11 Routine Lower Extremity Nerve Conduction Techniques

Tibial Motor Study *(Figure 11–1)*

Recording Site:

Abductor hallucis brevis (AHB) muscle:

- G1 placed 1 cm proximal and 1 cm inferior to the navicular prominence
- G2 placed over the metatarsal–phalangeal joint of the great toe

Stimulation Sites:

Medial ankle: Slightly proximal and posterior to the medial malleolus

Popliteal fossa: Mid-posterior knee over the popliteal pulse

Distal Distance:

9 cm

Key Points:

- The tibial compound muscle action potential (CMAP) often has an initial positive deflection, indicating that G1 is not over the motor endplate. If this occurs, the position of G1 should be changed slightly.
- CMAP amplitude at the popliteal fossa stimulation site often is lower than at the medial ankle stimulation site (normal controls may drop up to 50%). Thus, caution must be used whenever interpreting a drop in amplitude between the ankle and popliteal fossa as a conduction block on tibial motor studies. Side-to-side comparisons often are useful in this situation.
- High stimulation intensities often are required at the popliteal fossa to ensure supramaximal stimulation.
- Recording also can be done to the flexor hallucis brevis (FHB) muscle.

Peroneal Motor Study *(Figure 11–2)*

Recording Site:

Extensor digitorum brevis (EDB) muscle:

- Dorsal lateral foot with G1 placed over the muscle belly
- G2 placed distally over the metatarsal–phalangeal joint of the little toe

Stimulation Sites:

Ankle: Anterior ankle, slightly lateral to tibialis anterior tendon

Below fibular head: Lateral calf, one to two fingerbreadths inferior to fibular head (one can straddle the fibular neck with the stimulator)

Lateral popliteal fossa (above fibular neck): Lateral knee, adjacent to external hamstring tendons, at a distance of 10–12 cm from the below-fibular head site

Distal Distance:

9 cm

Key Points:

- Higher stimulation currents are needed at the below-fibular head site because the nerve lies deep at that location.
- Always perform the ankle, below-fibular neck, and above-fibular neck stimulations. If only the ankle and above-fibular neck stimulations are done, one can miss peroneal slowing across the fibular neck.
- Avoid excessive stimulation at the lateral popliteal fossa site to prevent co-stimulation of the tibial nerve.
- If there is a higher CMAP amplitude at the below-fibular head and popliteal fossa sites than at the ankle, consider an accessory peroneal nerve.

Peroneal Motor Study *(Figure 11–3)*

Recording Site:

Tibialis anterior (TA) muscle:

- Proximal to mid-anterior lateral calf with G1 placed over the muscle belly
- G2 placed distally over the anterior ankle

Stimulation Sites:

Below fibular head: Lateral calf, one to two fingerbreadths inferior to fibular head (one can straddle the fibular neck with the stimulator)

Lateral popliteal fossa (above fibular neck): Lateral knee, adjacent to external hamstring tendons, at a distance of 10–12 cm from the below-fibular head site

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Distal Distance:
Variable (5–10 cm)

Key Points:
- Recording the TA is especially valuable in patients with suspected peroneal neuropathy at the fibular neck. Demonstrating a conduction block, focal slowing across the fibular neck or both may be easier when recording the TA than the EDB.
- Higher stimulation currents are needed at the below-fibular head site because the nerve lies deep at that location.
- Avoid excessive stimulation at the lateral popliteal fossa site to prevent co-stimulation of the tibial nerve.

Femoral Motor Study *(Figure 11–4)*

Recording Site:
Rectus femoris muscle:
G1 placed over the anterior thigh, halfway between the inguinal crease and knee
G2 placed over a bony prominence at the knee

Stimulation Site:
Middle of the inguinal area: Slightly lateral to the femoral pulse, below the inguinal ligament

Distal Distance:
Variable

Key Points:
- Firm pressure is needed when holding the stimulator.
- Difficult study to perform in obese individuals; high currents are typically needed (e.g., >50 mA).
- Limited indications; this study usually is used to compare motor amplitudes from side to side to quantitate the degree of axonal loss in femoral neuropathies, lumbar plexopathies, and severe L4 radiculopathies.
- Normal amplitude is >3 mV; however, side-to-side comparisons are most useful when symptoms are unilateral.

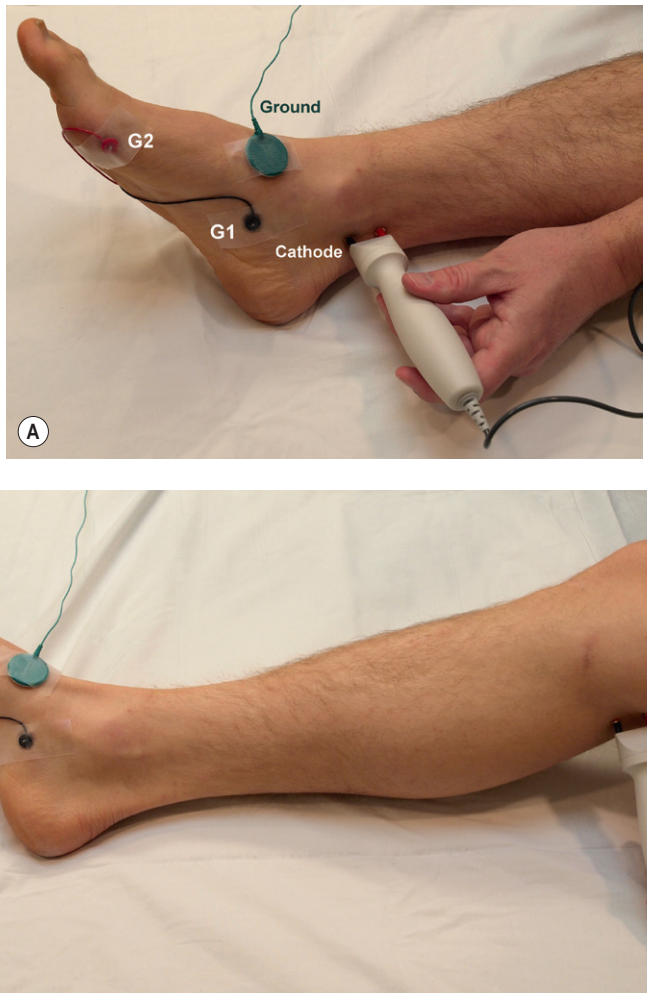

FIGURE 11–1 Tibial motor study. **A:** Distal stimulation site slightly proximal and posterior to the medial malleolus, recording the abductor hallucis brevis muscle. **B:** Proximal stimulation site in the middle of the popliteal fossa.

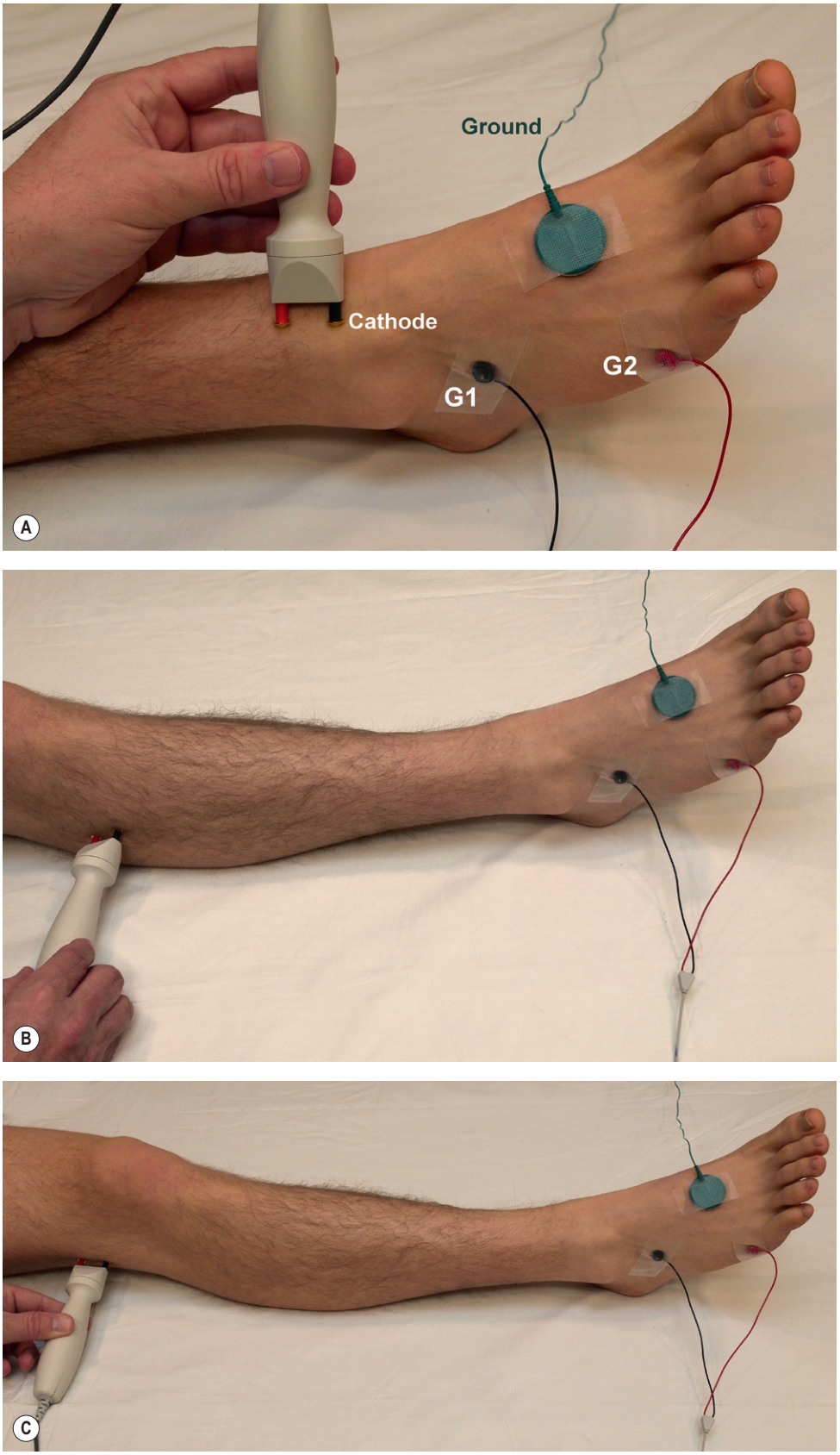

FIGURE 11–2 Peroneal motor study. **A:** Distal stimulation site over the anterior ankle, slightly lateral to the tibialis anterior tendon, recording the extensor digitorum brevis muscle. **B:** Proximal stimulation site below the fibular head. **C:** Proximal stimulation site in the lateral popliteal fossa above the fibular neck.

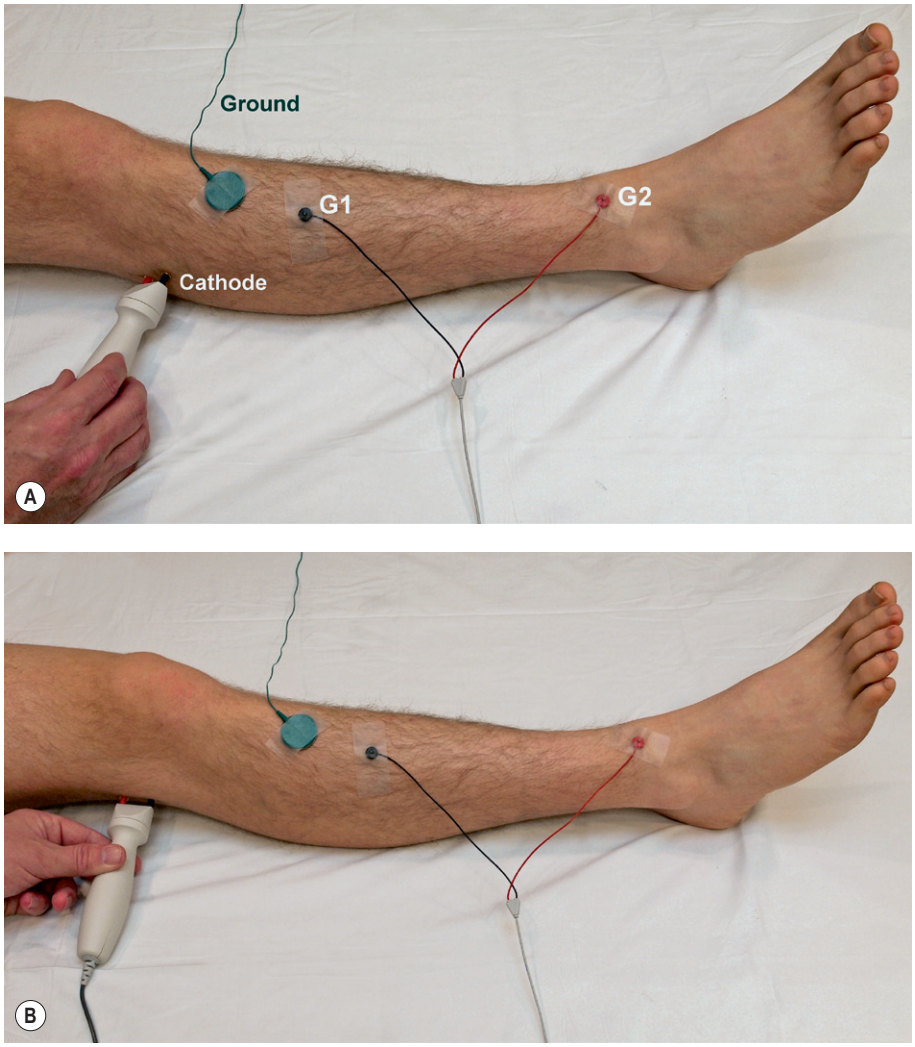

FIGURE 11–3 Peroneal motor study. **A:** Distal stimulation site below the fibular head, recording the tibialis anterior muscle **B:** Proximal stimulation site in the lateral popliteal fossa above the fibular neck.

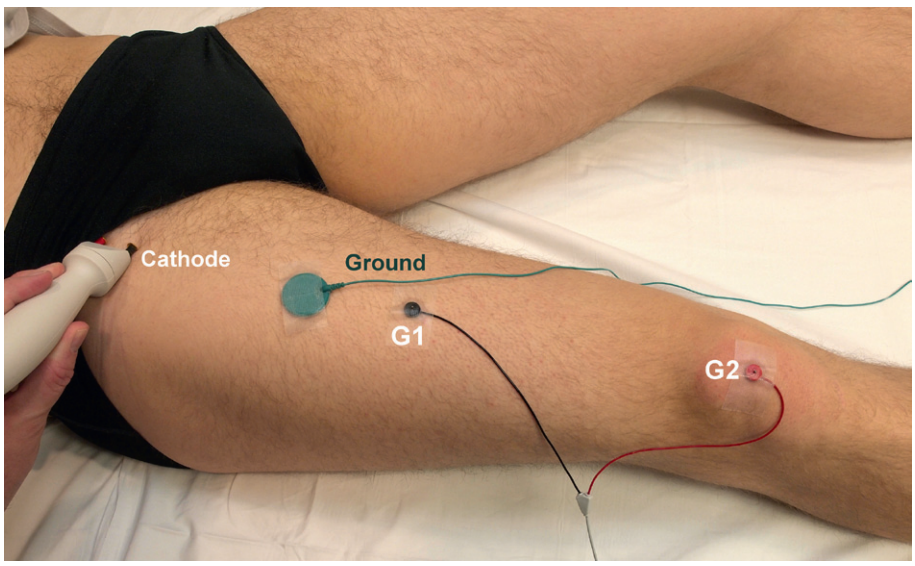

FIGURE 11–4 Femoral motor study. Stimulation site is slightly lateral to the femoral pulse, below the inguinal ligament. The rectus femoris is recorded, with G1 placed over the anterior thigh, halfway between the inguinal crease and knee, and G2 placed over a bony prominence at the knee.

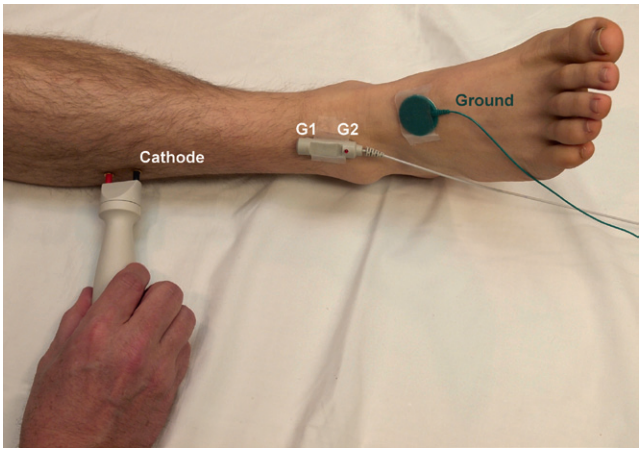

FIGURE 11–5 Superficial peroneal sensory study. Stimulation site is in the lateral calf; recording electrodes are placed between the tibialis anterior tendon and lateral malleolus.

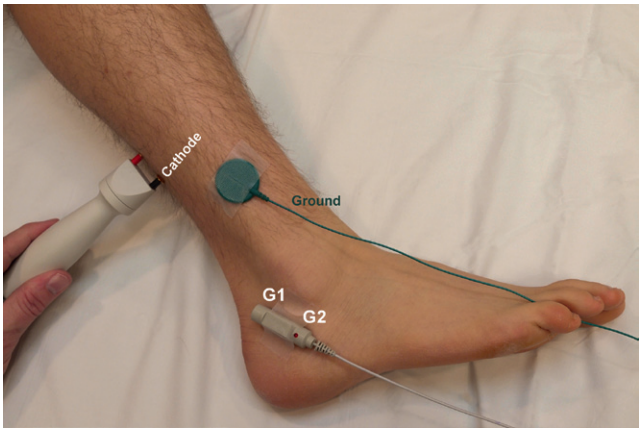

FIGURE 11–6 Sural sensory study. Stimulation site is in the posterior–lateral calf; recording electrodes are placed posterior to the lateral malleolus.

Superficial Peroneal Sensory Study *(Figure 11–5)*

Recording Site:

Lateral ankle:

G1 placed between the tibialis anterior tendon and lateral malleolus

G2 placed 3–4 cm distally

Stimulation Site:

Lateral calf

Distal Distance:

14 cm is the standard, but shorter distances may be helpful (see below)

Key Points:

- Although the normal value for peak latency is based on the standard distance of 14 cm, in many individuals, the nerve is much easier to stimulate at a shorter distance (typically 10–12 cm, and in some individuals as short as 7–9 cm). Supramaximal stimulation usually can be achieved with low stimulation intensities (e.g., 5–25 mA). Thus, if the response is not present stimulating at 14 cm or if high currents are needed, try a shorter distance of 10–12 cm, or 7–9 cm. If a good response is obtained at a shorter distance, do not use the peak latency to determine if the response is normal, but rather the calculated conduction velocity based on the onset latency and the distance used.
- May be abnormal in lesions of the peroneal nerve, sciatic nerve, or lumbosacral plexus.
- To maximize the response, the recording electrodes may have to be repositioned either slightly medially or laterally to the original position.
- Side-to-side comparisons of amplitude and latency often are helpful.
- Antidromic study described; for orthodromic study, recording and stimulation sites are reversed.

Sural Sensory Study *(Figure 11–6)*

Recording Site:

Posterior ankle:

G1 placed posterior to the lateral malleolus

G2 placed 3–4 cm distally

Stimulation Site:

Posterior–lateral calf

Distal Distance:

14 cm is the standard, but shorter distances may be helpful (see below)

Key Points:

- Although the normal value for peak latency is based on the standard distance of 14 cm, in many individuals, the nerve is much easier to stimulate at a shorter distance (typically 10–12 cm). Supramaximal stimulation usually can be achieved with low stimulation intensities (e.g., 5–25 mA). Thus, if the response is not present stimulating at 14 cm or if high currents are needed, try a shorter distance of 10–12 cm. If a good response is obtained, do not use the peak latency to determine if the response is normal, but rather the calculated conduction velocity based on the onset latency and the distance used.
- The study is best performed with the patient lying on his or her side, with the recording leg facing up.
- May be abnormal in lesions of the tibial nerve, sciatic nerve, or lumbosacral plexus.
- To maximize the response, the recording electrodes may have to be repositioned either slightly medially or laterally to the original position.

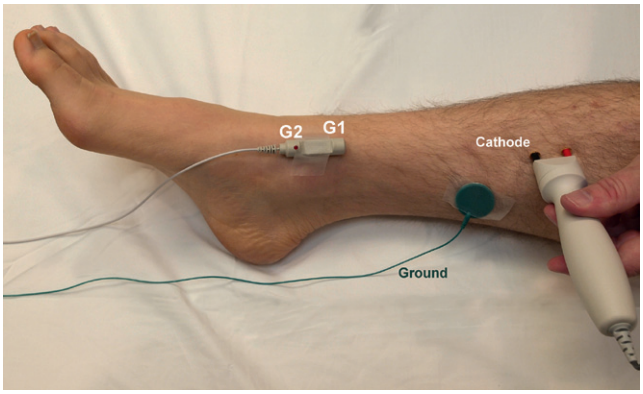

FIGURE 11–7 Saphenous sensory study. Stimulation site in the medial calf between the tibia and medial gastrocnemius; recording electrodes are placed between the medial malleolus and tibialis anterior tendon.

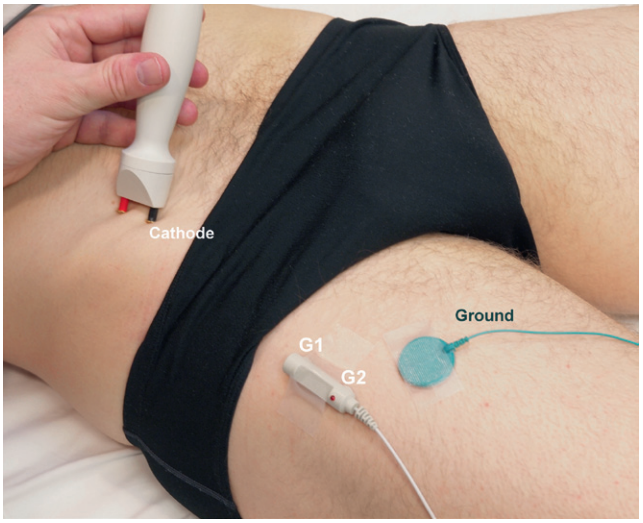

FIGURE 11–8 Lateral femoral cutaneous sensory study. Stimulation site in the inguinal area, above the inguinal ligament, and 1 cm medial to the anterior superior iliac spine (ASIS); recording electrodes are placed over the anterior thigh 12 cm distal to the stimulation site, on a line drawn directly from the ASIS to the lateral patella. Alternate recording site is 2 cm medial to the initial site.

- Side-to-side comparisons of amplitude and latency often are helpful.
- Antidromic study described; for orthodromic study, recording and stimulation sites are reversed.

Saphenous Sensory Study *(Figure 11–7)*

Recording Site:

Medial/Anterior ankle:

G1 placed between the medial malleolus and tibialis anterior tendon

G2 placed 3–4 cm distally

Stimulation Site:

Medial calf: Stimulator placed in the groove between the tibia and the medial gastrocnemius muscle

Distal Distance:

14 cm is the standard, but shorter distances may be helpful (see below)

Key Points:

- Although the normal value for peak latency is based on the standard distance of 14 cm, in many individuals, the nerve is much easier to stimulate at a shorter distance (typically 10–12 cm). Supramaximal stimulation usually can be achieved with low stimulation intensities (e.g., 5–25 mA). Thus, if the response is not present stimulating at 14 cm or if high currents are needed, try a shorter distance of 10–12 cm. If a good response is obtained, do not use the peak latency to determine if the response is normal, but rather the calculated conduction velocity based on the onset latency and the distance used.
- May be abnormal in lesions of the femoral nerve or lumbar plexus.
- To maximize the response, the recording electrodes may have to be repositioned either slightly medially or laterally to the original position.
- Side-to-side comparisons of amplitude and latency are required.
- Response often is small and may be difficult to obtain or absent in normal controls, especially those older than age 40. Side-to-side comparison is necessary before interpreting a low or absent potential as abnormal.
- Antidromic study described; for orthodromic study, recording and stimulation sites are reversed.

Lateral Femoral Cutaneous Sensory Study *(Figure 11–8)*

Recording Site:

Anterior thigh:

Option 1

G1 placed over anterior thigh, 12 cm distal to the stimulation site, on a line drawn directly from the anterior superior iliac spine (ASIS) to the lateral patella

G2 placed 3–4 cm distally

Option 2

Recording electrodes placed 2 cm medial to the Option 1 site

Stimulation Site:

Stimulator placed in the inguinal area above the inguinal ligament, 1 cm medial to the ASIS

Distal Distance:

12 cm is the standard, but shorter distances may be helpful (see below)

Key Points:

- Although the normal values are based on a standard distance of 12 cm, in some individuals, the nerve may be easier to stimulate at a shorter distance (typically 10 cm).
- There are some anatomical variations in terms of where the nerve runs in relationship to the anterior superior iliac spine (see Chapter 32). In more than 80% of individuals, the nerve lies between 0–1.5 cm lateral to the ASIS. However, rarely the nerve runs 5–8.5 cm medial to the ASIS. Thus, if no response is obtained, move the stimulator slightly lateral and then medial to the original stimulation site.
- Firm pressure is needed when holding the stimulator.
- Limited indications; may be abnormal in lesions of the lateral femoral cutaneous nerve (meralgia paresthetica) or lumbar plexus.
- Difficult study to perform in some obese individuals; high currents may be needed. One should always be cautious interpreting a low-amplitude or absent response as abnormal unless comparison studies are made side to side when symptoms are unilateral.
- A motor artifact may be present, which can be recognized by its longer duration than a typical sensory response.

Medial and Lateral Plantar Motor Studies

(Figure 11–9)

Recording Sites:

Abductor hallucis brevis (AHB) muscle:

G1 placed 1 cm proximal and 1 cm inferior to the navicular prominence

G2 placed over the metatarsal–phalangeal joint of the great toe

Abductor digiti quinti pedis (ADQP) muscle:

On lateral foot, G1 placed halfway between the lateral sole of the foot and the lower margin of the lateral malleolus

G2 placed over the metatarsal–phalangeal joint of the little toe

Stimulation Site:

Medial ankle: Slightly proximal and posterior to the medial malleolus

Distal Distance:

9 cm for AHB; variable for ADQP (distance measurement with obstetric calipers required)

Key Points:

- AHB is innervated by the medial plantar nerve and ADQP by the lateral plantar nerve.
- This study is useful in the evaluation of distal tibial neuropathy across the ankle (i.e., tarsal tunnel syndrome).
- Side-to-side comparisons of amplitude and latency are required.

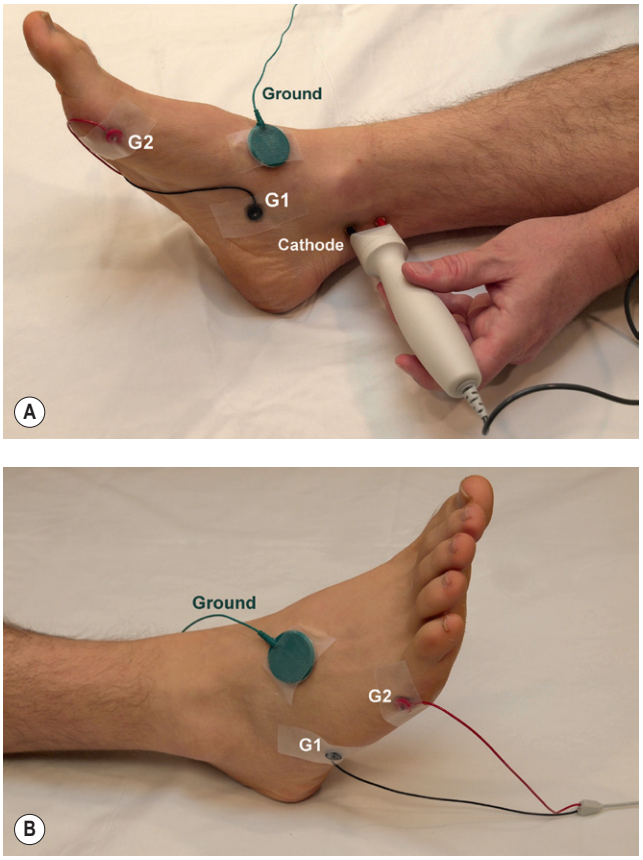

FIGURE 11–9 A: Medial plantar motor study. Stimulation site is slightly proximal and posterior to the medial malleolus, and the abductor hallucis brevis muscle is recorded. **B:** Lateral plantar motor study. Stimulation site is slightly proximal and posterior to the medial malleolus, and the abductor digiti quinti pedis muscle is recorded.

- CMAP of the AHB or ADQP often has an initial positive deflection, indicating that G1 is not over the motor endplate. If this occurs, the position of G1 should be changed slightly.

Medial and Lateral Plantar Sensory Studies

(Figure 11–10)

Recording Site:

Medial ankle:

G1 placed slightly proximal and posterior to the medial malleolus

G2 placed 3–4 cm proximally

Stimulation Sites:

Great toe (medial plantar sensory): Ring electrodes, with cathode placed proximally near the metatarsal–phalangeal joint of the great toe; anode placed 3–4 cm distally

Little toe (lateral plantar sensory): Ring electrodes, with cathode placed proximally near the metatarsal–phalangeal joint of the little toe; anode placed as distally as possible

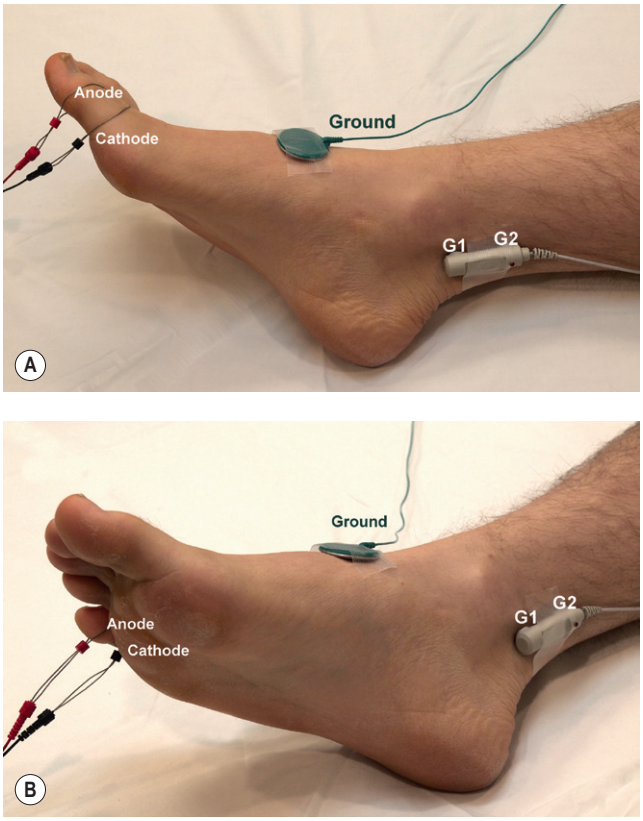

FIGURE 11–10 A: Medial plantar sensory study. The great toe is stimulated, and the tibial nerve is recorded slightly proximal and posterior to the medial malleolus. **B:** Lateral plantar sensory study. The little toe is stimulated, and the tibial nerve is recorded slightly proximal and posterior to the medial malleolus.

Distal Distance:

Variable

Key Points:

- Orthodromic study described; for antidromic study, recording and stimulation sites are reversed.
- This study is useful in the evaluation of distal tibial neuropathy across the ankle (i.e., tarsal tunnel syndrome).
- Potentials are very small and difficult to obtain, even in normal controls.
- Averaging often is required.
- Side-to-side comparisons of amplitude and latency are required.
- Side-to-side comparison is necessary before interpreting a low or absent potential as abnormal.

Medial and Lateral Plantar Mixed Nerve Studies *(Figure 11–11)*

Recording Site:

Medial ankle:

G1 placed slightly proximal and posterior to the medial malleolus

G2 placed 3–4 cm proximally

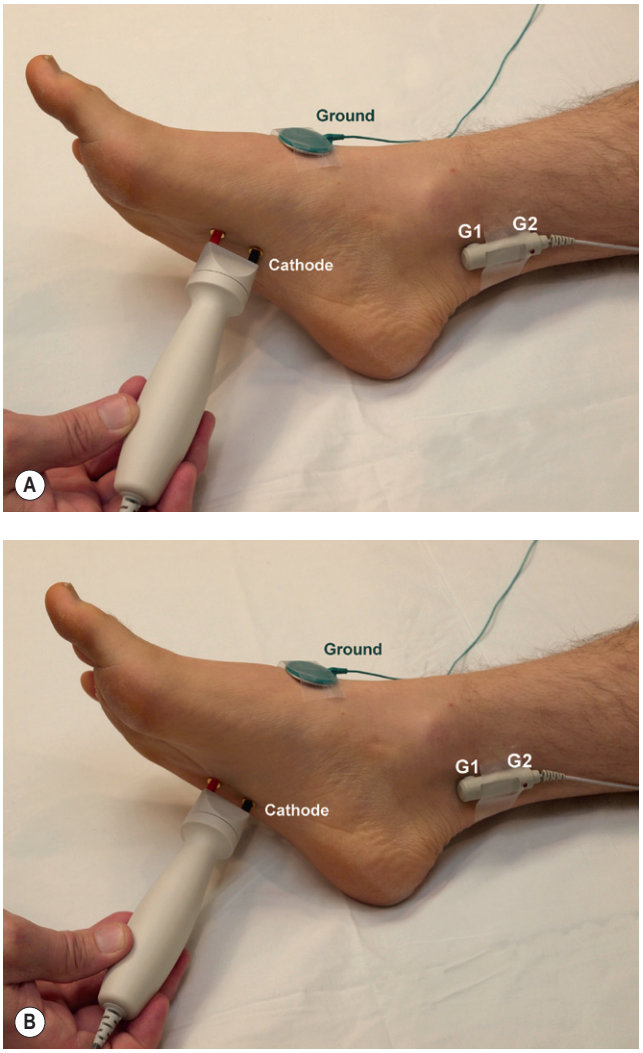

FIGURE 11–11 A: Medial plantar mixed study. The medial sole is stimulated, and the tibial nerve is recorded slightly proximal and posterior to the medial malleolus. **B:** Lateral plantar mixed study. The lateral sole is stimulated, and the tibial nerve is recorded slightly proximal and posterior to the medial malleolus.

Stimulation Sites:

Medial sole (medial plantar nerve): At a distance of 14 cm from the recording electrodes (measure 7 cm from the recording site into the sole of the foot, then an additional 7 cm on a line drawn parallel to the web space between the first and second toes)

Lateral sole (lateral plantar nerve): At a distance of 14 cm from the recording electrodes (measure 7 cm from the recording site into the sole of the foot, then an additional 7 cm on a line drawn parallel to the web space between the fourth and fifth toes)

Distal Distance:

14 cm

Key Points:

- Mixed nerve study, technically easier than orthodromic sensory studies.

- This study is useful in the evaluation of distal tibial neuropathy across the ankle (i.e., tarsal tunnel syndrome).
- Potentials may be small and difficult to obtain in normal controls, especially the lateral plantar response.
- Averaging often is required.
- Side-to-side comparisons of amplitude and latency are required.
- Side-to-side comparison is necessary before interpreting a low or absent potential as abnormal.

Soleus H Reflex Study *(Figure 11–12)*

Recording Site:

Soleus muscle:

Posterior calf with G1 placed one to two fingerbreadths distal to where the soleus meets the two bellies of the gastrocnemius

G2 placed over the Achilles tendon

Stimulation Site:

Popliteal fossa: Mid-posterior knee over the popliteal pulse

Distal Distance:

Variable (usually in the range of 20–25 cm)

Key Points:

- Stimulator pulse duration must be set at 1000 µs (i.e., 1 ms) to more selectively activate the Ia sensory fibers.
- H reflex occurs with low stimulation intensities.
- As stimulator current is slowly increased, the H reflex appears first, without a direct muscle response; as the current is increased further, the H reflex increases and a direct muscle response also occurs; as the direct muscle response grows the H reflex decreases.
- H reflex is a late reflex, usually with a triphasic morphology (positive–negative–positive) occurring at 25–34 ms.
- Comparison to the contralateral side is often helpful in determining if a latency is abnormal (latency difference >1.5 ms).
- The distal distance must be the same from side to side to ensure a valid side-to-side comparison
- H reflex is delayed or absent in polyneuropathy, tibial neuropathy, sciatic neuropathy, lumbosacral plexopathy, or S1 radiculopathy.

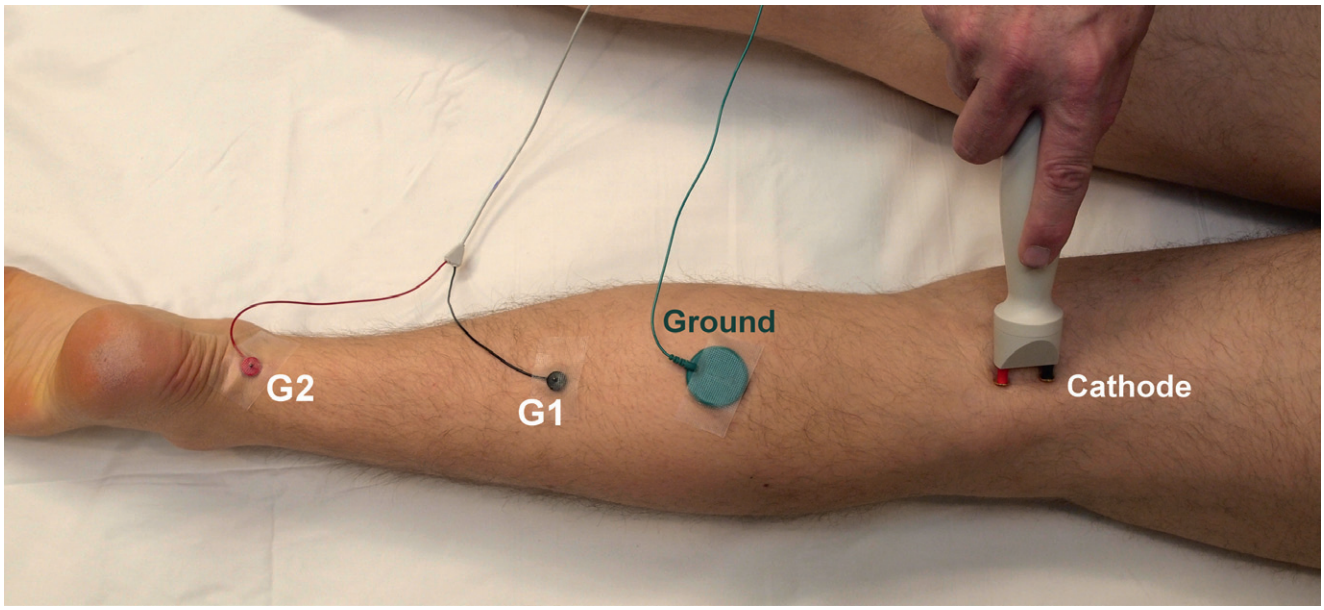

FIGURE 11–12 Soleus H reflex. The tibial nerve is stimulated in the middle of the popliteal fossa; the cathode is pointing rostral, and the soleus muscle is recorded.

NERVE CONDUCTION STUDIES OF THE LOWER EXTREMITY: NORMAL ADULT VALUES

Motor

Nerve	Record	Amplitude (mV)	Conduction Velocity (m/s)	Distal Latency (ms)	Distal Distance (cm)
Peroneal	Extensor digitorum brevis (EDB)	≥2.0	≥44	≤6.5	9
Peroneal†	Tibialis anterior (TA)	≥3.0	≥44	≤6.7	5–10
Tibial	Abductor hallucis brevis (AHB)	≥4.0	≥41	≤5.8	9
Tibial†	Abductor digiti quinti pedis (ADQP)	≥3.0	≥41	≤6.3	Variable*

*Difficult to measure unless calipers are used.

† In cases where one side is symptomatic and the other is not, it is often helpful to compare the amplitudes side to side, rather than use normal value tables.

Antidromic Sensory

Nerve	Record	Amplitude (μV)	Conduction Velocity (m/s)	Peak Latency (ms)	Distal Distance (cm)
Sural	Posterior ankle	≥6	≥40	≤4.4	14†
Superficial peroneal	Lateral ankle	≥6	≥40	≤4.4	14†
Saphenous*	Medial/anterior ankle	≥4	≥40	≤4.4	14†
Medial plantar*	Medial ankle	≥2	≥35	–	Variable
Lateral plantar*	Medial ankle	≥1	≥35	–	Variable
Lateral femoral cutaneous‡	Anterior thigh	≥4		≤2.6	12

*In some normal individuals without symptoms, especially those older than age 40, these responses may be very small, requiring electronic averaging, or may be absent. Thus, a low-amplitude or absent potential should not necessarily be interpreted as abnormal. Side-to-side comparisons often are very useful in this regard if one side is symptomatic and the other is not.

†Although the normal values for peak latency are based on the standard distance of 14 cm, in many individuals, it is much easier to stimulate at a shorter distance (typically 10–12 cm). Supramaximal stimulation usually can be achieved with low stimulation intensities (e.g., 5–25 mA). Thus, if the response is not present stimulating at 14 cm or if high currents are needed, try a shorter distance of 10–12 cm. If a good response is obtained, do not use the peak latency to determine if the response is normal, but rather the calculated conduction velocity based on the onset latency and the distance used.

‡Although the normal value for peak latency is based on the standard distance of 12 cm, in some individuals, the nerve may be easier to stimulate at a shorter distance (typically 10 cm). Difficult study to perform in obese individuals. Thus, a low-amplitude or absent potential should not necessarily be interpreted as abnormal unless side-to-side comparisons are done in patients with symptoms limited to one side.

Source: from Shin, Y.B., Park, J.H., Kwon, D.R., Park, B.K., 2006. Variability in conduction of the lateral femoral cutaneous nerve. Muscle Nerve 33 (5), 645–649. Values based on reported mean minus 2 SD for amplitude, and mean plus 2 SD for peak latency.

Plantar Mixed Nerve Studies

Nerve	Amplitude (μV)	Conduction Velocity (m/s)	Distal Peak Latency (ms)	Distance (cm)
Medial plantar*	≥3	≥45	≤3.7	14
Lateral plantar*	≥3	≥45	≤3.7	14

*In some normal individuals without symptoms, especially those older than age 40, these responses may be very small, requiring electronic averaging, or may be absent. Thus, a low-amplitude or absent potential should not necessarily be interpreted as abnormal. Side-to-side comparisons often are very useful in this regard.

Late Responses*

Nerve	Minimal F Latency (ms)	Minimal H Latency (ms)
Peroneal	≤56	N/A
Tibial	≤56	≤34†

*For tall or short patients, F responses and H reflexes must be normalized for height (see Chapter 4).

†Compare side to side. Any difference in latency >1.5 msec between sides is considered abnormal.

Notes:

1. All normal value tables assume controlled temperature and standard distances.
2. All motor and sensory amplitudes are measured from baseline to negative peak.
3. All sensory and mixed nerve distal latencies are peak latencies; however, all sensory and mixed nerve conduction velocities are calculated based on the onset latency.
4. Some values may have to be adjusted for extremes of height or age (see Chapter 8).
5. Comparison between the affected and unaffected limb often is very useful and may be more useful than normal value tables.
6. This is one set of normal values; others exist. Ideally, each laboratory should develop its own set of normal values.

Basic Overview of Electromyography 12

After the nerve conduction studies are completed, the electrophysiologic evaluation moves on to the needle electromyography (EMG) examination. Like the nerve conduction studies, each needle EMG study must be individualized based on the clinical findings and differential diagnosis and modified as the test proceeds and more data are obtained. Almost every muscle in the body can be studied with EMG. However, to do so is neither practical for the electromyographer nor desirable for the patient. For each study, a balance must be reached between the need to study a sufficient number of muscles to reach or exclude a diagnosis and the limits of the patient's ability to tolerate the examination. Patients' reactions to the needle EMG vary greatly. When the examination is performed skillfully, most patients tolerate it well, with only minor discomfort. Some patients, however, are extremely apprehensive and may have difficulty completing the examination. Young children, who may tolerate the nerve conductions well, frequently have difficulty with the needle examination. It is with these latter groups that the electromyographer must be especially skillful. *Before proceeding with the needle study, it often is useful to consider the possibility that the patient may tolerate EMG of only one or two muscles.* If this occurs, which muscles will one choose? The choice must be based on the following factors:

1. The differential diagnosis, determined by the clinical findings and nerve conduction data.
2. The ease with which the muscle can be located and activated [e.g., although both the tibialis anterior (TA) and medial gastrocnemius (MG) are distal leg muscles, the TA is much easier to activate than the MG].
3. The degree of pain associated with sampling the particular muscle [e.g., both the first dorsal interosseous (FDI) and abductor pollicis brevis (APB) are distal C8–T1 innervated muscles, but the APB is much more painful to sample than the FDI for most patients).

If there is any indication that the patient might not tolerate or complete the entire examination, the most important muscles should be sampled first. For instance, if a patient has proximal muscle weakness and the differential diagnosis rests primarily between a myopathy and a proximal neuropathic process (e.g., plexopathy, radiculopathy, motor neuron disease), it makes sense to sample a weak proximal muscle first. If one begins the examination by sampling distal muscles that are clinically normal and the patient asks to stop the examination after the distal muscles are sampled, the chance to reach a diagnosis may have been lost.

There is no doubt that the needle EMG is the more challenging part of the electrophysiologic examination. A successful study requires not only knowledge of anatomy and physiology but also sound EMG technique and good patient rapport. Two competing influences make the needle EMG study especially demanding. First, many of the abnormalities found on the needle study are subtle. At the same time, however, the range of normal findings is quite large and varies with age and with the muscle being studied. Although the basics of the needle EMG study, such as needle placement and recognition of certain types of abnormal spontaneous activity, usually can be learned in a short time, it is not unusual for it to take years to master recognition of many of the uncommon and subtle needle EMG findings.

EQUIPMENT

In addition to the EMG machine, an EMG needle, needle cable, ground electrode, and gloves are necessary to perform the needle EMG study. The ground electrode is applied to the limb being studied in order to suppress noise and for electrical safety. Disposable gloves must always be worn to prevent the transmission of bloodborne infections between the patient and the electromyographer. The EMG needle is connected to a cable and then plugged into the EMG machine. Either a concentric or monopolar EMG needle can be used (Figure 12–1). When an electrical potential is measured, including the potentials measured during the needle EMG study, voltage is measured as the difference between the active and reference recording electrodes. The concentric needle contains both the active and reference electrodes in the needle itself (Figure 12–2). The shaft of the needle serves as the reference electrode, whereas the active electrode runs as a very small wire through the center of the needle and is exposed at the needle tip. The end of the concentric needle is beveled, resulting in a recording area that has a "teardrop" configuration (Figure 12–3). In contrast, the monopolar needle is Teflon coated, and its exposed end serves as the active recording electrode. Its

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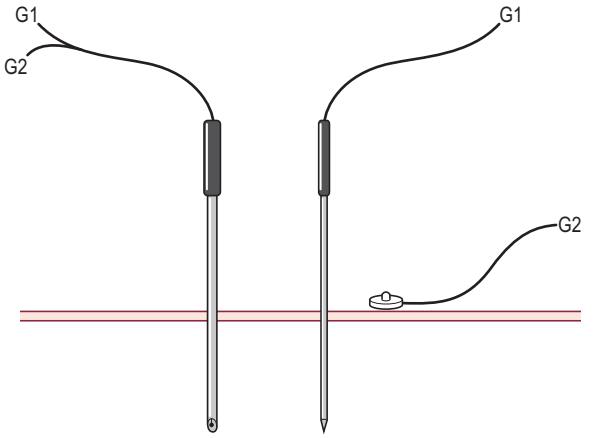

FIGURE 12–1 Electromyography needles. To the left is the concentric needle, which contains both the active (G1) and reference (G2) electrodes. The active electrode runs as a small wire through the needle center and is exposed at the tip, whereas the shaft of the needle serves as the reference electrode. To the right is the monopolar needle. In the monopolar montage, the needle is Teflon coated, and its exposed tip serves as the active electrode (G1). An additional surface disc electrode is needed as the reference electrode (G2).

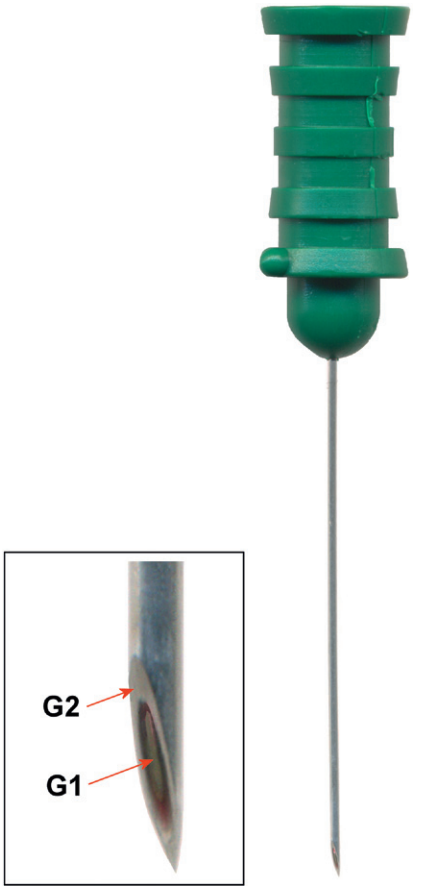

FIGURE 12–2 Concentric needle electrode. The shaft of the needle serves as the reference electrode (G2), whereas the active electrode (G1) runs as a very small wire through the center of the needle and is exposed at the needle tip, which is beveled. **Inset:** High magnification of the needle bevel. Note that the active electrode can be seen in the center.

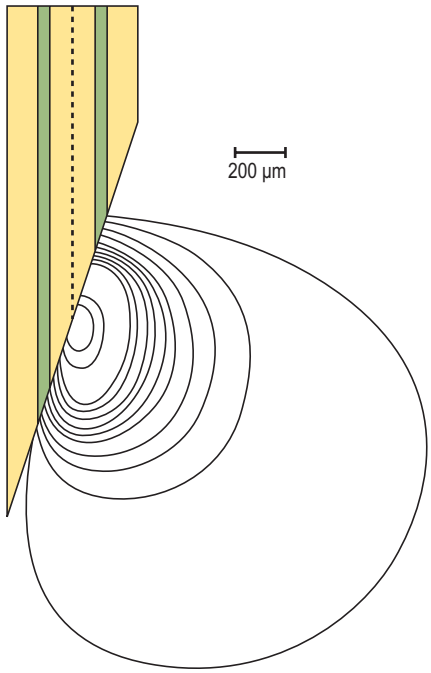

FIGURE 12–3 Recording field shape of the concentric needle electrode. As the end of the concentric needle is beveled, the resultant recording area has a "teardrop" configuration.
(Adapted from King, J.C., Dumitru, D., Nandedkar, S., 1997. Concentric and single fiber electrode spatial recording characteristics. Muscle Nerve 20, 1525–1533. Reprinted by permission of Wiley.)

recording area is that of a sphere around the tip of the needle. For the monopolar needle montage, an additional surface disc electrode is required as the reference electrode.

Both concentric and monopolar needles do a good job of recording the electrical signals from muscle. For recording motor unit action potentials (MUAPs), however, there are small differences between the two types of needle. With a concentric needle, the MUAP amplitude is slightly smaller and the major spike rise time shorter than those obtained with a monopolar needle (likely a reflection of the size and shape of the recording field of each needle) (Figure 12–4). Otherwise, there are no appreciable differences between the two in terms of the recorded waveforms. The concentric needle has the advantage of not requiring an additional reference electrode and is thus easier to use. The monopolar needle has the advantage of having a smaller caliber and a sharper point and may be slightly less painful and easier for patients to tolerate. This advantage, however, is not as critical as it was in the past, when needles were routinely sterilized and reused. Because reused needles often become less sharp with successive use, they are more painful when they penetrate the skin. All needles in use now, however, are disposable and should never be reused. The major disadvantage of the monopolar needle is the need for an additional reference electrode. Because the reference electrode must be placed close to the active electrode, it must be moved from location to location with each muscle sampled.

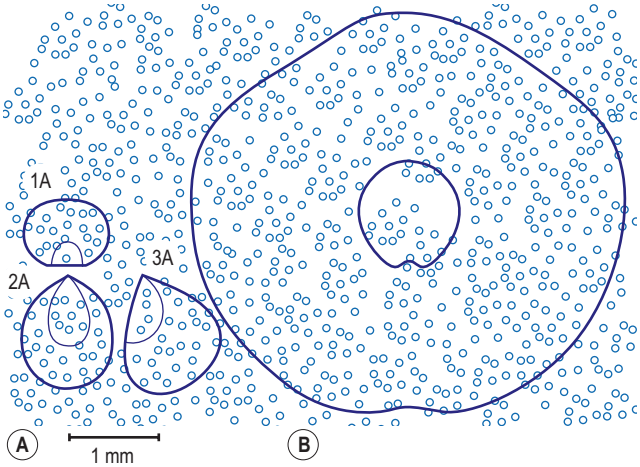

FIGURE 12–4 Comparison of recording fields of concentric and monopolar needle electrodes. **A:** Concentric needle recording field (**1A:** top view; **2A:** front view; **3A:** side view). **B:** Monopolar needle recording field (side view). Recording fields are superimposed upon a typical motor unit fiber distribution. The amplitude of the recorded motor unit action potential is derived primarily from the fibers near the needle tip. In the figure, the inner and outer lines represent the fibers that contribute 90 and 99% of the recorded amplitude, respectively (i.e., any fibers outside of these lines make no significant contribution to the recorded amplitude). Note that the monopolar needle has a much larger recording area.
(Adapted from King, J.C., Dumitru, D., Nandedkar, S., 1997. Concentric and single fiber electrode spatial recording characteristics. Muscle Nerve 20, 1525–1533. Reprinted by permission of Wiley.)

In addition, because the active electrode is an intramuscular needle and the reference is a surface disc, there is a much greater likelihood of electrode impedance mismatch and increased electrical noise. All in all, both needle types are satisfactory, but considering the advantages and disadvantages of each, the concentric needle is preferred by most electromyographers.

PATIENT PREPARATION

Before beginning the needle EMG examination, it is important to explain the procedure to the patient and allay any patient fears. After completing the nerve conduction studies, we usually tell every patient some version of the following before beginning the needle EMG:

We have finished the nerve conduction part of the test and are about to go on to the second part of the test, which usually is much shorter than the first part. There is no electrical stimulation with this part of the test. I will use a very small needle to record electrical potentials from inside your muscles. We will be checking several muscles, but the exact number of muscles will depend on what we find as we go along. For each muscle we look at, I will put this small needle into the muscle, and you will feel a quick pinch. The more relaxed you are when I put the needle in, the less you will feel the needle. We will look at the electrical activity of the muscle while it is relaxed, and then I will ask you to move the muscle slightly to look at the activity of the muscle while it is contracting. I will explain to you exactly what I am doing at each stage, how to relax the muscle, and how to move the muscle when I ask you to. When your muscle is contracting, the electrical signal from the muscle will go to the EMG machine so that I can see it on the screen, but more importantly, it also will go to a loudspeaker so that we both can hear it. This is important because, at certain times, I will ask you to move a little bit more or a little bit less, and by listening, you will know how much you are moving your muscle. Please feel free to ask me any questions as we go along, and let me know if you need to take a break at any time.

Afterward, the examiner should answer any questions from the patient before proceeding to the needle EMG examination. Good patient rapport both before and during the study is essential. Most of the needle study cannot be performed without good patient cooperation. Indeed, the more cooperative the patient, the more reliable the data obtained and the more quickly the test proceeds, leading to less discomfort and a better test for the patient.

TYPICAL NEEDLE ELECTROMYOGRAPHY EXAMINATION *(BOX 12–1)*

For each muscle being studied, one must be able to identify the proper needle insertion point, as well as know how to properly have the patient activate the muscle (see Chapter 13). The skin should always be cleaned with alcohol before the needle is inserted. Once the muscle has been selected for study, the first step is to locate the needle insertion

Box 12–1. Patient Preparation and Typical Needle Electromyography Examination

1. Explain the electromyography procedure to the patient to allay any patient fears.
2. Select first muscle for study.
3. Locate muscle by using anatomic landmarks.
4. Show patient how to activate muscle.
5. Palpate muscle during contraction.
6. Ask patient to relax muscle.
7. Insert needle into relaxed muscle.
8. Ask patient to contract muscle slightly to ensure proper placement.
9. Ask patient to relax muscle fully.
10. Assess insertional and spontaneous activity (sweep speed: 10 ms per division; sensitivity: 50 µV per division).
11. Perform 5–10 brief insertions in all four quadrants.
12. Assess MUAPs (sweep speed: 10 ms per division; sensitivity: 200 µV per division).
    A. Ask patient to contract muscle slightly and gently move needle until MUAPs become "sharp."
    B. Assess several locations for MUAP duration, amplitude, phases, recruitment, and activation.
    C. Use isometric contraction, if possible.
13. Proceed to next muscle.

MUAP, motor unit action potential.

point by identifying the proper anatomic landmarks. Next, one should ask the patient to activate and relax the muscle several times and palpate for muscle movement. Once the muscle location is properly identified and palpated, the patient is asked to relax. Inserting a needle into a contracted muscle is much more painful than putting a needle into a relaxed one. The needle is then quickly inserted through the skin into the muscle. Sometimes the patient finds it less painful if the electromyographer gently pinches the muscle between the fingertips to raise it a bit, before inserting the needle. Before proceeding further, the location of the needle must be confirmed. The patient is asked to activate the muscle of interest ever so slightly. *The low level of activation needs to be emphasized.* Many adjacent muscles will co-contract at higher levels of activation. If the needle is in the proper location, very sharp and crisp MUAPs will be seen with minimal contraction. If sharp MUAPs are not seen with minimal contraction, the needle should be either pulled back slightly or moved a bit deeper into the muscle before the examination proceeds. If this maneuver fails to produce sharp MUAPs, the needle must be removed, the muscle re-palpated, and the needle reinserted. *The important point to remember here is that one should not proceed unless one is certain that the needle is placed correctly in the muscle of interest.*

Once the correct needle placement has been established, the first part of the examination is to assess insertional and spontaneous activity at rest. This should be done with the sweep speed set at 10 ms per division and the sensitivity set at 50 μV per division. Most spontaneous discharges are of low amplitude and may be missed unless the sensitivity is set to at least 50 μV per division (see Chapter 14). Five to 10 brief insertions should be performed, looking for increased insertional activity and spontaneous discharges at rest. Muscle normally is quiet at rest, except for the potentials seen at the endplate zone. When the needle is quickly moved through muscle, there is a brief burst of muscle fiber potentials, typically lasting no longer than 300 ms after the needle has stopped moving. Increased insertional activity is defined as any activity other than endplate potentials that last longer than 300 ms after brief needle movement. Spontaneous activity is defined as any activity at rest that lasts longer than 3 seconds. One effective technique to sample for spontaneous and increased insertional activity is to insert the needle in all four quadrants at the needle site (see Chapter 14). Using this technique, the examiner first inserts the needle in one quadrant, moves it along a line from shallow to deeper, and then pulls it back to sample the next quadrant without removing the needle from the muscle. This is repeated until all four quadrants are sampled.

Once insertional and spontaneous activity have been characterized, the needle is left in place, and the analysis next turns to the evaluation of MUAPs. The sensitivity must be changed to 200 μV per division, while the sweep speed remains at 10 ms per division. MUAPs typically are much larger than abnormal spontaneous activity waveforms and hence require the change in sensitivity. To analyze MUAPs, the examiner asks the patient to slowly contract the muscle of interest. It is always best to have the patient contract the muscle in an even manner. MUAPs are very difficult to interpret in patients whose muscle contraction is uneven, especially those with a tremor.

A clinical pearl in performing needle EMG is to always employ isometric contraction if possible (isometric meaning the same muscle length). Indeed, it is often the physical muscle movement around the needle, especially at higher levels of force, that results in discomfort. This can be minimized by using isometric contraction. Thus, the electromyographer simply has to resist the movement of the muscle as the patient increases force. For example, when sampling the biceps, the electromyographer holds the needle in one hand while using the other hand to hold the patient's forearm steady, as the patient pushes against it. As the patient contracts more, the electromyographer holds the forearm even tighter to prevent the elbow joint from moving. Thus, even though more force is being generated, the muscle remains the same in length (i.e., isometric) as any actual movement is prevented by resistance from the electromyographer.

With the patient minimally activating the muscle, the needle is gently moved until the MUAPs become "sharp," that is, they become louder and crisper. As the needle moves closer to the MUAP, there is less intervening tissue to attenuate and filter the potential. Thus, the closer the needle to the MUAP, the higher the amplitude and the shorter the major spike rise time. It is at this point that the MUAP can be properly evaluated. MUAPs are assessed for duration, amplitude, and number of phases. In addition, the number of MUAPs, their relationship to the firing frequency, and the rate of firing itself (recruitment and activation pattern) are determined (see Chapter 15). As the patient slowly increases force, both the firing frequency and the number of MUAPs normally increase. After the MUAPs are assessed at one location, the needle is moved slightly within the muscle to a different site, and the process is repeated. Ideally, 10 to 20 different MUAPs should be studied.

Once insertional and spontaneous activity are characterized and the MUAP size, recruitment, and activation patterns are determined for each muscle sampled, one can generally determine whether a lesion is present. If there is a lesion, one can use the data to determine its severity and chronicity and, most importantly, whether the primary problem is neuropathic or myopathic. The distribution and pattern of abnormalities in different muscles, along with the nerve conduction studies and the clinical data, should allow one to make the final electrophysiologic diagnosis.