a higher probability of neurosensory impairment. Ideally, the implant clinician should ascertain the available bone above the mandibular canal via three-dimensional radiographic analysis (Fig. 9.41).

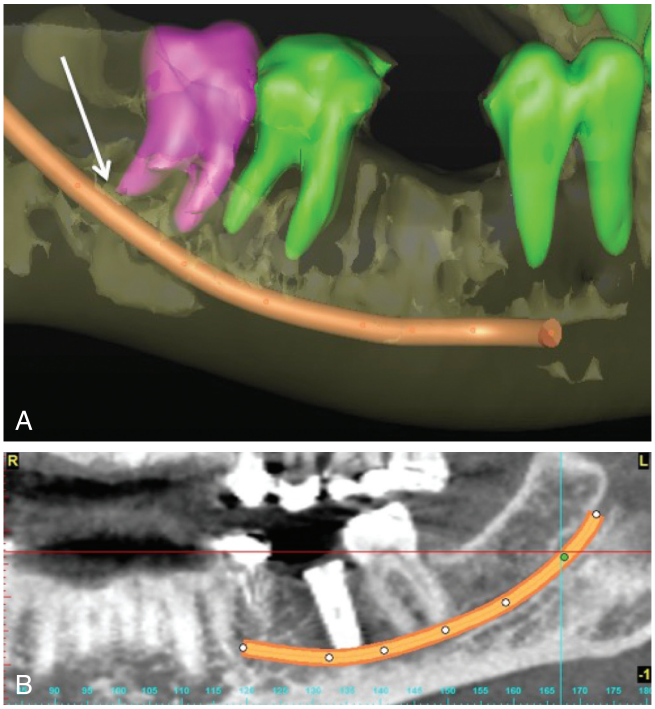


FIG 9.41 (A) Placement of implants at the level of the adjacent roots is ideal when an anatomic type 2 or 3 nerve is present *(arrow)*. (B) However, in type 1 nerve courses, this principle will lead to a greater chance of nerve impairment because of approximation of the implant and mandibular canal.

"As Long as There Is Not Excessive Bleeding, the Mandibular Canal Has Not Been Violated." Another unconventional technique in avoiding nerve impairment is the evaluation of the amount of bleeding from the osteotomy site. Many practitioners correlate the amount of hemorrhage with the proximity of the neurovascular bundle (inferior alveolar nerve, artery, vein, and lymphatic vessels). Anatomic

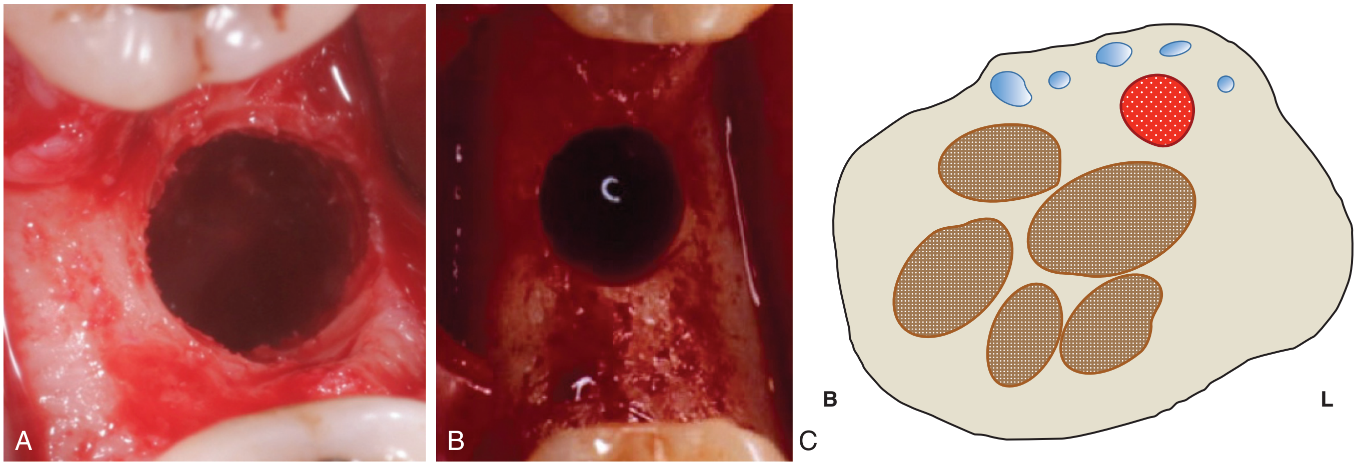


FIG 9.42 (A–B) The degree of bleeding within the osteotomy is not an indicator of proximity or violation of the neurovascular canal. (C) Although variations exist, multiple smaller veins *(blue)* are usually present superior to the polyfascicular inferior alveolar nerve *(brown)* with the inferior alveolar artery *(red)* superiorly and lingually positioned.

studies have shown the inferior alveolar artery may lie parallel to the nerve and lingual as it traverses anteriorly. Its position varies with respect to the inferior alveolar nerve within the mandibular canal. Other studies show the inferior alveolar artery appears to be solitary and lies superior and lingual to the inferior alveolar nerve, slightly above the horizontal position.[12] Additionally, there exists multiple inferior alveolar veins positioned superior to the nerve, which may cause venous oozing if directly traumatized.[11] A false positive may occur if this area is damaged as large marrow spaces, which can cause excessive bleeding, are common in the posterior mandible (D4 bone). The degree of bleeding should not be used as an indication of nerve proximity or violation of the mandibular canal (Fig. 9.42).

"Replacing Second Molars." There are many prosthetic and surgical disadvantages when evaluating edentulous second mandibular molar sites for implant placement. Disadvantages include high incidence of sublingual bony undercuts, which can result in perforation of the lingual plate or angulation issues, decreased interocclusal space (especially with supraeruption of the adjacent tooth), difficult access for surgery and prosthetic component insertion, and the fact there is 10% greater occlusal force on the second molar vs. the first molar. Function is not a primary reason for replacement because 90% of masticatory efficiency is generated anterior to the mesial half of the mandibular first molar, and cheek biting is more common in this area because of the proximity of the buccinators muscle. One of the most important disadvantages is the close approximation of the mandibular canal in the second molar area, which leads to difficulty in placement of implants in this area. When implants are placed, usually the available bone present is compromised in height. As a result, the second molar is often not replaced when the only posterior teeth missing are the second and third molars. The primary disadvantage of not replacing the second molar is extrusion of the opposing maxillary second molar. If extrusion is a significant concern, a full-coverage crown on the mandibular first molar may include an occlusal contact on with the mesial marginal ridge of the maxillary second molar (Fig. 9.43).

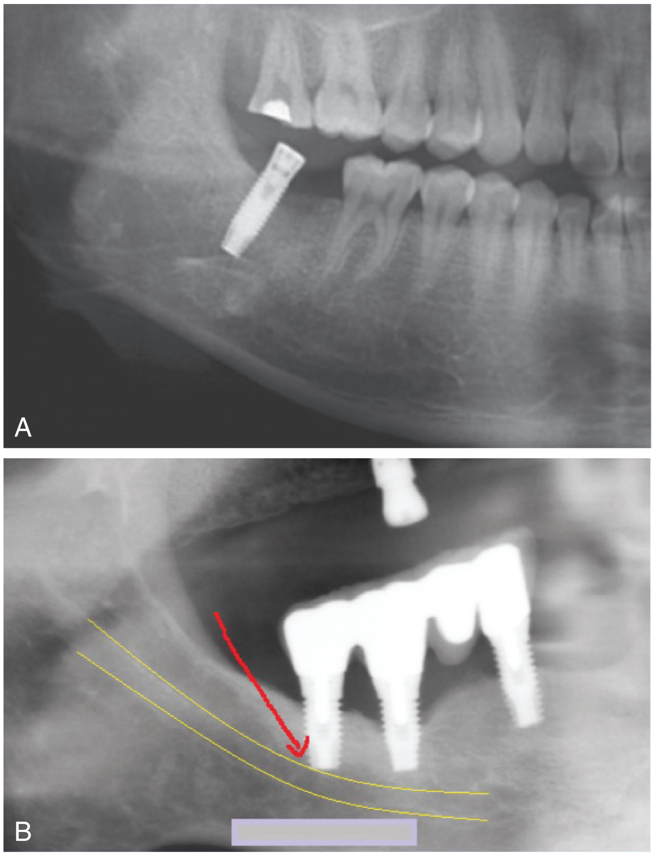


FIG 9.43 (A–B) Because of the curvature of the mandible in the ramus area, the mandibular canal is in close approximation to the second molar tooth roots in all types of nerve courses.

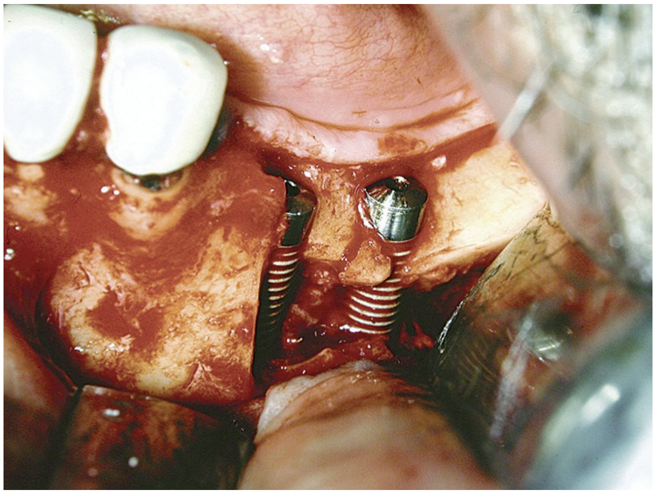


FIG 9.44 Nerve repositioning in which the IAN is positioned facially and implants placed in the prior position of the nerve bundle.

"Nerve Repositioning". Patients who exhibit compromised alveolar crest height in the posterior mandibular area can be very challenging. Techniques include the use of shorter implants, which become biomechanically compromised, or the use of bone grafting to increase available bone for future implant placement. An alternative technique is to reposition the inferior alveolar nerve laterally, either by nerve lateralization or nerve transposition. In nerve lateralization, the inferior alveolar nerve is exposed and retracted laterally while the dental implants are placed. The transposition technique, first published in 1987 by Jenson and Nock, includes the mental foramen in the osteotomy resulting in the inferior alveolar nerve being positioned more posterior.[71] The inherent risk with these complex procedures is neurosensory impairment (anesthesia, paresthesia, or dysesthesia) to the mental nerve branch. Although this is a valid treatment option in significantly atrophied cases, this technique should be reserved for practitioners with advanced training and experience with these procedures (Fig. 9.44).

SUMMARY

In implant dentistry today, one of the most serious complications is neurosensory impairment associated with implant placement or bone grafting. To avoid nerve damage a thorough understanding of the radiographic anatomy is paramount. If nerve impairment does occur, quick recognition and treatment is crucial to decreasing long-term morbidity. The nerves associated with the maxilla and mandible are associated with inconsistent anatomic locations. The implant clinician should understand the limitations of two-dimensional radiology and the importance of a comprehensive radiographic evaluation of the neural anatomy of the maxilla and mandible. Additionally, the clinician must understand the complications that may arise from unconventional surgical techniques that may increase the morbidity of the procedure.

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