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This Atlas is intended to illustrate the aspects of sonoanatomy that are important in the performance of ultrasound guided nerve blocks for acute and chronic pain medicine. The use of ultrasound has increased exponentially in the area of regional anesthesia and pain medicine in the last decade. During this time of evolution, learning sonoanatomy was hampered with the need to refer to various resources for the technical aspects of machine optimization, correlating sonoanatomy with gross anatomy and other imaging modalities and discovering the ergonomic aspects of imaging and intervention.

For regional anesthesia, transitioning from landmark based techniques for nerve blocks to real time ultrasound image guided nerve blocks required the development of the ability to visualize and understand the cross sectional anatomy of the area of interest outside the traditional transverse, sagittal and coronal axis views presented by current modalities such as computed tomography and magnetic resonance imaging.

For pain medicine, transitioning from fluoroscopy guided interventions to real time ultrasound image guided or assisted interventions required the development of new points of reference for interventions and a move away from traditional fluoroscopic guided endpoints for intervention.

This book is divided into chapters that present the sonoanatomy specific for interventions in the area of interest. With a total of 768 illustrations this book is designed to be the complete resource for gross anatomy, CT, MR and sonoanatomy of the specific area of interest for easy cross-reference between gross anatomy and the various modalities allowing users to better understand the sonoanatomy. These cross-referenced images are presented with the relevant anatomy in the same cross sectional plane of the ultrasound image. Within each area of interest, users are guided to acquire the ideal ultrasound image for targeted intervention with attention to the required ergonomics for operator safety and comfort.

Each approach to the relevant sonoanatomy is accompanied by clinical pearls to aid readers acquire ultrasound images of the area of interest with ease, provide guidance for successful intervention and avoid pitfalls.

This Atlas has been written both as an introduction for new users to ultrasonography and as a review and instruction aid for users familiar with the subject. It is our sincere hope that the users of this book will develop an appreciation of the ease and usefulness of ultrasonography and the beauty of sonoanatomy.
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A sound knowledge of the basic concepts of musculoskeletal ultrasound is essential to obtain optimal images during ultrasound-guided regional anesthesia (USGRA). This chapter briefly summarizes the ultrasound principles that the operator should be aware of when performing USGRA.

**Ultrasound Transducer Frequency**

Spatial resolution is the ability to distinguish two closely situated objects as separate. Spatial resolution includes axial resolution (the ability to distinguish two objects at different depths along the path of the ultrasound beam) and lateral resolution (the ability to distinguish two objects that are side by side perpendicular to the ultrasound beam). Higher transducer frequencies increase spatial resolution but penetrate poorly into the tissues. Lower transducer frequencies penetrate deeper into the tissues at the expense of lower spatial resolution. Spatial resolution and beam penetration have to be balanced when choosing the transducer frequency.

Examples: A high-frequency (6–13 MHz) ultrasound transducer is used to image superficial structures such as the brachial plexus in the interscalene groove or supraclavicular fossa. A lower-frequency transducer (5–10 MHz) is suitable for slightly deeper structures such as the brachial plexus in the infraclavicular fossa, and a low-frequency transducer (2–5 MHz) is used to image deep structures such as the lumbar paravertebral region or the sciatic nerve. High-frequency (6–13 MHz) linear transducers with a small footprint (25–26 mm) are particularly suited for regional blocks in young children.

**Scanning Plane**

Scans can be performed in the transverse (axial) or longitudinal plane. During a transverse scan, the transducer is oriented at right angles to the long axis of the target, producing a cross-sectional display of the structures (Fig. 1-1A). During a longitudinal (sagittal) scan, the transducer is oriented parallel to the long axis of the target (eg, a blood vessel or nerve) (Fig. 1-1B). During USGRA, ultrasound scans are most commonly performed in the transverse plane in order to easily visualize the nerves, the adjacent structures, and the circumferential spread of the local anesthetic.
Transducer and Image Orientation

The ultrasound image must be correctly oriented in order to accurately identify the anatomical relationships of the various structures on the display monitor. Ultrasound transducers have an orientation marker (e.g., a groove or a ridge) on one side of the transducer, which corresponds to a marker on the monitor (e.g., a dot or logo) (Fig. 1-2). There are no accepted standards on how to orient a transducer, but it is common to have the orientation marker on the transducer directed cephalad when performing a longitudinal scan, and directed towards the right side of the patient when performing a transverse scan (Fig. 1-3). In this way, the monitor “marker” should be at the upper-left corner of the screen representing the cephalad end during a longitudinal scan, or the right side of the patient during a transverse scan (Fig. 1-3). The top of the monitor represents superficial structures, and the bottom of the monitor deep structures.
The orientation marker should be pointed:
1. To the patient’s right side for a transverse scan
2. To the patient’s head for a longitudinal scan

**FIGURE 1-2** Transducer orientation. Note the orientation marker varies between different providers of ultrasound systems. L, longitudinal, T, transverse and C, coronal.

**FIGURE 1-3** Image orientation – transverse scan.

**Image Optimization**

The image should be optimized by adjusting the depth, focal zone, and gain. Imaging depth affects temporal resolution (the ability to accurately depict moving structures) and should be reduced to the smallest field of view (FOV) that is practical. The focal zone should be positioned at the region of interest to increase lateral resolution at that site. Reducing the total number of focal zones also improves temporal resolution. Finally, the time gain compensation (TGC) and overall gain should be adjusted to produce an image with appropriate brightness. The TGC is usually adjusted with the near field gain turned down and the far field gain turned up in steady progression to adjust for beam attenuation with depth.
**Echogenicity**

Certain terms are frequently used to describe the sonographic appearance of musculoskeletal structures (Fig. 1-4):

![Echogenicity of tissues.](image)

**FIGURE 1-4** Echogenicity of tissues.

*Isoechoic*: The structure is of the same brightness or echogenicity as the surrounding tissues.

*Hyperechoic*: The structure is bright.

*Hypoechoic*: The structure is dark but not completely black.

*Anechoic*: The structure has no echoes and appears completely black.

Contrast resolution is the ability to distinguish subtle differences in echogenicity between two adjacent structures.

**Axis of Intervention**

During USGRA, the block needle can be visualized in its short axis (out-of-plane approach) (Fig. 1-5) or long axis (in-plane approach) (Fig. 1-6). In the out-of-plane approach, the needle is initially outside the plane of imaging and therefore not visible. The needle only becomes visible when it crosses the plane of imaging and is seen as an echogenic dot on the monitor (Fig. 1-5). It is important to note that this echogenic dot may not represent the tip of the needle because it is a short-axis view. In the in-plane approach the needle is inserted along the plane of imaging and therefore both the shaft and tip of the needle are visible on the monitor (Fig. 1-6).
FIGURE 1-5 Axis of intervention – out-of-plane needle insertion.

FIGURE 1-6 Axis of intervention – in-plane needle insertion.

Both approaches are commonly used, and there are no data showing that one is better than
the other. Pros and cons for both methods have been debated. Proponents of the out-of-plane approach have had great success with this method and claim that it causes less needle-related trauma and pain because the needle is advanced through a shorter distance to the target. However, critics of the out-of-plane approach express concerns that the inability to reliably visualize the needle and using tissue movement as a surrogate marker to locate the needle tip during a procedure can lead to complications. The needle is better visualized in the in-plane approach, but this requires good hand–eye coordination, and reverberation artifacts from the shaft of the needle can be problematic. Moreover, there are claims that the in-plane approach also causes more discomfort in awake patients because longer needle insertion paths are required.

**Field of View and Needle Visibility**

Having an adequate FOV during USGRA is important because it not only allows one to visualize the “target,” but also the neighboring structures (eg, blood vessel, pleura, etc.) that one wishes to avoid injury to. Linear array transducers have a narrow FOV, whereas curved array transducers have a divergent ultrasound beam resulting in a wider FOV (Fig. 1-7).

![Comparative field of view of the infraclavicular fossa with linear and curved array transducers.](image)

**FIGURE 1-7** Comparative field of view of the infraclavicular fossa with linear and curved array transducers.

Needles are best visualized when imaged perpendicular to the ultrasound beam. Needles at steep angles required for deep blocks may not be easily visualized with linear array transducers. Linear array transducers are best suited for superficial blocks (eg, axillary or interscalene brachial plexus block, femoral nerve block). Curved array transducers are more suitable for deep blocks (eg, sciatic nerve block, lumbar plexus block, and central neuraxial blocks). However, curved array transducers have reduced lateral resolution at depth due to the diverging ultrasound beam.

Other factors can also influence needle visibility. The needle is better visualized in its long axis than in its short axis, and its visibility decreases linearly with smaller needle diameters. The needle tip is better visualized when in its long axis for shallow angles of insertion (less than 30 degrees), and in its short axis when the angle of insertion is steep (greater than 60 degrees). This is also true when the needle is inserted with its bevel facing the ultrasound
transducer. To overcome the effect of angle on needle visibility, some high-end ultrasound machines allow the operator to steer the ultrasound beam (beam steering) towards the needle during steep insertions. However, this requires experience, and decreases in needle visibility can still occur. Needle visibility is also enhanced in the presence of a medium-sized guide wire. Priming a needle with saline or air, insulating it, or inserting a stylet prior to insertion does not improve visibility.

We believe that the anesthesiologist’s skill in aligning the needle along the plane of imaging is by far the most important variable influencing needle visibility because minor deviations of even a few millimeters from this plane can result in an inability to visualize the needle. Even with experience, needle tip visibility is a problem when performing blocks at depth, in areas that are rich in fatty tissue, and in the elderly. Under such circumstances gently jiggling (rapid in-and-out movement) the needle and observing tissue movement or performing a test injection of saline or 5% dextrose (1–2 mL) and observing tissue distention can help locate the position of the needle tip. The preference is for 5% dextrose for the latter when nerve stimulation is used because it does not increase the electric current required to elicit a motor response.

**Anisotropy**

Anisotropy, or angular dependence, is a term used to describe the change in echogenicity of a structure with a change in the angle of insonation of the incident ultrasound beam (Fig. 1-8). It is frequently observed during scanning of nerves, muscles, and tendons. This occurs because the amplitude of the echoes returning to the transducer varies with the angle of insonation. Nerves are best visualized when the incident beam is at right angles; small changes in the angle away from the perpendicular can significantly reduce their echogenicity. Therefore, during USGRA the transducer should be tilted from side to side to minimize anisotropy and optimize visualization of the nerve. Although poorly understood, different nerves also exhibit differences in anisotropy; this may be related to the internal architecture of the nerve.
Anisotropy – effect of angulation of the transducer on the echogenicity of the median nerve (white arrow) in the forearm. The median nerve appears hypoechoic in the image on the right.

**Identification of Normal Structures**

**Nerve**

Peripheral nerves consist of hypoechoic nerve fascicles surrounded by hyperechoic connective tissue and have a “honeycomb” appearance in the transverse axis (Fig. 1-9). They have a fibrillar appearance in the longitudinal axis with fine parallel hyperechoic lines separated by fine hypoechoic lines. Generally, nerves appear hyperechoic, but the appearance can vary depending on the surrounding structures. For example, nerves appear hyperechoic when surrounded by hypoechogenic muscle, but can appear hypoechogenic when surrounded by hyperechoic fat. The echogenicity of a nerve may also vary depending on the location where it is scanned; for example, the brachial plexus nerves appear hypoechogenic at the interscalene groove, but are hyperechogenic at the infraclavicular fossa and axilla. The exact reason for this is not clear, but may be related to the relative proportion of neural and connective tissue within the nerve. The ratio of neural to non-neural tissue content within the epineurium of the nerve increases from 1:1 in the interscalene/supraclavicular fossa to 1:2 in the mid-infraclavicular/paracoracoid regions. Nerve motion can also be demonstrated on dynamic ultrasound imaging.
Tendon

Tendons are hyperechoic with a fibrillar pattern on longitudinal scans. Tendons are more hyperechoic than nerves and move more than adjacent nerves when the corresponding muscle is contracted or passively stretched.

Muscle

Muscle fiber bundles are hypoechoic. The separating and surrounding connective tissue perimysium and epimysium are hyperechoic (Fig. 1-9). Muscle fibers converge to become tendons or aponeuroses.

Subcutaneous Fat

Subcutaneous fat lobules appear as round to oval hypoechoic nodules that are separated by fine hyperechoic septa. They are slightly compressible and appear similar on transverse and longitudinal scans.

Bone

Bone reflects most of the ultrasound beam. Therefore, the bone surface appears hyperechoic on ultrasound with posterior acoustic shadowing, and possibly posterior reverberation, distal to it (Fig. 1-10).
FIGURE 1-10 Echogenicity of bone, pleura and lung at the intercostal space. Note the acoustic shadow deep to the rib.

**Fascia**

Fascia, peritoneum, and aponeuroses appear as thin hyperechoic layers.

**Blood Vessel**

Blood vessels have anechoic lumens. Arteries are intrinsically pulsatile and are not compressible with moderate pressure. Veins are not pulsatile and are compressible. Color Doppler or Power Doppler modes can also be used to demonstrate the presence of blood flow and differentiate arteries from veins.

**Pleura**

The pleura appear as a hyperechoic line slightly deep to the hyperechoic ribs (Fig. 1-10). “Comet-tail” artifacts may be present as vertically oriented echogenicities arising from the pleura. On real-time imaging, sliding movement between the parietal and visceral pleura can be discerned with respiration (lung sliding sign).

**Special Ultrasound Features**

**Tissue Harmonic Imaging**

Harmonics refer to frequencies that are integral multiples of the frequency of the transmitted pulse (the fundamental frequency or first harmonic). The second harmonic has a frequency of twice the fundamental frequency. Harmonics are generated due to tissues distorting the transmitted pulse, usually at the center of the image (midfield) rather than at superficial or deep locations. Structures that cause imaging artifacts also tend to produce less or no harmonics. Tissue Harmonic Imaging (THI) is a technique in which structures that produce harmonics are selectively displayed, reducing imaging artifacts. This results in reduced noise and improved spatial and contrast resolution (Fig. 1-11). THI is most suitable for assessment of midfield structures.
FIGURE 1-11 Effect of Tissue Harmonic Imaging (THI) during ultrasound imaging of the infraclavicular fossa. Note the improved spatial and contrast resolution on the right.

**Compound Imaging**

Ultrasound images depend on reflection of the ultrasound beam from tissue interfaces back to the transducer. Not all tissues are good reflectors, and certain structures cause scattering of the ultrasound beam resulting in scattered signals radiating in all directions. As a result only a small amount of energy is reflected back to the transducer. The scattering of the ultrasound beam results in noise, which makes the ultrasound image appear grainy. In compound imaging, the same structure is imaged from several different angles using computed beam steering. The returning echoes are then processed producing a composite image that has reduced noise and improved definition (Fig. 1-12). The disadvantage of compound imaging is increased blurring of the image with movement.

FIGURE 1-12 Effect of Compound Imaging during ultrasound imaging of the axilla. Note the reduction in noise and the improved definition of the image on the right.
Panoramic Imaging

Conventional 2-D ultrasound has a limited FOV and allows visualization of only a small portion of any large structure. Panoramic imaging, as the name implies, is a technique used to extend the FOV so that larger structures can be visualized in their entirety. During a panoramic scan, the operator slowly slides the transducer across a region of interest. Image information obtained during this motion is accumulated and then combined to form the composite panoramic image (Fig. 1-13). Although useful for annotation, documentation, teaching, and research, it is rarely used during USGRA at present.

Panoramic Imaging of the Forearm

![Panoramic Imaging of the Forearm](image)

**FIGURE 1-13** Panoramic transverse sonogram of the midforearm. FDS, flexor digitorum superficialis; FDP, flexor digitorum profundus; FPL, flexor pollicis longus; FCU, flexor carpi ulnaris.

Three-Dimensional Ultrasound

Three-dimensional ultrasound acquires data as a volume and allows reconstruction at any imaging plane without needing to move the transducer (Figs. 1-14 and 1-15). This can improve spatial awareness at the region of interest, visualization of the block needle, and distribution of the local anesthetic. Potential advantages include reduced needle-associated complications and increased block success with smaller volumes of local anesthetic. In addition, the volume data can be stored and retrospectively analyzed for teaching or research. The main challenges with 3-D ultrasound at present include lack of availability of ergonomic probes that can operate at high frequencies to assess superficial structures, slow screen refresh rates, and reduced temporal resolution when performing real-time interventions.
FIGURE 1-14  A multiplanar 3-D ultrasound image of the sciatic nerve at the midthigh with the reference marker (green crosshair) placed over the sciatic nerve.

FIGURE 1-15  A rendered 3-D ultrasound image of the sciatic nerve at the midthigh. The front and right surfaces of the 3-D volume are displayed. Note the hypoechoic perineural space posterior to the sciatic nerve in this image.
Artifacts

An ultrasound artifact is information that is visible in the ultrasound image that does not correlate with any anatomical structure. The ultrasound machine makes several assumptions when generating an image:

1. The ultrasound beam travels in a straight line with a constant rate of attenuation.
2. The speed of sound through body tissue is 1540 meters/second.
3. The ultrasound beam is infinitely thin with all echoes originating from its central axis.
4. The depth of a reflector is directly related to the round-trip time of the ultrasound signal.

Artifacts arise when there is deviation from these assumptions. Some artifacts are undesirable and interfere with interpretation, whereas others help identify certain structures. It is essential to recognize them in order to avoid misinterpretation. Therefore, whenever a structure appears abnormal on ultrasound, it must be examined at different angles and orientations to avoid making a wrong interpretation. Real anatomical structures are visible in all planes of imaging, whereas artifacts are generally only visible in one plane.

Artifacts that are frequently encountered during USGRA include:

1. **Contact artifact**
   This is the most common artifact that occurs whenever there is a loss of acoustic coupling between the skin and the transducer. This could simply occur because the transducer is not touching the skin, but more frequently it is due to air bubbles that are trapped between the skin and the transducer. Therefore, it is prudent to apply liberal amounts of ultrasound gel to exclude air from the skin–transducer interface.

2. **Reverberation artifact**
   Reverberation artifacts, also known as “repetitive echoes,” occur whenever there is repeated reflection of the ultrasound beam between two highly reflective surfaces. Some of the ultrasound signals returning to the transducer are reflected back, which then strike the original interface and are reflected back towards the transducer a second time. As a result, the first reverberation artifact is twice as far from the skin surface as the original interface. One may also see a second or third reverberation artifact (Fig. 1-16). Due to attenuation, the intensity of the artifacts decreases with increasing distance from the transducer. Reverberation artifacts are frequently seen during ultrasound-guided axillary brachial plexus blocks, particularly when the needle is viewed in its long axis (Fig. 1-17). They are reduced if the needle is less perpendicular to the transducer, but this may also reduce needle visibility.
3. **Mirror image artifact**

Mirror image artifact is a type of reverberation artifact that occurs at highly reflective interfaces. The first image is displayed in the correct position, and a false image is produced on the other side of the reflector due to its mirrorlike effect (Fig. 1-18).
4. Propagation speed artifact

These artifacts occur when the media through which the ultrasound beam passes does not propagate at 1540 meters/second, resulting in echoes that appear at incorrect depths on the monitor. An example of propagation speed artifact is the “bayonet artifact,” which has been reported during an ultrasound-guided axillary brachial plexus block. The shaft of the needle appeared bent when it accidentally traversed the axillary artery. We have observed the same phenomenon after local anesthetic injection during a popliteal sciatic nerve block (Fig. 1-19). This happens because of the difference in the velocity of sound between whole blood (1580 meters/second), or the injected local anesthetic, and soft tissue (1540 meters/second).
5. **Acoustic shadowing**

An acoustic shadow is a hypoechoic or anechoic region deep to surfaces that are highly reflective or attenuating such as bone ([Fig. 1-10](#)) or metallic implants. The implication for regional anesthesia is that tissues in the region of the shadow cannot be visualized. One benefit of this artifact is that the acoustic shadow of the block needle helps in identifying its location.

6. **Acoustic enhancement**

Acoustic enhancement results when the ultrasound beam passes through a low-attenuating structure resulting in brighter echoes from the deeper tissues. It is commonly seen deep to fluid-filled structures such as blood vessels. The increased brightness may saturate the display and make it difficult to identify nerves posterior to large blood vessels. A common example is when one visualizes the posterior cord of the brachial plexus at the paracoracoid (lateral infraclavicular fossa) location. The bright echoes posterior to the axillary artery (second part) and deep to the pectoralis major and minor muscles may be confused as the posterior cord ([Fig. 1-20](#)).

**FIGURE 1-19** Bayonet artifact induced by the local anesthetic injection during an ultrasound guided popliteal sciatic nerve block. Note the shaft of the needle appears bent close to the area occupied by the local anesthetic.

**FIGURE 1-20** Acoustic enhancement seen posterior to the axillary artery and vein during an ultrasound guided infraclavicular brachial plexus block. The bright echoes posterior the axillary artery may be confused as the posterior cord.

**Imaging the Challenging Patient**

**The Elderly Patient**

Muscle fibers become hyperechoic with age ([Fig. 1-21](#)) due to muscle atrophy and infiltration by fat and connective tissue. The hyperechoic muscle is more likely to reflect the ultrasound beam and reduce penetration of deeper structures. Reduced contrast resolution between the
echogenic muscle and an adjacent echogenic nerve decreases accurate delineation of the peripheral nerve. These factors make USGRA in the elderly challenging. Strategies that can help depict the peripheral nerve in the elderly include THI to improve resolution, compound imaging to reduce noise, and increasing the dynamic range to improve contrast resolution.

**FIGURE 1-21** Effect of age on the echogenicity of musculoskeletal structures. Note the increase in echogenicity and the loss of contrast between the nerve and the muscle in the elderly. BM, biceps muscle, RA, radial artery.

**The Obese Patient**

Excess adipose tissue hinders ultrasound imaging by attenuating the transmitted ultrasound beam, increasing scatter, and increasing the overall depth to the region of interest. The main strategies likely to improve image quality include using a low-frequency transducer to increase penetration, maximizing the power output to boost the signal-to-noise ratio, decreasing the dynamic range to produce high-contrast images, narrowing the sector width to improve resolution, and using physical compression to reduce the depth to the region of interest. Compound imaging, THI, and a speckle reduction filter can also be useful. Brightness color (B-color or color B-mode imaging) can also be used in imaging the obese patient. B-color is based on the principle that the human eye can only appreciate a limited number of shades of gray, but is able to distinguish a greater number of color hues. Subtle differences in musculoskeletal imaging can be enhanced by using a color-scale display.

**Doppler Ultrasound: The Basics**

Doppler ultrasound essentially measures a moving object. When ultrasound waves hit a
stationary object, the reflected ultrasound has the same frequency as the transmitted ultrasound. If the object is moving towards the transducer (source of the ultrasound), the reflected frequency will be higher than the transmitted frequency. If the object is moving away from the transducer, the reflected frequency will be lower than the transmitted frequency. This change in frequency of the reflected ultrasound is a result of the Doppler effect (Fig. 1-22):

\[
\Delta F = F_R - F_T = \frac{2F_T v \cos \theta}{C}
\]

From this equation, the following points can be made:

1. Doppler shift is dependent on the velocity of the moving object. In addition, information can be obtained on the direction of the moving object. If the object is moving towards the transducer, the change in frequency is greater than zero. If the object is moving away from the transducer, the change in frequency is less than zero.

2. Doppler shift is also dependent on the ultrasound-transmitted frequency. Higher transmitted ultrasound frequencies produce larger Doppler shifts and better sensitivity to moving objects, but also result in higher tissue attenuation. Lower transmitted ultrasound frequencies have better penetration of tissue. Sensitivity and penetration have to be balanced when choosing the ultrasound-transmitted frequency.

3. Maximum Doppler shift is obtained when the Doppler angle is 0 degrees, and no Doppler shift is obtained when the Doppler angle is 90 degrees (remember that \( \cos 0 = 1 \) and \( \cos 90 = 0 \); Fig. 1-23). Optimal imaging is obtained when the transducer is as parallel as possible to the direction of the moving object. When the Doppler angle is above 60 degrees, small changes in the Doppler angle result in large changes in \( \cos \theta \), and therefore, proportionately larger errors.
FIGURE 1-23 ▶ Doppler ultrasound image of an artery. A. Poor signal is shown in the center (white arrows) because flow in that part of the vessel is near 90 degrees to the ultrasound beam and little Doppler shift is observed. B. Flow is clearly seen when the vessel is significantly less than 90 degrees to the ultrasound beam.

In contrast, with a conventional gray-scale display, the best images are obtained when the structures are imaged perpendicular to the ultrasound beam.

**Doppler Display**

The Doppler shift can be presented as a Color Doppler or a Spectral Doppler image.

**Color Doppler**

Color Doppler displays different colors (usually red and blue), depending on flow direction, and uses the degree of color saturation to indicate the amount of Doppler shift (Figs. 1-24 and 1-25). Its limitation compared to Spectral Doppler is that it is a qualitative assessment.
FIGURE 1-24 Color Doppler image. In this example, red indicates flow towards the transducer (or probe) and blue indicates flow away from the transducer. Each color pixel represents the mean Doppler shift at that point.

FIGURE 1-25 Color Doppler bar and image. In this example, blue indicates flow towards the transducer and red indicates flow away from the transducer. Deep shades represent low velocities and light shades represent high velocities. Velocity scale indicators are present at each end of the color bar.

**Power Doppler**

Power Doppler is an alternative means of displaying a color map by assessing the number of moving blood cells (power) rather than mean Doppler shift. It does not measure velocity or direction and therefore is less dependent on the Doppler angle than Color Doppler. It also
does not suffer from aliasing and has less visible noise. This results in increased sensitivity for detecting flow at the expense of velocity and direction information (Fig. 1-26). Power Doppler is extremely sensitive to movement, which can cause flash artifacts.

![Power Doppler image of an artery. No direction information is available.](image)

**FIGURE 1-26** Power Doppler image of an artery. No direction information is available.

**Spectral Doppler**

Spectral Doppler presents the Doppler shift data in graphic form as a plot of the frequency spectrum over time (Fig. 1-27). It displays the peak and range of velocities at a single location along the ultrasound beam. Specific measurements are made on the Spectral Doppler display to obtain information related to flow resistance.

![Spectral Doppler image of the external iliac vein. The venous waveform changes with respiration.](image)

**FIGURE 1-27** Spectral Doppler image of the external iliac vein. The venous waveform changes with respiration.

**Other Technical Considerations**

**Aliasing**

Doppler data (Pulsed-Wave Doppler) is reconstructed from regularly timed transmitted and received ultrasound pulses equivalent to the pulse repetition frequency (PRF) of the Doppler machine. A low PRF is required when assessing deep vessels in order to allow enough time for the transmitted ultrasound pulse to arrive back before transmitting a new pulse. If the PRF is less than twice the maximum Doppler shift of the moving object (Nyquist limit), aliasing results (Figs. 1-28 and 1-29).
FIGURE 1-28  A. Spectral Doppler display of an artery demonstrating aliasing – “wraparound” of the higher velocities to display below the baseline. B. Aliasing can be reduced in this example by moving the baseline downwards (increasing the velocity scale above baseline).

FIGURE 1-29  Color Doppler display of an artery demonstrating aliasing (white arrow) – wraparound of the color map from one flow direction to the opposite direction. Aliasing is only seen in one portion due to higher velocities in that region.

Aliasing can be reduced by increasing the PRF (increasing the velocity scale) or by reducing the Doppler shift (increasing the Doppler angle or using a lower-frequency transducer).

Spectral Broadening

Spectral broadening indicates a large range of flow velocities at a particular location and is one of the criteria used for diagnosing high-grade vessel stenosis. Artifactual spectral broadening can also be produced by using an excessively large sample volume, by placing
the sample volume too near the vessel wall, or by excessive system gain (Fig. 1-30).

**FIGURE 1-30** A. Spectral broadening of an arterial waveform due to placing the sample volume too near the vessel wall. B. Normal waveform for comparison.

**Doppler Gain**

Optimal gain settings should be obtained for accurate Doppler assessment (Fig. 1-31). Too low of a gain can result in underestimation of the peak velocity. Too high of a gain results in artifactual spectral broadening and can result in overestimation of the peak velocity.

**FIGURE 1-31** A. Spectral Doppler gain. A. Undergain. B. Optimal gain. C. Overgain.

**Basic Steps for Doppler Imaging**

1. Optimize the gray-scale image with the focal zone at the intended blood vessel.
2. Activate the Color Doppler.
3. Position the color box over the vessel (keep the box size as small as reasonably possible).
4. Steer the color box to align with blood flow.
5. Choose the appropriate velocity scale.
6. Optimize the Color Doppler gain.
7. Place the Pulsed-Wave Doppler cursor within the vessel lumen, and adjust the sample volume as required (try to avoid the vessel walls).
8. Align the angle-correction cursor with the blood flow. If the Doppler angle is more than 60 degrees, reposition the transducer to obtain a smaller Doppler angle.
10. Optimize the Spectral Doppler velocity scale, baseline, and gain.

**Suggested Reading**

CHAPTER 2

Sonoanatomy Relevant for Ultrasound-Guided Upper Extremity Nerve Blocks

Introduction

The neural innervations of the upper extremity provide unique opportunities for a wide selection of neural blockade options that can be tailored to the desired outcome needed for anesthesia or analgesia of the extremity.

Gross Anatomy

The brachial plexus traverses the posterior triangle of the neck and the axilla. It provides complete innervation to the upper extremity. Proximally, the brachial plexus originates from the ventral primary rami of the cervical spinal nerves (C5–T1) (Figs. 2-1 and 2-2) and extends from the cervical spinal roots in the neck to its terminal nerves in the axilla (Fig. 2-3). The C5 and C6 rami unite to form the superior trunk, the C7 rami forms the middle trunk, and the C8 and T1 rami unite to form the inferior trunk (Fig. 2-4). The trunks of the brachial plexus are located in the interscalene groove between the scalenus anterior and the scalenus medius muscles, at the level of the cricoid cartilage (approximate C6 vertebral body level) and deep to the sternocleidomastoid muscle (Fig. 2-5). The anterior tubercle of the C6 vertebra is the most prominent of all the vertebrae (Chassaignac’s tubercle), and the C7 transverse process lacks the anterior tubercle. This feature can be used to sonographically identify the C7 nerve root. At the root level, the plexus gives off the dorsal scapular nerve and the long thoracic nerve (Fig. 2-4).
FIGURE 2-1  Anatomical illustration showing the formation of the brachial plexus. The roots, trunks, and divisions of the brachial plexus have been represented using different colors to illustrate the formation of the cords and the terminal branches of the plexus.

FIGURE 2-2  A magnetic resonance neurography (MRN) image of the brachial plexus showing the formation of the brachial plexus in a healthy young volunteer.
FIGURE 2-3 Brachial plexus. Note the formation of the plexus and the relation of the nerve roots to the transverse process of the cervical vertebra.
FIGURE 2-4 The brachial plexus and relation of its components to the subclavian and axillary artery.
FIGURE 2-5 Brachial plexus and its relation to the scalene muscles. Note how the brachial plexus is sandwiched between the anterior and middle scalene muscles.

At the supraclavicular fossa, the trunks of the brachial plexus are superficial and divide into their anterior and posterior divisions and reunite as the cords distal to the clavicle. The trunks and divisions lie above the first rib between the scalenus anterior and scalenus medius muscles (Fig. 2-6). The subclavian artery crosses over the top of the first rib at this point as it exits the thoracic inlet and travels in the fascial plane between the scalenus anterior and the scalenus medius and is anteromedial to the trunks and divisions of the brachial plexus at this level (Fig. 2-6). The subclavian vein crosses the first rib lying anteriorly to the insertion of the scalenus anterior (Fig. 2-7). The pleura lies immediately deep to the first rib. At the trunk level, the plexus gives off the nerve to the subclavius and suprascapular nerve.
Anatomy of the brachial plexus at the interscalene groove and supraclavicular fossa. Note the relation of the suprascapular and transverse cervical artery to the brachial plexus. SA, subclavian artery; SV, subclavian vein; IJV, internal jugular vein.

Brachial plexus at the supraclavicular fossa. Note the relation of the trunks of the brachial plexus to the first rib, subclavian artery, and the scalene muscles. The trunks and divisions of the brachial plexus are located posterolateral to the subclavian artery. SA, subclavian artery; SV, subclavian vein.

Lateral to the first rib the six divisions of the brachial plexus regroup to form the three cords of the brachial plexus. The posterior cord is formed from the three posterior divisions (C5–C8 and T1), the lateral cord from the anterior division of the upper and middle trunk (C5–C7), and the medial cord is a continuation of the anterior division of the lower trunk (C8 and T1). The cords then enters the “costoclavicular space” (CCS, Fig. 2-8), which is located deep and posterior to the middle-third of the clavicle.¹² Within the CCS the cords are
clustered together lateral to the axillary artery and between the clavicular head of the pectoralis major muscle and the subclavius muscle anteriorly, and the serratus muscle overlying the second rib posteriorly (Figs. 2-8 and 2-9). The topography of the cords relative to the axillary artery and to one another is consistent at the CCS (Figs. 2-9 to 2-11). The lateral cord is the most superficial of the three cords and always lies anterior to both the medial and posterior cords (Figs. 2-9 to 2-11). The medial cord is directly posterior to the lateral cord but medial to the posterior cord (Fig. 2-9 to 2-11). The posterior cord is the most lateral of the three cords at the CCS, and it is immediately lateral to the medial cord but posterolateral to the lateral cord (Figs. 2-9 to 2-11). The cords then descend to the lateral infraclavicular fossa, deep to the pectoralis minor muscle, where they occupy their respective position relative to the second part of the axillary artery (Fig. 2-12). The posterior cord is located posterior to the artery, the lateral cord lies in the superolateral aspect of the artery, and the medial cord lies in the inferomedial aspect of the artery. Position of the cords at the lateral infraclavicular fossa is variable and affected by the position (abduction) of the arm. The lateral cord gives off the lateral pectoral nerve, musculocutaneous nerve and lateral root of median nerve; the posterior cord gives off the upper and lower subscapular nerves, the thoracodorsal nerve, radial nerve, and axillary nerve; the medial cord gives off the medial pectoral nerve, the medial cutaneous nerve of the arm, medial cutaneous nerve of the forearm, ulnar nerve, and medial root of the median nerve.

**FIGURE 2-8** Sagittal anatomic section through the midpoint of the clavicle showing the costoclavicular space between the pectoral head of the pectoralis major and subclavius muscle anteriorly and the upper slips of the serratus anterior muscle overlying the second rib posteriorly. Note how the cords of the brachial plexus are clustered together and lie cranial to the first part of the axillary artery. AA, axillary artery; AV, axillary vein.
FIGURE 2-9 Transverse anatomic section through the right costoclavicular space showing the anatomic arrangement and relations of the cords of the brachial plexus. The anatomy is presented as though one were looking at it from caudal to cranial (caudocranial view). Note how the cords of the brachial plexus are clustered together lateral to the axillary artery.

FIGURE 2-10 Histological section from the right costoclavicular space, stained with hematoxylin and eosin, showing the anatomic arrangement and relations of the cords of the brachial plexus (caudocranial view) to one another and to the axillary artery.
The main terminal branches of the brachial plexus—median, radial, ulnar, and musculocutaneous nerve—leave the axilla with the axillary artery (Fig. 2-13) and continue their course into the arm (Fig. 2-14). At the anterior axillary fold, the musculocutaneous nerve leaves the brachial plexus and travels between the biceps brachii and the coracobrachialis in the proximal arm and subsequently between the biceps brachii and the brachialis in the midarm. Just before the cubital fossa, it emerges on the lateral border of the biceps tendon and pierces the deep fascia to become superficial and continue its course down the lateral aspect of the forearm as the lateral cutaneous nerve of the forearm.
FIGURE 2-13  Anatomy of the axilla at the level of the anterior axillary fold (ie, where the pectoralis major muscle joins the biceps muscle). Note the relation of the median, ulnar, and radial nerve to the axillary artery and how the musculocutaneous nerve (MCN) is embedded within the substance of the coracobraclialis muscle. AA, axillary artery; AV, axillary vein.

FIGURE 2-14  Anatomical illustration showing the terminal branches of the brachial plexus as they course through the arm and upper forearm.

Brachial Plexus: Interscalene Groove

Gross Anatomy
In the posterior triangle, the roots and trunks of the brachial plexus lie between scalenus anterior and medius muscles (Figs. 2-15 and 2-16). As the cervical nerve root (C3–C6) exits from the intervertebral foramen, it travels between the anterior and posterior tubercle of the corresponding cervical vertebra (Figs. 2-17 and 2-18). This unique feature can be easily demonstrated using ultrasound. Deep to the cervical nerve root, the vertebral artery travels in the foramen transversarium (Fig. 2-17) of the C6 to C1 vertebrae and ascends cranially.

**FIGURE 2-15** Coronal anatomical section showing the roots, trunks, divisions, and cords of the brachial plexus. SCM, sternocleidomastoid muscle; VA, vertebral artery; SA, subclavian artery.

**FIGURE 2-16** Transverse anatomical section of the neck showing the brachial plexus sandwiched between the scalenus anterior and scalenus medius muscles in the interscalene groove. SCM, sternocleidomastoid muscle; IJV, internal jugular vein; CA, carotid artery.
FIGURE 2-17 Transverse anatomical section of the neck through the C6 vertebral body showing the anterior and posterior tubercle of the C6 transverse process. Note how the C6 nerve root exits the intervertebral foramen and the location of the vertebral artery in the foramen transversarium.

FIGURE 2-18 Transverse anatomical section of the neck through the C7 vertebral body showing the C7 transverse process with only one (posterior) tubercle. The anterior tubercle is missing.

Computed Tomography Anatomy of the Neck and Interscalene Region

Figs. 2-19 and 2-20
FIGURE 2-19 CT image of the cervical region at the level of C6. Note the C6 nerve root as it exits the intervertebral foramen and lies between the anterior and posterior tubercle of the C6 transverse process before it enters the interscalene groove. Also note the vertebral artery in the foramen transversarium of C6 vertebra. SCM, sternocleidomastoid muscle; IJV, internal jugular vein; NR, nerve root; VB, vertebral body; VA, vertebral artery.

FIGURE 2-20 CT image of the cervical region at the level of C7. Note the vertebral artery in close proximity to the C7 nerve root before it enters the foramen transversarium of C6. VA, vertebral artery; NR, nerve root; ScA, scalenus anterior; ScM, scalenus medius; ISG, interscalene groove; TP, transverse process; SCM, sternocleidomastoid; IJV, internal jugular vein.

Magnetic Resonance Imaging Anatomy of the Neck and Interscalene Region
Figs. 2-21 and 2-22

FIGURE 2-21 MRI image of the neck at the level of C6 vertebra. Note the C6 nerve root (NR) between the anterior and posterior tubercle of the C6 transverse process and the C5 nerve root in the interscalene groove between the scalenus anterior (ScA) and scalenus medius (ScM) muscle. The vertebral artery (VA) is seen in the foramen transversarium of the C6 transverse process. VB, vertebral body; CA, carotid artery; SCM, sternocleidomastoid; IJV, internal jugular vein.

FIGURE 2-22 MRI image of the neck at the level of C7 vertebra. Note the vertebral artery in close proximity of the C7 nerve root before it enters the foramen transversarium of C6 vertebra. The nerve roots (C6 and C7) of the brachial plexus are seen in the interscalene groove (ISG) between the scalenus anterior (ScA) and the scalenus medius (ScM) muscle. VA, vertebral artery; NR, nerve root; SCM, sternocleidomastoid; IJV, internal jugular vein;
Technique of Ultrasound Imaging of the Brachial Plexus at the Interscalene Groove

1. Position:
   a. Patient: Supine or semisitting position with head turned to the contralateral side (Fig. 2-23). The head rests on a low pillow with the arm adducted by the side.

   ![Figure 2-23](image)
   Figure showing the position of the patient and the ultrasound transducer during a transverse scan of the neck at the level of the interscalene groove. Note how the ultrasound transducer is tilted (oblique) slightly caudally towards the supraclavicular fossa.

   a. Patient: Supine or semisitting position with head turned to the contralateral side (Fig. 2-23). The head rests on a low pillow with the arm adducted by the side.

   b. Operator and ultrasound machine: Operator is positioned at the head end of the patient. The ultrasound machine is placed ipsilateral to the side examined and directly in front. The position of the operator and ultrasound machine can be easily reversed for convenience or, for example, to allow a right-handed operator to perform an ultrasound-guided interscalene brachial plexus block on the left side using his or her right hand.

2. Transducer selection: High-frequency (15-8 or 17-5 MHz) linear array transducer.

3. Scan technique: As part of a scan routine, it is advisable to start the ultrasound scan of the neck by placing the transducer in the midline (Fig. 2-24) at the level of the cricoid cartilage (C6). Place the transducer in a transverse orientation to image the cricoid cartilage (Fig. 2-25) or trachea (Fig. 2-26) in cross-section. Slide the transducer laterally to the side of interest, and identify the sternocleidomastoid muscle, trachea, thyroid, carotid artery, and internal jugular vein. Continue to manipulate the transducer laterally in the transverse plane to the lateral edge of the sternocleidomastoid muscle. The scalenus anterior and scalenus medius with the interscalene groove are located deep to the lateral edge of the sternocleidomastoid muscle (Figs. 2-27 and 2-28). Alternatively one can perform a transverse scan of the subclavian artery at the supraclavicular fossa (see later). The trunks and divisions of the brachial plexus are seen as a cluster of hypoechoic and
rounded nodules on the posterolateral aspect of the subclavian artery, like a “bunch of grapes,” and between the scalenus anterior and scalenus medius muscles. Now slowly slide the transducer cephalad with a sweeping action when the roots and/or trunks of the brachial plexus are clearly delineated in the interscalene groove.

**FIGURE 2-24** Figure showing the position of the patient and the ultrasound transducer during a transverse scan of the neck in the midline at the level of the cricoid cartilage.

**FIGURE 2-25** Transverse sonogram of the neck at the level of the cricoid cartilage (CC). The CC is seen as an “inverted-U” or arched shaped structure. The inner surface of the anterior wall of the CC is lined by the bright air-mucosal interface (AMI), and the two lobes of the thyroid gland are seen as uniformly hyperechoic structures lateral to the CC. The posterior wall of the CC is obscured by an air column and reverberation artifacts, but one can identify the cricothyroid junction (CTJ) as a hypoechoic gap in the posterolateral wall of the CC. SM, strap muscles; CA, carotid artery.
FIGURE 2-26 Transverse sonogram of the neck at the level of the upper trachea. The trachea appears hypoechoic, is “U-shaped,” and is outlined by the bright A-M interface anteriorly. However, unlike at the level of the cricoid cartilage the thyroid isthmus is seen anterior to the trachea, and the cervical esophagus may also be identified posterolateral and to the left of the trachea. SCM, sternocleidomastoid muscle; IJV, internal jugular vein; CA, carotid artery.

FIGURE 2-27 Anatomical section of the neck showing the brachial plexus sandwiched between the scalenus anterior and scalenus medius muscles in the interscalene groove. IJV, internal jugular vein; CA, carotid artery.
4. **Sonoanatomy:** At the interscalene groove, the trunks of the brachial plexus are located between the scalenus anterior and the scalenus medius muscles (Fig. 2-29). They appear round to oval in shape, are hypoechoic in appearance, and may have a hyperechoic rim (Fig. 2-30). The carotid artery and internal jugular vein are visualized medially, and the vertebral artery can also be seen adjacent to the C7 transverse process deep to the interscalene groove (Fig. 2-29).
anterior surface of scalenus anterior muscle.

FIGURE 2-30 Zoomed (coned) view of the interscalene groove showing the hypoechoic roots and trunks of the brachial plexus sandwiched between the scalenus anterior and scalenus medius muscles. Also note the hypoechoic phrenic nerve on the anterior surface of the scalenus anterior.

5. Clinical Pearls: The trunks of the brachial plexus are best visualized within the interscalene groove just below the level of the cricoid cartilage. They appear as three hypoechoic round-to-oval shaped structures, which produce a sonographic pattern resembling “traffic signal lights.” If one traces these neural elements medially and proximally to their intervertebral foramen, each of the cervical nerve roots can be identified as they lie anterior to the corresponding transverse processes. The roots of the brachial plexus are best visualized at the C6 (Fig. 2-31) or C7 (Fig. 2-32) vertebral level. The C6 transverse process is distinctive, as it is the first cervical vertebra counting from below, which has two tubercles (anterior and posterior, Fig. 2-31) on the transverse process. C3 to C6 cervical vertebrae have both the anterior and posterior tubercle on the transverse process. The C7 transverse process has only one tubercle (the anterior tubercle is rudimentary or absent), and this is typically posterior to the nerve root (Fig. 2-32). As a result of the two tubercles, the transverse processes of the lower cervical vertebrae (C3–C6) produce a “U” shaped or “fish mouth” pattern on the sonogram (Fig. 2-31). The resultant sonographic pattern has also been referred to as the “two-humped camel” sign. The corresponding nerve roots can be visualized, coursing within the groove formed by the anterior and posterior tubercle just before they enter the neural foramen, by sliding the transducer proximally and distally. During the sliding maneuver, the vertebral artery can be visualized in the space between two adjacent transverse processes (intertransverse space). This can be confirmed using Color or Power Doppler. The vertebral artery is best visualized at the C7 vertebral level because of the absence of the anterior tubercle on the transverse process (Fig. 2-32). Alternatively the vertebral artery can be visualized by performing a sagittal scan at the level of transverse process through the intertransverse space (Fig. 2-33). The phrenic nerve may be seen on the anterior surface of the scalenus
anterior (Figs. 2-29 and 2-30) as a small hypoechoic structure, and its identity can be confirmed by tracing the nerve proximally and distally along its course, also referred to as the “trace back technique.” It is also common to visualize vascular structures at the base of the posterior triangle of the neck. These may be the inferior thyroid artery, vertebral artery, suprascapular artery (see later), or the transverse cervical artery (Fig. 2-34). Verifying their course and origin allows one to confirm the identity of the artery. The superficial cervical plexus may also be visualized as a small collection of hypoechoic nerves deep to or lateral to the sternocleidomastoid muscle.

![Transverse sonogram of the neck at the level of the C6 transverse process.](image)

**FIGURE 2-31** Transverse sonogram of the neck at the level of the C6 transverse process. Note the anterior and posterior tubercles of the C6 transverse process and the roots of the hypoechoic C5 and C6 nerve root. The outlines of the anterior and posterior tubercles of the C6 transverse have been highlighted in the sonogram. Also note the location of the vertebral artery (VA) relative to the transverse process. IJV, internal jugular vein; CA, carotid artery; VA, vertebral artery; NR, nerve root.
FIGURE 2-32  ■ Transverse sonogram of the neck at the level of the C7 transverse process. Note the transverse process of C7 has only one tubercle (ie, the posterior tubercle). The anterior tubercle is missing or very rudimentary. Also note the C6 and C7 nerve roots and the location of the vertebral artery (VA) relative to the transverse process. The outlines of the posterior tubercle of the C7 transverse have been highlighted in the sonogram. IJV, internal jugular vein; CA, carotid artery; NR, nerve root.

FIGURE 2-33  ■ Sagittal sonogram of the neck demonstrating the vertebral artery through the space (intertransverse space) between the C4 and C5 transverse process (TP).
FIGURE 2-34 Transverse sonogram of the neck at the level of the interscalene groove (A, without and B, with Color Doppler) showing the transverse cervical artery, which is a branch of the thyrocervical trunk. It crosses the neck from a medial to lateral direction lying anterior to the scalene muscles and in front or in between the divisions of the brachial plexus.

Assessment of Diaphragm Excursions

Ultrasound imaging is a safe, simple, and accurate method of evaluating diaphragmatic function (excursion) in patients with diaphragmatic paresis or paralysis. In regional anesthesia ultrasound imaging can be used to evaluate phrenic nerve involvement by assessing diaphragmatic excursion after an interscalene brachial plexus block. A 5-2 MHz curved array transducer is used, and a B-mode ultrasound scan is initially performed with the patient in the supine position. A transverse scan of the subcostal region is performed with the ultrasound transducer placed between the midclavicular and midaxillary line. The liver or spleen (on the left side) provides the acoustic window for the ultrasound scan. For optimal imaging the ultrasound transducer is also directed cranially, posteriorly, and medially to image the posterior third of the diaphragm. Once an optimal B-mode image is obtained, the M-mode function is activated, with the M-mode line passing through the diaphragm (Fig. 2-35). Resting or forced diaphragmatic excursion after the “sniff test” (rapid nasal inspiration with the mouth closed) can then be assessed.
FIGURE 2-35 Figure showing the use of M-mode ultrasound to evaluate diaphragmatic excursion. Note the M-mode line passes through the right lobe of the liver, diaphragm, and part of the lung posteriorly in the B-mode image. The M-mode trace (below) shows the excursion of the liver, diaphragm (hyperechoic line), and lung toward the transducer along this line with time.

Brachial Plexus: Supraclavicular Fossa

Gross Anatomy

At the supraclavicular fossa, the brachial plexus is relatively superficial and lies beneath the subcutaneous tissue and the inferior belly of the omohyoid. The trunks and division of the brachial plexus are seen as a cluster of nerves on the posterolateral aspect (Figs. 2-6, 2-7, 2-15, and 2-36) of the subclavian artery (Figs. 2-4 to 2-7). The subclavian artery lies on top of the first rib (Fig. 2-36), and the subclavian vein is anterior to the scalenus anterior muscle (Figs. 2-6 and 2-7).
Coronal anatomical section through the supraclavicular fossa. Note the relation of the components of the brachial plexus to the scalene muscles, subclavian artery, and the first rib at the supraclavicular fossa. SCM, sternocleidomastoid muscle; IJV, internal jugular vein; SA, subclavian artery.

**Computed Tomography Anatomy of the Supraclavicular Fossa**

Fig. 2-37

Sagittal CT image showing the subclavian artery on top of the first rib and the close relation of the components of the brachial plexus to the first rib, lung, and scalene muscles.
Magnetic Resonance Imaging Anatomy of the Supraclavicular Fossa

Fig. 2-38

![Coronal MRI image showing the close relation of the components (trunks and divisions) of the brachial plexus to the first rib, lung, subclavian artery, and the scalene muscles.]

Technique of Ultrasound Imaging of the Brachial Plexus at the Supraclavicular Fossa

1. **Position:**
   a. **Patient:** Supine position with head turned to the contralateral side. Position the head on a low pillow with the arm adducted by the side. A small roll or jelly pad placed under the shoulder may be helpful, as it increases the distance between the bed and the transducer. This facilitates needle placement and manipulation during an in-plane approach for supraclavicular brachial plexus block.
   b. **Operator and ultrasound machine:** The operator sits or stands at the head end of the patient. The ultrasound machine is placed ipsilateral to the side to be examined and directly in front of the operator.

2. **Transducer selection:** High-frequency (15-8 or 17-5 MHz) linear array transducer.

3. **Scan technique:** The transducer is placed parallel to the clavicle in the supraclavicular fossa (Fig. 2-39). The ultrasound beam is directed towards the first rib and thoracic inlet (Fig. 2-40). The first reference structure to locate is the subclavian artery as it crosses the first rib.
4. Sonoanatomy: At the supraclavicular fossa the trunks and divisions of the brachial plexus appear as a cluster of hypoechoic nodules, each with a hyperechoic rim (Fig. 2-41). Collectively, they appear as a “bunch of grapes” on the posterolateral aspect of the subclavian artery. Variations in this relationship have been described with the brachial plexus located farther laterally in relation to the subclavian artery. The subclavian artery is pulsatile, can be demonstrated using Color Doppler, and is seen on top of the first rib. The first rib appears hyperechoic and is associated with an acoustic shadow (Fig.
2-41). The pleura is hyperechoic, deep to or on either side of the first rib, and exhibits the typical “lung sliding” sign.\textsuperscript{14}

\textbf{FIGURE 2-41} Transverse sonogram of the suprACLavicular fossa. The trunks and divisions of the brachial plexus are visualized like a “bunch of grapes” on the posterolateral aspect of the subclavian artery. SA, subclavian artery; IJV, internal jugular vein.

5. \textbf{Clinical Pearls:} With the transducer placed as described earlier and the subclavian artery visualized, optimization of the image to best visualize the brachial plexus is achieved with the tilting maneuver. The subclavian vein can often be seen lying on top of the pleura medially. It is also common to visualize one or more small arteries in this area. These are the suprascapular artery (Fig. 2-42) and the transverse cervical artery (Figs. 2-6 and 2-34).\textsuperscript{15}
FIGURE 2-42 Doppler sonogram of the supraclavicular fossa demonstrating the suprascapular artery as it courses through the trunks and divisions of the brachial plexus. SA, subclavian artery; IJV, internal jugular vein.

Brachial Plexus: Infraclavicular Fossa

Gross Anatomy

The infraclavicular fossa can be divided into two main areas: (1) the medial infraclavicular fossa (MICF), which extends from the lateral border of the first rib cranially to the superior (medial) border of the pectoralis minor muscle inferiorly, and (2) the lateral infraclavicular fossa (LICF), which lies deep to the pectoral muscles and in relation to the second part of the axillary artery. At the MICF, the cords of the brachial plexus emerge from under the clavicle and enter the CCS lying deep to the pectoralis major (clavicular head) and subclavius muscle anteriorly and the upper slips of the serratus anterior muscles posteriorly (Figs. 2-8 and 2-9). The cords of the plexus are clustered together lateral to the first part of the axillary artery (Figs. 2-9 to 2-11).1–3 This anatomical arrangement of the cords at the CCS makes it a suitable site for brachial plexus block (costoclavicular BPB).2 Very few BPB techniques have been described at the medial infraclavicular fossa.16,17 This may be due to the close proximity of the pleura to the plexus and the fear of inadvertent pleural or pulmonary puncture. As the plexus descends laterally towards the axilla, the cords of the brachial plexus are closely related to the second part of the axillary artery. They lie deep to the pectoralis major and minor muscles and anterior to the subscapularis muscle (Fig. 2-43). At the paracoracoid location or LICF, the cords of the brachial plexus have taken up their respective position around the axillary artery (Figs. 2-43 and 2-44). Generally, the lateral cord is superior, the posterior cord is posterior, and the medial cord is caudal to the axillary artery, respectively (Figs. 2-12 and 2-43). The position of the individual cords of the plexus can vary with the position of the arm (abduction or adduction).5 Also the pleura and lung are not part of the posterior relation of the brachial plexus at the LICF (Fig. 2-44). Therefore it is a popular site for infraclavicular BPB,18 as pleural puncture is thought to be unlikely. However, inadvertent pleural puncture has been reported,19 which may be due to the block needle being inserted more medially than intended19 when the pleura and lung are posterior to the axillary artery and brachial plexus (Fig. 2-44). Pleural complications should be avoidable with ultrasound guidance.
FIGURE 2-43 Sagittal anatomical section of the infraclavicular fossa from just medial and inferior to the coracoid process (paracoracoid). AA, axillary artery.

FIGURE 2-44 Sagittal anatomical section of the infraclavicular fossa from between the midpoint of the clavicle and the coracoid process (ie, between the medial infraclavicular fossa and the paracoracoid location). Note that the pleura and lung are visualized posteriorly at this...
Computed Tomography Anatomy of the Infraclavicular Fossa

Figs. 2-45 to 2-48

**FIGURE 2-45** Transverse CT image of the medial infraclavicular fossa showing the relation of the cords of the brachial plexus to the axillary vessels and the cephalic vein.

**FIGURE 2-46** Sagittal CT image of the medial infraclavicular fossa at the level of the midpoint of the clavicle. Note the relationship of the pectoralis major and subclavius muscles to the neurovascular bundle and how the cords of the brachial plexus are clustered on the superior aspect of the axillary artery.
FIGURE 2-47  Sagittal CT image of the infraclavicular fossa from midway between the midpoint of the clavicle and the coracoid process. AA, axillary artery; AV, axillary vein.

FIGURE 2-48  Sagittal CT image of the infraclavicular fossa from immediately medial to the coracoid process (paracoracoid location). Note the relationship of the cords of the brachial plexus to the second part of the axillary artery. AA, axillary artery; AV, axillary vein.

Magnetic Resonance Imaging Anatomy of the Infraclavicular Fossa

Figs. 2-49 to 2-52
FIGURE 2-49  Transverse (axial) MRI image of the medial infraclavicular fossa.

FIGURE 2-50  Sagittal MRI image of the brachial plexus at the medial infraclavicular fossa. AA, axillary artery; AV, axillary vein.
**FIGURE 2-51** Sagittal MRI image of the brachial plexus at the infraclavicular fossa between the midpoint of the clavicle and the coracoid process. AA, axillary artery; AV, axillary vein.

**FIGURE 2-52** Sagittal MRI image of the brachial plexus at the lateral infraclavicular fossa.
Technique of Ultrasound Imaging of the Brachial Plexus at the Medial Infraclavicular Fossa

1. Position:
   a. **Patient:** Supine with the ipsilateral arm abducted (90 degrees) and the head turned slightly to the contralateral side.
   b. **Operator and ultrasound machine:** The operator is positioned at the head end of the patient. The ultrasound machine is placed on the ipsilateral side to be examined and directly in front.

2. Transducer selection: High-frequency linear array transducer (12-5 or 15-8 MHz).

3. Scan technique:
   a. **Transverse scan of the MICF:** Transverse scan of the MICF is performed in five sequential steps, over five contiguous sites (Fig. 2-53). This is done to better define the anatomy of the CCS and the neighboring structures that are relevant for infraclavicular BPB.

![Illustration showing the positions of the ultrasound transducer during the ultrasound scan sequence at the medial infraclavicular fossa (MICF). Note that positions 1 to 5 are over contiguous sites over the MICF and in the order in which the scan is performed.](image)

**Step 1:** The transducer is positioned directly over the midpoint of the clavicle in the transverse orientation (Fig. 2-54) with its orientation marker directed laterally (outwards). The clavicle is visualized as a curved hyperechoic structure with an underlying acoustic shadow (Fig. 2-55).
**FIGURE 2-54** Figure showing the position and orientation of the ultrasound transducer during a transverse ultrasound scan for the brachial plexus at the medial infraclavicular fossa and the costoclavicular space.

**FIGURE 2-55** Figure demonstrating the transverse sonographic view of the clavicle as obtained during Step 1 of the transverse ultrasound scan sequence at the medial infraclavicular fossa (MICF).

**Step 2:** The transducer is gently moved caudally until it slips off the inferior border of the clavicle and the axillary artery (first part) and vein are visualized. It may be necessary to gently tilt the transducer cephalad to direct the ultrasound beam towards the CCS, that is, the space between the posterior surface of the clavicle and the second rib (Figs. 2-56 to 2-59). The ultrasound image is optimized until all three cords of the brachial plexus are clearly visualized lateral to the axillary artery (Figs. 2-56 and 2-58). If the ultrasound image is less than optimal, the medial end of the ultrasound transducer should be gently pivoted caudally to try and insonate the ultrasound beam at right angles to the cords and
thus minimize anisotropy (Fig. 2-56).

**FIGURE 2-56** Transverse sonogram of the medial infraclavicular fossa immediately below the midpoint of the clavicle (Step 2 of the transverse ultrasound scan sequence) demonstrating the cords of the brachial plexus in the costoclavicular space. Note the arm of the subject is abducted and the three cords are clustered together lateral to the axillary artery (AA). Accompanying photographs illustrate the position and orientation of the ultrasound transducer during the scan.

**FIGURE 2-57** Figure highlighting the anatomical structures that are insonated during a transverse ultrasound scan for the brachial plexus at the medial infraclavicular fossa below the midpoint of the clavicle. AA, axillary artery.
FIGURE 2-58  Transverse sonogram of the medial infraclavicular fossa immediately below the midpoint of the clavicle (Step 2 of the transverse ultrasound scan sequence) demonstrating the cords of the brachial plexus in the costoclavicular space. Note the relationship of the cords to one another and to the axillary artery.

FIGURE 2-59  Coned (zoomed) view of the right costoclavicular space demonstrating the cords of the brachial plexus within the costoclavicular space and lying lateral to the axillary artery. Note the relationship of the cords to one another and to the axillary artery.

**Step 3:** The transducer is then gently manipulated laterally, maintaining the same transverse orientation and applying minimal pressure over the area scanned, until the cephalic vein is visualized (Figs. 2-60 and 2-61).
FIGURE 2-60  Transverse oblique sonogram of the right medial infraclavicular fossa (MICF) from just distal to the costoclavicular space (Step 3 of the transverse scan sequence). Note how the cephalic vein arches over the cords of the brachial plexus and the axillary artery to join the axillary vein from a lateral to medial direction. PM, pectoralis major muscle; CV, cephalic vein; AA, axillary artery; AV, axillary vein.

FIGURE 2-61  Transverse oblique sonogram (zoomed view) of the medial infraclavicular fossa (MICF) showing the cephalic vein joining the axillary vein. Note the cords of the brachial plexus are located posterior to the cephalic vein and lateral to the axillary artery.

**Step 4:** From this position the transducer is manipulated further laterally until the
The thoracoacromial artery (TAA) is seen to emerge from the axillary artery (second part) (Figs. 2-62 and 2-63).

**FIGURE 2-62** Transverse oblique sonogram of the medial infraclavicular fossa (MICF) immediately below the level of the cephalic vein (Step 4 of the transverse scan sequence) demonstrating the origin and division of the thoracoacromial artery (TAA). The TAA may be seen as one or more vessels because it divides into four (clavicular, acromial, deltoid, and pectoral) branches close to the upper border of the pectoralis minor (Pm) muscle. PM, pectoralis major muscle; AA, axillary artery; AV, axillary vein.

**FIGURE 2-63** Transverse oblique sonogram of the upper part of the lateral infraclavicular...
fossa (LICF) close to the upper border of the pectoralis minor muscle (Step 5 of the transverse scan sequence). Note the thoracoacromial artery (TAA) is seen as a single vessel (close to its origin) in this sonogram. The cords of the brachial plexus are also seen as a cluster of nerves lying lateral and superolateral to the axillary artery (second part). The TAA may be confused for the medial cord in the upper part of the LICF.

**Step 5:** The ultrasound transducer is manipulated further laterally to the LICF (Fig. 2-64).

![LICF Sagittal scan](image)

**FIGURE 2-64** Sagittal sonogram of the lateral infraclavicular fossa (LICF). Note the lateral and posterior cords are visualized above the axillary artery (second part). Also the thoracoacromial artery (TAA) is identified as a round, hypoechoic structure between the axillary artery and vein, and may be confused for the medial cord unless one used Doppler ultrasound.

**b. Sagittal scan of the MICF:** A sagittal scan of the MICF can be performed with the ultrasound transducer (a) at right angles to the midpoint of the clavicle (Figs. 2-65 to 2-67) or (b) with the ultrasound transducer parallel to (or in line with) the neurovascular structures (Figs. 2-68 to 2-70). From each of these positions the ultrasound transducer is gently manipulated laterally (ie, towards the shoulder) to view the related anatomy.
FIGURE 2-65 Figure showing the position and orientation of the ultrasound transducer during a sagittal ultrasound scan of the medial infraclavicular fossa immediately below the midpoint of the clavicle.

FIGURE 2-66 Sagittal sonogram of the medial infraclavicular fossa immediately below the midpoint of the clavicle showing the cords of the brachial plexus clustered together above the axillary artery and in a triangular space (costoclavicular) bound by the clavicular head of pectoralis major and subclavius muscle anteriorly, and the serratus anterior muscle posteriorly, the axillary artery inferiorly, and the inferior surface of the clavicle superiorly. AA, axillary artery; AV, axillary vein.
FIGURE 2-67 Sagittal sonogram of the medial infraclavicular fossa lateral to the position described earlier (Fig. 2-66). Note how the cords of the brachial plexus (BP) are clustered together and located above the axillary artery in a space (costoclavicular) bound by the inferior surface of the clavicle superiorly, the axillary artery inferiorly, the subclavius muscle anteriorly, and the serratus anterior muscle posteriorly. The cephalic vein (CV) is located anterior to the axillary artery. AA, axillary artery; AV, axillary vein.

FIGURE 2-68 Sagittal sonogram of the medial infraclavicular fossa showing the cephalic vein joining the axillary vein. Note how the cords of the brachial plexus are clustered together posterior to the cephalic vein and superior to the axillary artery. The position of the cephalic vein relative to the cords of the brachial plexus in the sagittal sonogram often precludes safe needle insertion at this level.
FIGURE 2-69 Sagittal sonogram of the medial infraclavicular fossa with the ultrasound transducer placed parallel (in-line) to the axillary vein (Step 1 of the sagittal scan sequence). Note the axillary vein lies between the subclavius muscle anteriorly and the serratus anterior (SA) muscle posteriorly at the costoclavicular space. Also the cephalic vein is seen joining the anterior wall of the axillary vein (AV) from above. PM, pectoralis major muscle. Accompanying photograph illustrates the position and orientation of the transducer during the ultrasound scan.
**FIGURE 2-70** Sagittal sonogram of the medial infraclavicular fossa (MICF) with the ultrasound transducer positioned parallel to the axillary artery (Step 2 of the sagittal scan sequence). Note the axillary artery (AA) enters the MICF by traversing the costoclavicular space between the clavicular head of the pectoralis major (PM) and subclavius muscle anterior and the upper slips of the serratus anterior (SA) muscle overlying the second rib posteriorly. The cephalic vein is also seen in the MICF anterior to the axillary artery. The thoracoacromial artery also originates from the axillary artery close to the upper border of the pectoralis minor muscle and ascends cranially before it divides into its four (clavicular, acromial, deltoid, and pectoral) branches. Accompanying photograph illustrates the position and orientation of the transducer during the ultrasound scan.

4. **Sonoanatomy of the MICF:**

   a. **Transverse sonoanatomy of the MICF:** On a transverse sonogram of the upper part of the MICF immediately below the midpoint of the clavicle (Step 2 of the transverse scan sequence), one can visualize the CCS between the clavicular head of the pectoralis major and subclavius muscle anteriorly and the serratus anterior muscle overlying the second rib posteriorly (Figs. 2-58 and 2-59). The first part of the axillary artery and the axillary vein appear as two hypoechoic round-to-oval structures within the CCS (Fig. 2-58). The axillary artery is pulsatile and located lateral to the axillary vein (Fig. 2-58). Deep to the axillary artery the upper slips of the serratus anterior muscle, second rib, intercostal muscles, and parietal pleura are clearly delineated (Fig. 2-59). The cords are clustered together lateral to the axillary artery, and they exhibit a consistent triangular topographical arrangement (Figs. 2-58 and 2-59). The lateral cord is the most superficial of the three cords and lies anterior to both the medial and posterior cords (Figs. 2-58 and 2-59). The medial cord is directly posterior to the lateral cord but medial to the posterior cord (Fig. 2-58). The posterior cord is the most lateral of the three cords at the CCS, and it is immediately lateral to the medial cord but posterolateral to the lateral cord (Figs. 2-58 and 2-59). In the transverse sonogram immediately lateral to the CCS (Step 3 of the transverse scan sequence), the cephalic vein is seen arching over the axillary artery to join the axillary vein from a lateral to medial direction (Figs. 2-60 and 2-61). The cephalic vein is easily compressible with pressure from the transducer, but the axillary artery is more resistant to compression. The cords of the brachial plexus are seen as a hyperechoic cluster of nerves that lie deep to the cephalic vein and lateral to the axillary artery (Figs. 2-60 and 2-61). Because the cephalic vein lies anterior to the cords, this ultrasound window is not ideal for performing BPB because of the risk of puncturing the cephalic vein. Also if one does see the cephalic vein in the ultrasound window during a costoclavicular BPB, then it implies that the transducer is positioned lower than the desired location. If one now slides or tilts the transducer slightly laterally from the scan position described earlier (Step 4 of the transverse scan sequence), the cephalic vein is no longer visible and the TAA, which is a branch of the axillary artery, is visualized (Figs. 2-62 and 2-63). It is seen emerging from the anterior surface of the axillary artery and may be seen either as two arteries (Fig. 2-62) or as a single vessel lying deep and close to the upper border of the pectoralis minor muscle (Fig. 2-63). From this position gentle lateral manipulation of the transducer will reveal the LICF where the cords of the brachial plexus are closely related to the second part of the axillary artery (Fig. 2-64).

   b. **Sagittal sonoanatomy of the MICF:** On a sagittal sonogram of the MICF, with the ultrasound transducer positioned at a right angle to the midpoint of the clavicle (Fig.
2-65), the cords of the brachial plexus are seen as multiple hypoechoic round to oval, structures each with a hyperechoic rim lying superior to the pulsatile axillary artery (Figs. 2-66 to 2-68). The cords lie within the CCS formed by the pectoralis major and subclavius muscle anteriorly and the upper slips of the serratus anterior muscle and chest wall posteriorly (Figs. 2-66 to 2-68). The axillary vein is located caudal to the axillary artery (Figs. 2-66 to 2-68), and the cephalic vein joins the axillary vein from above (Fig. 2-68). Deep to the serratus anterior muscle outlines of the anterior intercostal space and the hyperechoic pleura are clearly visualized. The arrangement of the cords in the sagittal sonogram is also consistent,20 with the lateral cord lying anterior to the medial cord, and the posterior cords lying superior to the medial and lateral cord (Figs. 2-66 to 2-68).

On a sagittal sonogram of the MICF, with the ultrasound transducer positioned parallel to the long axis of the neurovascular structures (Figs. 2-69 to 2-71) and from a medial to lateral direction, the axillary vein is the first structure visualized (Fig. 2-69). The axillary vein is hypoechoic, nonpulsatile, easily compressible, and lies on the anterior chest wall. The cephalic vein is also delineated and, after it traverses the gap between the clavicular head of the pectoralis major and the subclavius muscle, joins the axillary vein from above (Fig. 2-69). In the adjoining sagittal sonogram, the pulsatile axillary artery is visualized (Fig. 2-70). The axillary artery, after it emerges from the CCS, lies in the MICF, deep to the clavicular head of the pectoralis major muscle and above the superior border of the pectoralis minor muscle (Fig. 2-69). The cephalic vein lies anterior to the axillary artery at the MICF (Fig. 2-69). The axillary artery continues distally to enter the LICF, where it is located posterior to the pectoralis major and minor muscles (Fig. 2-70). The axillary artery also gives off the TAA from its anterior wall, and the latter ascends cranially, lying close to the posterior surface of the pectoralis minor muscle (Fig. 2-70). In the sagittal sonogram acquired immediately lateral and parallel to the axillary artery, the cords of the brachial plexus are visualized as longitudinal hyperechoic structures (Fig. 2-71) and lying within the CCS (close to the clavicle), MICF and LICF from a cranial to caudal direction (Fig. 2-71). At the MICF the cephalic vein and TAA (possibly the pectoral branch) lie anterior to the cords (Fig. 2-71). Due to the anatomic arrangement of the cords at the MICF (Figs. 2-10 and 2-11), all three cords of the brachial plexus are rarely visualized in a single sagittal sonogram. It is more common to visualize two cords, that is, the lateral cord lying anterior to the medial cord (Fig. 2-71).
FIGURE 2-71 — Sagittal sonogram of the medial infraclavicular fossa (MICF) with the ultrasound transducer positioned parallel to the axillary artery (Step 3 of the sagittal scan sequence). The cords of the brachial plexus are seen as hyperechoic longitudinal structures exiting the costoclavicular space to enter the MICF and then the lateral infraclavicular fossa deep to the pectoralis minor. Note the relationship of the cephalic vein (CV) and thoracoacromial artery (TAA) to the cords of the brachial plexus at the MICF. Accompanying photograph illustrates the position and orientation of the transducer during the ultrasound scan. PM, pectoralis major muscle; Pm, pectoralis minor muscle; SA, serratus anterior muscle.

5. **Clinical Pearls:** The CCS may offer advantages for BPB, and ultrasound-guided costoclavicular BPB has recently been described. At the CCS, and in contrast to that at the LICF, the cords of the brachial plexus are relatively superficial (2–3 cm) in location, they are clustered together lateral to the axillary artery, and they share a consistent anatomical relationship with one another and to the axillary artery. All three cords of the brachial plexus are also visualized in a single transverse sonogram of the MICF. Therefore, it is possible to produce BPB at the CCS using a single injection of a relatively low volume (20 mL) of local anesthetic, unlike that at the LICF where multiple injections and relatively large volumes of local anesthetics (up to 35 mL) are often required to produce an effective BPB. The CCS is also a useful site for catheter placement when a continuous BPB is planned for postoperative pain management, because the cords are close to one another. In our experience continuous BPB can be achieved via the CCS using very small volumes of local anesthetic for the infusion (eg, 4–5 mL/h of levobupivacaine 0.125%). However, currently there are limited published data on the safety and efficacy of BPB at the MICF. Overall, a medial approach may be desirable for BPB, but needle interventions at the MICF carry a definite risk of pleural puncture. Therefore, until more data on safety and efficacy are available, infraclavicular BPB techniques at the MICF should be considered an advanced technique and used with
caution because the lateral sagittal infraclavicular BPB technique, despite some of its limitations, is effective and has a long track record of safety.18,23

Ultrasound Imaging of the Brachial Plexus at the Lateral Infraclavicular Fossa

1. **Position:**
   a. **Patient:** Supine with the ipsilateral arm abducted (90 degrees) and the head turned slightly to the contralateral side.
   b. **Operator and ultrasound machine:** The operator is positioned at the head end of the patient. The ultrasound machine is placed on the ipsilateral side to be examined and directly in front.

2. **Transducer selection:** High-frequency linear array transducer (12-5 or 15-8 MHz). For ultrasound imaging of the LICF (paracoracoid location), we prefer to use a high-frequency linear array transducer (12-5 or 15-8 MHz, Fig. 2-72). However, in muscular or obese individuals, a high-frequency curved array transducer (eg, 8-5 MHz) with a small footprint may be preferable.

3. **Scan technique:** The transducer is positioned just below the clavicle and over the deltopectoral groove, medial and inferior to the coracoid process (Figs. 2-64 and 2-72). The first objective is to locate the axillary artery and vein. It may be necessary to gently tilt, slide, or rotate the transducer to obtain an optimal view of the axillary artery. Also during the scan it is possible to obtain a sagittal view of the LICF with (medial position, Figs. 2-73 and 2-74) or without (lateral position, Figs. 2-75 to 2-77) insonating the chest wall and pleura.

**FIGURE 2-72** Figure showing the position and orientation of the ultrasound transducer during a sagittal ultrasound scan of the lateral infraclavicular fossa immediately medial and inferior to the coracoid process (paracoracoid location).
FIGURE 2-73 Figure highlighting the anatomical structures that are insonated during a sagittal ultrasound scan for the brachial plexus immediately medial and inferior to the coracoid process (paracoracoid location). AA, axillary artery.

FIGURE 2-74 Sagittal sonogram of the lateral infraclavicular fossa midway between the midpoint of the clavicle and the coracoid process. Note the pleura is visible posteriorly and deep to the axillary artery and vein. AA, axillary artery; AV, axillary vein.
FIGURE 2-75 Figure highlighting the anatomical structures that are insonated during a sagittal ultrasound scan for the brachial plexus in the lateral infraclavicular fossa midway between the midpoint of the clavicle and the coracoid process (paracoracoid location). AA, axillary artery.

FIGURE 2-76 Sagittal sonogram of the lateral infraclavicular fossa with the ultrasound transducer placed immediately medial and inferior to the coracoid process. AA, axillary artery; AV, axillary vein.
FIGURE 2-77 Sagittal sonogram of the lateral infraclavicular fossa in chroma mode with the ultrasound transducer placed immediately medial and inferior to the coracoid process. Chroma mode using different shades of color (color maps) is often used to improve contrast resolution and therefore recognition of structures in an ultrasound image. AA, axillary artery; AV, axillary vein.

4. Sonoanatomy at the LICF: On a sagittal sonogram of the LICF (paracoracoid location), the axillary artery (second part) appears as a hypoechoic round-to-oval pulsatile structure under the pectoralis major and minor muscles (Figs. 2-76 and 2-77). The axillary vein is also hypoechoic, oval to elliptical in shape, and located caudal to the artery. The shape and size of the axillary vein may change during the respiratory cycle. The cords of the brachial plexus are closely related to the axillary artery. If one likens the cross-sectional image of the axillary artery to a clock face with its 12 o’clock position located anteriorly and the 6 o’clock position located posterior to the artery, then with the arm adducted at the shoulder, the lateral, medial, and posterior cords of the brachial plexus are most frequently observed in the 10 o’clock, 3 o’clock, and 6 o’clock positions, respectively (Figs. 2-76 and 2-77). Despite this relation in most cases it is not easy to identify all three cords of the brachial plexus in a single ultrasound scan plane. Also the position of the cords of the brachial plexus varies with abduction or adduction of the arm. If the transducer is moved medially, the pleura comes into view (Fig. 2-74). One can understand how inadvertent pleural puncture can occur during an infraclavicular (lateral sagittal) BPB (Fig. 2-74). We recommend that the pleura be routinely identified as part of the scan during a lateral sagittal infraclavicular BPB and the needle inserted lateral to this site, that is, through an ultrasound window where no pleura is visualized (Figs. 2-76 and 2-77).

5. Clinical Pearls: Ultrasound visualization of the brachial plexus at the LICF is best achieved with the arm in the abducted position. Abduction of the arm brings the cords closer to the skin and elevates the lateral part of the clavicle, which makes more space available below the clavicle for placement of the ultrasound transducer. In the paracoracoid area, the axillary artery is 3 to 7 cm under the skin surface. This makes confirmation of the artery by compressibility insensitive. Also, although one may expect
to be able to compress the axillary vein with pressure at the LICF, it may not always be possible. Therefore, it is advisable to use Doppler ultrasound whenever possible to differentiate the artery from the vein. Rarely one may visualize a bifid axillary artery\(^{25}\) in the infraclavicular fossa as a normal variant of the axillary artery anatomy. It is also common to see a hyperechoic shadow posterior to the axillary artery at the 6 o’clock position. This is usually an artifact caused by acoustic enhancement resulting from the sudden reduction in acoustic impedance as the ultrasound signal travels through the blood in the axillary artery. This hyperechoic shadow may be mistaken as the posterior cord. Tilting the transducer or performing a “trace back technique”\(^9\) may help to differentiate an artifact from the posterior cord. The LICF is a popular site for brachial plexus catheter placement. The target location for the catheter placement should be posterior (ie, at the 6 or 7 o’clock position) to the axillary artery. The muscles of the chest wall, through which the catheter is passed, help stabilize the catheter and may prevent catheter dislodgement.

**Brachial Plexus: Axilla**

**Gross Anatomy**

As the brachial plexus enters the arm, its four main terminal nerves (median, ulnar, radial, and musculocutaneous) travel in close proximity to the third part of the axillary artery (Fig. 2-13 and 2-78). The nerves lie superficial to the conjoint tendon of the teres major and latissimus dorsi muscles and under the subcutaneous tissue lateral to the anterior axillary fold (Fig. 2-78). When the arm is abducted and externally rotated, the median nerve is located on the anterior or anterolateral aspect of the axillary artery (97.9%), the ulnar nerve is located on the anteromedial side of the artery (91.3%), and the radial nerve is located posterior to the axillary artery (89.9%).\(^{26}\) The musculocutaneous nerve lies between the coracobrachialis and biceps muscles, but can also be within the substance of the coracobrachialis muscle (Figs. 2-78 to 2-81). Occasionally the musculocutaneous nerve may also be located adjacent to the median nerve.
FIGURE 2-78 Cross-sectional anatomy of the axilla at the level of the anterior axillary fold (i.e., where the pectoralis major muscle joins the biceps muscle). Note the relation of the median, ulnar, and radial nerve to the axillary artery and how the musculocutaneous nerve is embedded within the substance of the coracobrachialis muscle.

FIGURE 2-79 Transverse anatomical section of the axilla. AA, axillary artery; M, median nerve; U, ulnar nerve; R, radial nerve; CB, coracobrachialis muscle; MC, musculocutaneous nerve.
Magnetic Resonance Imaging Anatomy of the Axilla

Figs. 2-80 and 2-81

**FIGURE 2-80** Transverse (axial) MRI of the axilla above the anterior axillary fold. Note the position of the musculocutaneous nerve.

**FIGURE 2-81** Transverse (axial) MRI of the axilla at the level of the anterior axillary fold. Note the musculocutaneous nerve is located between the biceps and coracobrachialis muscle.

**Technique of Ultrasound Imaging of the Brachial Plexus at the Axilla**

1. **Position:**
a. **Patient:** Supine with the ipsilateral arm abducted 90 degrees at the shoulder.

b. **Operator and ultrasound machine:** The operator sits at the head end of the patient, and the ultrasound machine is placed directly in front on the ipsilateral side. Alternatively, the position of the operator and the ultrasound machine can be reversed.

2. **Transducer selection:** High-frequency linear array transducer (15-8 or 12-5 MHz).

3. **Scan technique:** The ultrasound transducer is placed transversely across the upper arm (Figs. 2-82 and 2-83) at the axillary fold just lateral to the pectoralis major muscle (Figs. 2-84 and 2-85). The initial goal is to identify the axillary artery. Minor adjustments (tilting or rotation) in the position of the ultrasound transducer may be required to obtain a true or optimal cross-sectional image of the axillary artery. The axillary vein is compressible and lies medial to the axillary artery. Doppler ultrasound can also be used to differentiate the axillary artery from the vein. It is common to see more than one vein in the sonogram. These vascular structures should be confirmed by compression and occlusion before any needle intervention. Doppler ultrasound can also be used to confirm hypoechoic structures that are suspected to be vascular in nature. The conjoint tendon of the latissimus dorsi and teres major muscles and its humeral insertion should subsequently be identified. It may be necessary to slide the transducer medially to visualize this tendon. The conjoint tendon is a useful sonographic landmark to locate the radial nerve as it often lies on top of this tendon.

![Figure 2-82](image-url) Figure showing the position of the ultrasound transducer relative to the...
humerus during an ultrasound scan of the axilla at the axillary fold.

**FIGURE 2-83** Figure highlighting the anatomical structures that are insonated during a transverse ultrasound scan of the axilla. AA, axillary artery; M, median nerve; U, ulnar nerve; R, radial nerve; CB, coracobrachialis muscle; MC, musculocutaneous nerve.

**FIGURE 2-84** Figure showing the position and orientation of the ultrasound transducer during a transverse ultrasound scan of the axilla at the axillary fold.
FIGURE 2-85 ■ Figure showing the position and orientation of the ultrasound transducer during a transverse ultrasound scan of the axilla at the axillary fold (different view compared to Figure 2-84). Note how the ultrasound transducer is positioned just distal to the anterior axillary fold.

4. Sonoanatomy: The axillary artery, when imaged in true cross-section, is typically round, pulsatile, and relatively superficial in location (Figs. 2-86 to 2-88). The axillary vein is also hypoechoic, situated caudal to the artery, oval or elliptical in shape, and may collapse from pressure of the transducer. The shape and size of the axillary vein may also vary during the respiratory cycle. Lateral to the axillary artery is the biceps and the coracobrachialis muscles. The musculocutaneous nerve lies in a fascial plane between these two muscles and is frequently visualized as an elliptical hyperechoic structure (Fig. 2-89). However, the shape and size of the musculocutaneous nerve are variable and can also be oval, round, flat-oval, or triangular (Figs. 2-86 to 2-90) in shape. On the posterior aspect of the axillary artery, a diagonal hyperechoic structure travelling from the anteromedial to the posterolateral direction can be visualized. This is the conjoint tendon, and the triceps muscle is seen posterior to this tendon (Figs. 2-86 to 2-89). The nerves in the axilla have mixed echogenicity, but are more frequently hyperechoic in appearance. The position of the various terminal nerves of the brachial plexus, relative to the axillary artery, in the axilla is also variable. The nerves are highly mobile and can be seen to change their position relative to the artery when pressure is applied on the ultrasound transducer. If one imagines the transverse image of the axillary artery as a clock face where the 9 o’clock position represents the lateral aspect and the 3 o’clock position represents the medial aspect of the artery, then the median nerve is typically located in the anterolateral (9 to 12 o’clock) sector. The radial nerve is typically located on the surface of the conjoint tendon, in the posteromedial (4 to 6 o’clock) sector deep to the axillary artery. The ulnar nerve is typically located in the caudal (2 to 4 o’clock) sector, and there may be several veins between it and the axillary artery.
FIGURE 2-86  Transverse sonogram of the axilla. AV, axillary vein; AA, axillary artery; U, ulnar nerve; R, radial nerve; CB, coracobrachialis muscle; MC, musculocutaneous nerve.

FIGURE 2-87  Transverse sonogram of the axilla showing all four terminal branches of the brachial plexus. M, median nerve; R, radial nerve; U, ulnar nerve; MC, musculocutaneous nerve; CB, coracobrachialis muscle; AA, axillary artery; AV, axillary vein.
FIGURE 2-88  High-resolution transverse sonogram of the axilla acquired using a 13-MHz linear ultrasound transducer. All four terminal branches of the brachial plexus are clearly delineated. Note the tissues plane/compartment separating the radial nerve from the ulnar nerve in this sonogram. AA, axillary artery; AV, axillary vein.

FIGURE 2-89  Transverse sonogram of the musculocutaneous nerve at the upper arm. The musculocutaneous nerve is located between the biceps and coracobrachialis muscles and appears oval in shape. AA, axillary artery; AV, axillary vein.
FIGURE 2-90  Transverse sonogram of the musculocutaneous nerve at the upper arm in sepia chroma mode. The musculocutaneous nerve is located between the biceps and coracobrachialis muscles and appears triangular in shape. AA, axillary artery; AV, axillary vein.

5. **Clinical Pearls:** The axillary region is highly vascular, and examination of the brachial plexus in this area should be preceded by a careful examination to locate the arteries and veins around the potential target nerves. Alternating firm and light pressure on the ultrasound transducer can be used to delineate the veins in the axilla during the scout scan. It is common for the veins in the axilla to be occluded by light pressure. This may increase the potential risk for inadvertent intravascular injection if intravascular placement of the block needle or spread of the injectate is not recognized on the ultrasound image during the injection. Rarely a bifid axillary artery may be seen as a normal variant in the axilla. The “trace back” technique is useful to confirm the identity of a particular nerve in the axilla. The median nerve can be traced and observed to travel with the brachial artery. The ulnar nerve can be traced and is seen on the medial aspect of the brachial artery. The radial nerve typically lies on the anterior surface of the conjoint tendon and descends deep towards the spiral groove of the humerus with the deep artery of the arm. The musculocutaneous nerve lies in a plane between the biceps and coracobrachialis muscles and moves away from the axillary artery as it descends down the arm.

**Midhumeral Region – Median and Ulnar Nerve**

**Gross Anatomy**

In the upper arm the terminal branches of the brachial plexus (ie, the median, ulnar, and radial nerves) separate from one another and take up their respective positions. The median nerve is closely related to the brachial artery throughout its course in the arm. In the midhumeral region, the median nerve lies lateral to the artery (Figs. 2-91 and 2-92); in the middle of the arm it crosses the artery anteriorly from the lateral to medial side and continues
to descend on the medial side of the artery (Figs. 2-14, 2-93, and 2-94) up to the elbow. At the antecubital fossa the median nerve is relatively superficial and lies medial to the brachial artery, posterior to the bicipital aponeurosis, and anterior to the brachialis muscle (Figs. 2-95 and 2-96).

**FIGURE 2-91** Cross-sectional anatomy of the arm at the midhumeral level. Note the relation of the median and ulnar nerve to the brachial artery. MACN, medial antebrachial cutaneous nerve; MBCN, medial brachial cutaneous nerve.

**FIGURE 2-92** Transverse anatomical section of the arm at the midhumeral level. BA, brachial artery; BV, brachial vein; CB, coracobrachialis muscle.
FIGURE 2-93 Cross-sectional anatomy of the lower arm above the elbow joint. MACN, medial antebrachial cutaneous nerve; LACN, lateral antebrachial cutaneous nerve; PACN, posterior antebrachial cutaneous nerve.

FIGURE 2-94 Transverse anatomical section of the lower arm above the elbow joint. M, median nerve, U, ulnar nerve; BA, brachial artery; BV, brachial vein.
In the arm, the ulnar nerve lies medial to the brachial artery up to about the insertion of the coracobrachialis muscle, where it pierces the medial intermuscular septum to enter the posterior compartment of the arm. It then continues its distal course and passes behind the medial epicondyle to enter the ulnar nerve sulcus (Fig. 2-96).

**FIGURE 2-96**  Cross-sectional anatomy of the arm at the level of the elbow joint. FCR, flexor carpi radialis; PL, palmaris longus; FDS, flexor digitorum superficialis.

**Magnetic Resonance Imaging Anatomy of the Midhumeral Region**

Fig. 2-97
 Technique of Ultrasound Imaging for the Median and Ulnar Nerve at the Midhumeral Region

1. **Position:**
   a. **Patient:** Supine with the ipsilateral arm abducted and externally rotated such that the palm of the hand is facing the ceiling.
   b. **Operator and ultrasound machine:** For a right-sided scan, a right-handed operator sits or stands at the head end of the patient and the ultrasound machine is placed directly in front on the ipsilateral side. Alternatively, the position of the operator and ultrasound machine can be reversed.

2. **Transducer selection:** High-frequency (15-8 or 17-5 MHz) linear array transducer.

3. **Scan technique:** The transducer is placed transversely across the groove between the biceps and triceps muscle at the middle of the humerus on the medial aspect (Figs. 2-98 to 2-100). The initial goal is to identify the brachial artery. The image should be optimized by rotation or tilting the transducer to obtain a true cross-sectional image of the brachial artery. Vascular structures should be identified by compression and occlusion before intervention. Doppler can be used to confirm hypoechoic structures that are suspected to be vascular in nature.

![Image of Transverse (axial) MRI of the arm at the midhumeral level.](image)
FIGURE 2-98 Figure showing the position of the ultrasound transducer relative to the humerus during an ultrasound scan of the arm at the level of the midhumerus.
FIGURE 2-99  Figure showing the position and orientation of the ultrasound transducer during a transverse ultrasound scan of the arm at the midhumeral level.

FIGURE 2-100  Figure highlighting the anatomical structures that are insonated during a transverse scan of the arm at the midhumeral level. M, median nerve; U, ulnar nerve; BA, brachial artery; BV, brachial vein; CB, coracobrachialis muscle.

4. Sonoanatomy: The median and ulnar nerves are visualized as hyperechoic structures with a honeycomb appearance. Both nerves lie adjacent to the brachial artery at this level (Fig. 2-101).

FIGURE 2-101  Transverse sonogram of the median nerve and ulnar nerve at the midhumeral level. BA, brachial artery; BV, brachial vein; CB, coracobrachialis muscle.
5. **Clinical Pearls:** The median and ulnar nerves are confirmed in this region using the “trace back” technique. Both nerves can easily be followed proximally and distally along the arm. The median nerve typically lies on the lateral aspect of the brachial artery proximally, crosses the brachial artery anteriorly, and continues on its medial side distally. The ulnar nerve lies in the medial side of the brachial artery. The position of both nerves in relation to the artery are variable, and they can be observed “rolling” from one to the other side of the artery.

**Midhumeral Region – Radial Nerve**

**Gross Anatomy**

At the level of the anterior axillary fold, the radial nerve lies deep to the axillary artery and superficial to the conjoint tendon (Figs. 2-78 and 2-88). It then enters the posterior compartment of the arm to lie in the spiral groove on the posterior aspect of the humerus and in between the medial and lateral heads of the triceps muscles (Figs. 2-88, 2-102, and 2-103). The radial nerve then emerges on the lateral aspect of the humerus and comes to lie between the brachialis, brachioradialis, and extensor carpi radialis longus muscles. It gives off the posterior antebrachial cutaneous nerve and continuous to the radial tunnel in the forearm (upper), where it divides into its superficial and deep branches.

![Diagram of the Radial Nerve](http://radiologyme.com/)

**FIGURE 2-102** Anatomy of the radial nerve at the level of the spiral groove of the humerus.
FIGURE 2-103  ■ Transverse anatomical section of the arm at the level of the radial groove.

Magnetic Resonance Imaging of the Midhumeral Region (Radial Nerve)

Figs. 2-104 and 2-105

FIGURE 2-104  ■ Transverse (axial) MRI of the arm at the level of the radial groove.
Ultrasound Scan Technique for Radial Nerve at the Radial Groove

1. **Position:**
   a. **Patient:** Supine with the patient asked to touch the opposite shoulder tip with the ipsilateral hand. An assistant may help to steady the arm in position.
   b. **Operator and ultrasound machine:** The operator sits or stands caudal to the abducted arm facing the head of the patient. The ultrasound machine is placed cephalad to the abducted arm on the ipsilateral side and directly in front of the operator.

2. **Transducer selection:** High-frequency (15-8 or 17-5 MHz) linear array transducer.

3. **Scan technique:** The transducer is placed transversely over the posterolateral aspect of the midhumerus (Figs. 2-106 to 2-108). The initial goal is to image the triceps muscle and the humerus. The image should be optimized by gently rotating and tilting the transducer to minimize anisotropy and obtain a true cross-sectional image of the radial nerve in the radial groove (spiral or musculospiral groove), together with the deep artery of the arm, which is also referred to as the profunda brachii artery (Figs. 2-109 and 2-110).
FIGURE 2-106 Figure showing the position of the ultrasound transducer relative to the humerus during an ultrasound scan of the arm at the level of the radial groove.

FIGURE 2-107 Figure showing the position and orientation of the ultrasound transducer
during an ultrasound scan for the radial nerve at the radial groove.

**FIGURE 2-108** Figure highlighting the anatomical structures that are insonated during a transverse scan of the arm at the level of the radial groove.

**FIGURE 2-109** Transverse sonogram of the radial nerve at the radial groove of the humerus.
4. **Sonoanatomy:** The posterior surface of the humerus appears as a hyperechoic curvilinear structure with a corresponding acoustic shadow anteriorly. The radial nerve is visualized as an oval hypoechoic structure with a hyperechoic outline in the spiral groove between the two heads of the triceps muscle. It is also common to visualize the pulsatile deep artery of the arm, which accompanies the radial nerve at the spiral groove (Figs. 2-109 and 2-110).

5. **Clinical Pearls:** The radial nerve is confirmed at the spiral groove using the “trace back” technique. Although the radial nerve can be imaged at the spiral groove of the humerus, its blockade at this site does not confer any advantage to blockade nearer the elbow.29

**Ultrasound Scan Technique for Radial Nerve at the Lateral Aspect of the Arm**

1. **Position:**
   a. **Patient:** Supine with the arm abducted and internally rotated such that the hand and forearm are resting on the abdomen (Fig. 2-111).
b. **Operator and ultrasound machine:** The operator sits or stands at the patient’s side on the side to be examined, and the ultrasound machine is placed directly in front of the operator on the ipsilateral side.

2. **Transducer selection:** High-frequency (15-8 or 17-5 MHz) linear array transducer.

3. **Scan technique:** The ultrasound transducer is positioned transversely over the lateral aspect of the lower arm (Fig. 2-111).

4. **Sonoanatomy:** The lateral aspect of the humerus is visualized as a hyperechoic structure with a corresponding acoustic shadow anteriorly (Figs. 2-112 and 2-113). The radial nerve and its posterior antebrachial cutaneous branch are often seen as round-to-oval hypoechoic structures between the brachialis (medially) and the brachioradialis and extensor carpi radialis longus muscles (laterally).
FIGURE 2-112 Transverse sonogram of the radial nerve at the lateral aspect of the arm. Accompanying photograph illustrates the position and orientation of the transducer during the ultrasound scan.

FIGURE 2-113 Transverse sonogram of the radial nerve at the lateral aspect of the arm. PACN, posterior antebrachial cutaneous nerve.

5. Clinical Pearls: The lateral aspect of the lower arm can be a useful site for rescue block of the radial nerve during forearm and hand surgery because a single injection of local anesthetic at this site will block both the superficial and deep branches of the nerve.

Elbow Region – Median, Ulnar, and Radial Nerves

Gross Anatomy

At the elbow, the median nerve lies medial to the brachial artery, deep to the bicipital aponeurosis and on the anterior surface of the brachialis muscle (Figs. 2-14, 2-95, and 2-96). The ulnar nerve winds around the medial aspect of the medial epicondyle in the ulnar groove (Figs. 2-95, 2-96, and 2-102) and enters the anterior compartment of the forearm between the two heads of the flexor carpi ulnaris and comes to lie between the flexor carpi ulnaris (medially), flexor digitorum superficialis, and the flexor digitorum profundus in the forearm (Figs. 2-114 and 2-115). The radial nerve lies beneath the brachioradialis in the anterior compartment of the lower arm (Figs. 2-93 and 2-95). Within 3 cm of the elbow joint the radial nerve divides into its superficial (cutaneous branch) and deep (posterior interosseous nerve) branches (Fig. 2-9). The deep branch winds around the neck of the radius and travels distally between the superficial and deep layers of the supinator muscle (Fig. 2-115) in the “radial tunnel” (Fig. 2-114) and enters the posterior compartment of the arm as the posterior interosseous nerve. The deep branch of the radial nerve is often accompanied by the recurrent branch of the radial artery and its vena comitans. The superficial branch of the radial nerve runs under the brachioradialis and on the supinator and pronator teres muscles.
It then descends close to the lateral aspect of the radial artery in the midforearm (Figs. 2-116 and 2-117) after which it leaves the artery and courses backward under the tendon of the brachioradialis to reach the posterior surface of the wrist.

**FIGURE 2-114** Transverse anatomical section of the upper forearm at the radial tunnel. FCR, flexor carpi radialis muscle; PL, palmaris longus muscle; FDS, flexor digitorum superficialis muscle; FCU, flexor carpi ulnaris muscle; BCR, brachioradialis muscle; FDP, flexor digitorum profundus muscle.

**FIGURE 2-115** Cross-sectional anatomy of the proximal forearm just below the elbow joint. LACN, lateral antebrachial cutaneous nerve; PACN, posterior antebrachial cutaneous nerve.
nerve.

FIGURE 2-116 Cross-sectional anatomy of the mid forearm showing the median, ulnar, and radial nerves.

FIGURE 2-117 Median, radial, and ulnar nerve at the forearm.

Magnetic Resonance Imaging of the Elbow Region

Figs. 2-118 to 2-120
FIGURE 2-118 Transverse (axial) MRI demonstrating the median nerve at the level of the elbow joint (cubital fossa).

FIGURE 2-119 Transverse (axial) MRI of the upper forearm demonstrating the radial nerve in the radial tunnel. ECRL, extensor carpi radialis longus muscle; ECRB, extensor carpi radialis brevis muscle; EDC, extensor digitorum communis muscle; FDP, flexor digitorum profundus muscle; FCU, flexor carpi ulnaris muscle; FDS, flexor digitorum superficialis.
Elbow Region Ultrasound Scan Technique

1. **Position:**
   a. **Patient:** Supine with the arm abducted 90 degrees at the shoulder and externally rotated such that the palm of the hand is facing the ceiling.
   b. **Operator and ultrasound machine:** The operator is positioned at the caudal side of the abducted arm facing the head of the patient. The ultrasound machine is placed on the ipsilateral side cephalad to the abducted arm directly in front of the operator.

2. **Transducer selection:** High-frequency (15-8 or 17-5 MHz) linear array transducer.

3. **Scan technique:** The median nerve is imaged by placing the transducer transversely across the elbow joint (Figs. 2-121 and 2-122). The initial goal is to image the brachial artery in a true cross-sectional view. The brachial artery and median nerve are relatively superficial at this level with only the bicep aponeurosis, subcutaneous tissue, and skin covering it. The median nerve is located medial to the brachial artery (Fig. 2-123). To locate the radial nerve at the elbow, identify the brachial artery as described earlier and slide the transducer laterally towards the lateral humeral epicondyle and 2 to 3 cm below the elbow joint (Figs. 2-124 and 2-125). The radial nerve or its branches are located between the brachioradialis and supinator muscle. The ulnar nerve can be imaged by abducting the arm at the shoulder with external rotation to expose the posteromedial aspect of the medial humeral epicondyle (Figs. 2-126 and 2-127). Manual palpation of the ulnar groove may aid initial transducer placement. The ultrasound transducer is placed transversely across the ulnar groove to obtain a transverse image of the ulnar nerve. Contact artifacts are a problem when scanning for the ulnar nerve at the ulnar groove. Therefore, it is easier to locate the ulnar nerve just proximal to the ulnar groove (Fig. 2-128).
**FIGURE 2-121** Figure showing the position and orientation of the ultrasound transducer during an ultrasound scan for the median nerve at the cubital fossa.

**FIGURE 2-122** Figure highlighting the anatomical structures that are insonated during an ultrasound scan for the median nerve at the level of the elbow joint. Basilic V, basilic vein; FCR, flexor carpi radialis muscle; PL, palmaris longus muscle; FDS, flexor digitorum superficialis muscle.
FIGURE 2-123 Transverse sonogram of the median nerve at the elbow. Note the median nerve lies immediately medial to the brachial artery. BA, brachial artery.

FIGURE 2-124 Figure showing the position and orientation of the ultrasound transducer during an ultrasound scan for the radial nerve at the lateral aspect of the upper forearm (radial tunnel).
FIGURE 2-125 Figure highlighting the anatomical structures that are insonated during a transverse ultrasound scan for the radial nerve at the lateral aspect of the upper forearm (radial tunnel). FCR, flexor carpi radialis muscle; PL, palmaris longus muscle; FDS, flexor digitorum superficialis muscle; FCU, flexor carpi ulnaris muscle; BCR, brachioradialis muscle.

FIGURE 2-126 Figure showing the position and orientation of the ultrasound transducer during an ultrasound scan for the ulnar nerve at the posteromedial aspect of the elbow.
**FIGURE 2-127** Figure highlighting the anatomical structures that are insonated during an ultrasound scan for the ulnar nerve at the ulnar groove. PL, palmaris longus muscle; FDS, flexor digitorum superficialis muscle; FCR, flexor carpi radialis muscle.

**FIGURE 2-128** Transverse sonogram of the ulnar nerve just above the ulnar groove and on the posteromedial aspect of the lower arm. Accompanying photograph illustrates the position and orientation of the transducer during the ultrasound scan.

4. **Sonoanatomy:** The median nerve appears as an oval or elliptical-shaped, hyperechoic, and honeycombed structure medial to the brachial artery at the elbow (Fig. 2-123). The ulnar nerve at the ulnar groove is frequently triangular in shape and hypoechoic in appearance (Fig. 2-129). Proximal to the ulnar groove the ulnar nerve is relatively superficial and appears hypoechoic (Fig. 2-128). When examining the radial nerve at the elbow, the
radius appears as a curved hyperechoic structure with an accompanying acoustic shadow anteriorly. The two branches of the radial nerve are seen as discrete hypoechoic structures between the brachioradialis and the supinator muscle (Fig. 2-130). The recurrent branch of the radial artery accompanies the deep branch and can be identified using Doppler ultrasound.

**FIGURE 2-129** Transverse sonogram of the ulnar nerve at the elbow just proximal to the ulnar groove.

**FIGURE 2-130** Transverse sonogram showing the superficial and deep branches of the radial nerve lying in between the brachioradialis and supinator muscle at the lateral aspect of the upper forearm.
5. **Clinical Pearls**: The identity of the nerves at the elbow is confirmed using the “trace back” technique and visualized along their expected course based on anatomical knowledge. Median nerve block at the elbow can be performed as a rescue block or when there is surgical dressing or plaster casts covering the forearm. When examining the ulnar nerve at the ulnar groove or cubital tunnel, apply liberal amounts of ultrasound gel and apply minimal pressure during the ultrasound scan to reduce contact artifacts. It may also be safer to perform an ulnar nerve block at a more proximal site rather than at the ulnar groove because of the perceived increased risk of nerve injury at the ulnar groove.

**Midforearm Region – Median, Ulnar, and Radial Nerves**

**Gross Anatomy**

In the midforearm the median nerve lies in a fascial plane between the flexor digitorum superficialis and the flexor digitorum profundus muscle (Figs. 2-116 and 2-131). At the wrist, the median nerve lies lateral to the flexor digitorum superficialis muscle and beneath the palmaris longus tendon (Fig. 2-132) and continues under the flexor retinaculum to enter the hand. At the midforearm the ulnar nerve runs between the flexor digitorum profundus (posteriorly), the flexor digitorum superficialis (anteriorly), and the flexor carpi ulnaris (medially) muscle (Fig. 2-116). In the distal forearm the ulnar nerve is accompanied by the ulnar artery (Fig. 2-132) and enters the hand superficial to the flexor retinaculum.

[FIGURE 2-131](http://radiologyme.com/) Transverse anatomical section through the midforearm showing the median nerve. FCR, flexor carpi radialis muscle; PL, palmaris longus muscle; FDS, flexor digitorum superficialis muscle; FCU, flexor carpi ulnaris muscle; BCR, brachioradialis muscle; FPL, flexor pollicis longus muscle; FDS, flexor digitorum superficialis muscle; FDP, flexor digitorum profundus muscle; ECU, extensor carpi ulnaris muscle; APL, abductor pollicis longus muscle.
FIGURE 2-132  ■ Cross-sectional anatomy of the distal forearm showing the median, ulnar, and superficial and deep (posterior interosseous nerve) branches of the radial nerve.

Magnetic Resonance Imaging Anatomy of the Midforearm

Figs. 2-133 and 2-134

FIGURE 2-133  ■ Transverse (axial) MRI of the midforearm demonstrating the median, radial, and ulnar nerves. FDP, flexor digitorum profundus.
FIGURE 2-134 Transverse (axial) MRI of the distal forearm demonstrating the median and radial nerve. FDS, flexor digitorum superficialis muscle; FDP, flexor digitorum profundus muscle.

**Midforearm Ultrasound Scan Technique**

1. **Position:**
   - **Patient:** Supine with the arm abducted and externally rotated such that the palm of the hand is facing the ceiling.
   - **Operator and ultrasound machine:** The operator is positioned at the caudad side of the abducted arm facing the head of the patient. The ultrasound machine is placed on the ipsilateral side to be examined on the cephalad side of the abducted arm directly in front of the operator.

2. **Transducer selection:** High-frequency (15-8 or 17-5 MHz) linear array transducer.

3. **Scan technique:** To image the median nerve, the ultrasound transducer is placed in the transverse orientation across the volar surface of the midforearm (Figs. 2-135 to 2-137). The median nerve is seen as a hyperechoic nodule between the flexor digitorum superficialis, which is superficial to the nerve, and the flexor digitorum profundus, which is deep to the nerve (Figs. 2-138 to 2-141). To image the ulnar nerve, slide the ultrasound medially from the earlier position. It may be easier to start the ultrasound scan at the wrist by locating the ulnar artery (Figs. 2-142 and 2-143). The ulnar nerve lies medial to the ulnar artery at the wrist. One can then trace the ulnar nerve back to the midforearm (Figs. 2-144 and 2-145). To image the superficial (cutaneous) branch of the radial nerve, the ultrasound transducer is placed laterally on the volar surface of the midforearm and traced distally (Fig. 2-146). The superficial branch of the radial nerve is seen lateral to the radial artery (Fig. 2-147).
FIGURE 2-135  ■ Figure showing the position of the ultrasound transducer relative to the forearm during an ultrasound scan for the median nerve at the midforearm.
**FIGURE 2-136** Figure showing the position and orientation of the ultrasound transducer during an ultrasound scan for the median nerve at the midforearm.

**FIGURE 2-137** Figure highlighting the anatomical structures that are insonated during an ultrasound scan for the median nerve at the midforearm. FCR, flexor carpi radialis muscle; PL, palmaris longus muscle; FDS, flexor digitorum superficialis muscle; FCU, flexor carpi ulnaris muscle; BCR, brachioradialis muscle; FPL, flexor pollicis longus muscle; FDP, flexor digitorum profundus muscle; ECU, extensor carpi ulnaris; APL, abductor pollicis longus muscle.

**FIGURE 2-138** Transverse sonogram of the median nerve at the midforearm.
FIGURE 2-139  ■ Transverse sonogram of the median nerve at the midforearm in sepia mode.

FIGURE 2-140  ■ Sagittal sonogram of the median nerve at the midforearm.
FIGURE 2-141  Three-dimensional multiplanar image of the median nerve at the midforearm. Reference marker has been placed over the median nerve: (a) transverse view, (b) sagittal view, and (c) coronal view.

FIGURE 2-142  Figure showing the position and orientation of the ultrasound transducer during a ultrasound scan for the median nerve at the distal forearm.
**FIGURE 2-143** Figure highlighting the anatomical structures that are insonated during an ultrasound scan for the ulnar nerve at the midforearm. FCR, flexor carpi radialis muscle; FDS, flexor digitorum superficialis muscle; FPL, flexor pollicis longus muscle; FDP, flexor digitorum profundus muscle; FCU, flexor carpi ulnaris.

**FIGURE 2-144** Transverse sonogram of the median and ulnar nerves at the midforearm.
FIGURE 2-145 Transverse sonogram of the median and ulnar nerves at the midforearm in sepia mode.

FIGURE 2-146 Figure showing the position and orientation of the ultrasound transducer during an ultrasound scan at the distal forearm to insonate the superficial branch of the radial nerve and the median nerve.
FIGURE 2-147  ■ Transverse sonogram demonstrating the superficial branch of the radial nerve at the distal forearm. Note the superficial branch of the radial nerve is hyperechoic and located lateral to the radial artery.

4. **Sonoanatomy:** The median, radial, and ulnar nerves all appear as an elliptical/oval, hyperechoic, and honeycombed structure on a transverse sonogram of the midforearm.

5. **Clinical Pearls:** The nerves in the forearm are markedly anisotropic. Therefore, one should gently tilt or rotate the ultrasound transducer during the ultrasound scan to minimize anisotropy and optimize the image. The “trace back” technique is particularly useful for confirmation of nerves in the forearm. The course of the nerves can be followed throughout the forearm, and the flat surface of the forearm also allows for easy manipulation of the transducer to image the nerves in their long (sagittal) axis for confirmation. In the distal forearm and wrist, it may be more challenging to image the median nerve, as there are many tendons at this location. In the forearm the median nerve is accompanied by the median artery, which is a branch of the anterior interosseous artery. The radial nerve below the elbow is small and hard to visualize using ultrasound. Therefore, the “trace back” technique should be used to confirm the identity of the radial nerve below the elbow. The superficial branch of the radial nerve is also a small nerve and may not be readily visualized in the distal forearm.

**References**

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CHAPTER 3

Sonoanatomy Relevant for Ultrasound-Guided Lower Extremity Nerve Blocks

Introduction

Four main nerves of the lumbosacral plexus provide sensory and motor innervation to the lower extremity: the femoral, lateral femoral cutaneous, obturator, and the sciatic nerve.

Gross Anatomy

The anatomy of the lumbar plexus is described in detail in Chapter 8 (Fig. 3-1). The terminal nerves of the lumbosacral plexus relevant for innervating the lower extremity include the lateral cutaneous nerve of the thigh, the femoral nerve, the obturator nerve, and the sciatic nerve. The lateral cutaneous nerve of the thigh and the femoral nerve leave the lumbar plexus along the posterolateral border of the psoas major muscle; the obturator nerve emerges from the medial border of the psoas muscle at the pelvic brim and crosses in front of the sacroiliac joint.¹ The sacral plexus provides sensorimotor innervation to the posterior thigh, most of the lower extremity, the entire foot, and parts of the pelvis. It is formed by the union of the anterior primary rami of the spinal nerves of L4, L5, S1, S2, S3, and S4 (lumbosacral plexus, Fig. 3-2). The sacral plexus lies deep within the pelvis between the piriformis muscle posteriorly and the pelvis fascia anteriorly (Fig. 3-3). The sigmoid colon, ureter, internal iliac artery, and vein lie anterior to it. The superior gluteal artery and vein lie between the lumbosacral trunk and the first sacral nerve, and the inferior gluteal artery and vein lie between the second and third sacral nerves. The nerves forming the sacral plexus converge as they descend towards the lower part of the greater sciatic foramen and unite within the pelvis to form the sciatic nerve (Fig. 3-4). The sciatic nerve is the largest (thickest) nerve of the body and exits the pelvis through the greater sciatic foramen, between the piriformis and the superior gemellus muscles (Fig. 3-5), to enter the “subgluteal space” between the greater trochanter and ischial tuberosity (Figs. 3-6 and 3-7).²,³ Sciatic nerve and piriformis muscle anomaly are seen in 16.2% (95% CI: 10.7–23.5%) of individuals.⁴ The entire sciatic nerve or one of its components (tibial or common peroneal) may rarely exit the pelvis by passing through or above the superior border of the piriformis muscle.⁴ The sciatic nerve, after it emerges from the pelvis, descends along the back of the thigh, lying deep to the semitendinosus and biceps femoris muscles, to about its lower third (Figs. 3-8 and 3-9), where it bifurcates into its two branches: the tibial and common peroneal (fibular) nerves. This bifurcation may take place at any point between its origin at the sacral plexus and the lower third of the thigh or at a variable distance from the popliteal crease.⁵ The tibial and common peroneal nerves may also arise separately from the sacral plexus.
FIGURE 3-1 Anatomical illustration showing the formation of the lumbosacral plexus.

FIGURE 3-2 Anatomical illustration (frontal view) showing the formation of the sacral plexus and the sciatic nerve.
FIGURE 3-3 Anatomical illustration (frontal view) showing the relation of the sacral plexus to the piriformis muscle and the greater sciatic foramen. Note how the superior gluteal, inferior gluteal, and pudendal nerve exit the greater sciatic foramen.

FIGURE 3-4 Anatomical illustration (dorsal view) showing the sciatic nerve as it exits the pelvis through the greater sciatic foramen. Note the relation of the superior and inferior gluteal nerves, posterior cutaneous nerve of the thigh, nerve to obturator internus, and pudendal nerve to the sciatic nerve as they exit the greater sciatic foramen.
**FIGURE 3-5** Anatomical illustration showing the relation of the sciatic nerve to the muscles of the buttock and upper thigh.

**FIGURE 3-6** Multiplanar 3-D anatomy (rendered from the Visible Human Server) of the sciatic nerve at the subgluteal space. Note the reference marker (green crosshair) has been placed over the sciatic nerve in the transverse view and its corresponding position in the sagittal and coronal images can be seen. AM, adductor magnus; VL, vastus lateralis; IT, ischial tuberosity; QF, quadratus femoris; GM, gluteus maximus; GS, gemellus superior; GI, gemellus inferior; BF, biceps femoris; OI, obturator internus; PF, piriformis.
FIGURE 3-7 Anatomical illustration showing the transverse anatomy of the gluteal region at the level of the greater trochanter and ischial tuberosity. Note the subgluteal space and its contents between the gluteus maximus and quadratus femoris muscles.

Femoral Nerve at the Inguinal Region

Gross Anatomy

The femoral nerve is the largest branch of the lumbar plexus and originates from the posterior divisions of the anterior primary rami of the L2, L3, and L4 spinal nerves. It descends through the fibers of the psoas muscle and exits the lateral border of the inferior part of the psoas muscle in the retroperitoneal space. It then descends between the psoas and the iliacus muscle deep to the fascia iliaca. It enters the femoral triangle of the thigh behind the inguinal ligament, lying lateral to the femoral artery and in a groove between the iliacus and psoas muscles (Fig. 3-10 and 3-11). In between the inguinal ligament and the inguinal crease, the femoral vein, femoral artery, and the femoral nerve have a “VAN” (vein, artery, nerve) relation from the medial to lateral side (Fig. 3-11). The femoral artery and vein are enclosed by the femoral sheath and lie deep to the fascia lata (deep fascia of the thigh), and the femoral nerve lies outside the femoral sheath and deep to both the fascia lata and fascia iliaca on the anteromedial aspect of the iliopsoas muscle (Fig. 3-12). The femoral nerve divides into its anterior and posterior branch after a short course of about 2 cm below the inguinal ligament or at the level of the inguinal crease.6
FIGURE 3-8 Multiplanar 3-D anatomy of the sciatic nerve at the midthigh. AL, adductor longus; AM, adductor magnus; BF, biceps femoris; GM, gluteus maximus; RF, rectus femoris; SM, semimembranosus; SR, sartorius; ST, semitendinosus; VI, vastus intermedialis; VL, vastus lateralis; VM, vastus medialis.
FIGURE 3-9 Multiplanar 3-D anatomy of the sciatic nerve at or close to the apex of the popliteal fossa. AM, adductor magnus; AL, adductor longus; BF, biceps femoris; GR, gracilis; SM, semimembranosus; SR, sartorius; ST, semitendinosus; VI, vastus intermedialis; VL, vastus lateralis; VM, vastus medialis; RF, rectus femoris.

FIGURE 3-10 Anatomy of the femoral nerve at the inguinal region. Note the relation of the femoral nerve to the femoral artery and vein and the iliopsoas muscle.

FIGURE 3-11 Transverse anatomical section of the inguinal region at the level of the inguinal ligament. Note the relation of the femoral nerve to the iliopsoas muscle.
FIGURE 3-12  Fascial anatomy in relation to the femoral nerve at the level of the inguinal crease. Note both the femoral artery and vein lie deep to the fascia lata and are enclosed by the femoral sheath, and the femoral nerve lies outside the femoral sheath and deep to both the fascia lata and iliaca.

Computed Tomography Anatomy of the Inguinal Region

Fig. 3-13

FIGURE 3-13  Transverse (axial) CT of the inguinal region at the level of the inguinal crease showing the relation of the femoral nerve to the femoral vessel, fascia lata, fascia iliaca, and iliopsoas muscle. FA, femoral artery; FV, femoral vein.

Magnetic Resonance Imaging Anatomy of the Inguinal Region

Fig. 3-14
FIGURE 3-14 Transverse (axial) MRI image of the inguinal region showing the femoral nerve at the level of the inguinal crease. Note the relation of the femoral nerve to the femoral vessels and the neighboring fascia (lata and iliaca).

Femoral Nerve Ultrasound Scan Technique

1. **Position:**
   a. **Patient:** Supine with the ipsilateral leg slightly abducted and externally rotated and the knee slightly flexed.
   b. **Operator and ultrasound machine:** The operator stands on the side of the intervention and faces the patient’s head. The ultrasound machine is placed on the same side between the operator and the patient’s head. Alternatively, the operator may choose to position the ultrasound machine based on his or her “handedness.” Right-handed operators who hold the ultrasound transducer with their left hand and carry out needle interventions with their right hand should stand on the right side of the patient and position the ultrasound machine on the contralateral side and directly in front. This is vice versa for left-handed operators.

2. **Transducer selection:** High-frequency (15-8 or 17-5 MHz) linear array transducer.

3. **Scan technique:** For a transverse scan of the femoral nerve, place the ultrasound transducer parallel to the inguinal ligament and approximately 1 cm proximal to the inguinal crease (Figs. 3-15 to 3-17). Gently slide the transducer in a medial to lateral direction until a cross-sectional view of the femoral artery is obtained. The femoral vein lies medial to the femoral artery, and the femoral nerve is lateral to the artery (Fig. 3-18). The femoral vein is compressible, but the femoral artery may not be easily compressible. Color or Power Doppler should be used to differentiate the femoral artery from the vein as part of one’s scan routine (Fig. 3-19). The femoral nerve is most commonly seen on the anteromedial surface of the iliopsoas muscle (Fig. 3-18).
**FIGURE 3-15** Figure showing the position of the ultrasound transducer during a transverse ultrasound scan for the femoral nerve at the inguinal region.
FIGURE 3-16  Figure showing the position and orientation of the ultrasound transducer during a transverse ultrasound scan for the femoral nerve at the inguinal region.

FIGURE 3-17  Figure highlighting the anatomical structures that are insonated during a transverse ultrasound scan for the femoral nerve at the inguinal region. FA, femoral artery; FV, femoral vein.
4. **Sonoanatomy:** The femoral nerve is typically identified on the anteromedial surface of the psoas muscle as a flat, hyperechoic, and elliptical-shaped structure (Fig. 3-18). Outlines of the fascia iliaca, with the femoral nerve lying deep to this fascia, may be visualized in some individuals (Fig. 3-18).

5. **Clinical Pearls:** The femoral nerve is markedly anisotropic in the inguinal region. Therefore, it may be necessary to gently tilt or rotate the transducer during the ultrasound.
scan before it can be clearly delineated. It is our experience that the position of the femoral nerve, relative to the femoral artery, in the femoral triangle is quite variable. Therefore, we prefer to look for the femoral nerve on the anteromedial surface of the iliopsoas muscle rather than immediately lateral to the femoral artery during the scan. Also in order to locate the femoral nerve before it divides into its anterior and posterior branches, it is preferable to start the ultrasound scan immediately below the inguinal ligament rather than at the inguinal crease. The profunda femoris artery, which is the largest branch of the femoral artery, can be a useful clue as to the level at which the ultrasound scan is being performed. If the profunda femoris artery is seen adjacent (lateral) to the femoral artery in the ultrasound image (Fig. 3-20), it indicates that the ultrasound scan is being performed too low and below the division of the femoral nerve because the profunda femoris artery is generally given off from the femoral artery, about 4 cm below the inguinal ligament.

FIGURE 3-20 Transverse sonogram of the inguinal region showing the origin of the profunda femoris artery from the femoral artery.

Obturator Nerve at the Inguinal Region

Gross Anatomy

The obturator nerve is a branch of the lumbar plexus and formed by the anterior division of the anterior primary rami of the L2, L3, and L4 spinal nerves. It exits the pelvis and enters the thigh through the obturator canal. It then divides into its anterior and posterior divisions, usually lateral and distal to the pubic tubercle (Fig. 3-1).8 The anterior division courses distally, lying between the adductor brevis and the adductor longus muscles, and the posterior division passes distally between the adductor brevis and adductor magnus muscles (Figs. 3-21 and 3-22).
FIGURE 3-21  Anatomical section of the anterior and medial compartments of the thigh 5 to 8 cm distal to the inguinal crease.

FIGURE 3-22  Cross-sectional anatomy of the thigh distal to the inguinal crease. Note the relation of the anterior and posterior divisions of the obturator nerve to the adductor muscles (longus, brevis, and magnus).

Computed Tomography Anatomy of the Upper Thigh

Fig. 3-23
**FIGURE 3-23** Transverse (axial) CT of the proximal thigh showing the obturator nerves and their relations. FV, femoral vein.

**Magnetic Resonance Imaging Anatomy of the Upper Thigh**

**Fig. 3-24**

**FIGURE 3-24** Transverse (axial) MRI image of the proximal thigh showing the obturator nerves and their relations.

**Obturator Nerve Ultrasound Scan Technique**

1. **Position:**
**a. Patient:** Supine with the ipsilateral leg straight and slightly externally rotated at the hip. This position allows optimal visualization of the obturator nerve and its branches.  

**b. Operator and ultrasound machine:** The operator stands on the ipsilateral side of the scan or intervention and faces the patient’s head. The ultrasound machine is placed on the ipsilateral side directly in front of the operator. Alternatively, the operator may choose to position the ultrasound machine depending on his or her “handedness.” Right-handed operators who hold the ultrasound transducer with their left hand and carry out needle interventions with their right hand should stand on the right side of the patient and position the ultrasound machine on the opposite side of the patient. This is vice versa for left-handed operators.

**2. Transducer selection:** High-frequency (15-8 or 17-5 MHz) linear array transducer.

**3. Scan technique:** The transducer is placed in the transverse orientation 2 cm distal to the pubic tubercle on the medial aspect of the thigh (Figs. 3-25 and 3-26). Alternatively start the ultrasound scan by placing the transducer parallel to the inguinal ligament and over the inguinal crease. Then slide the transducer medially until the pectineus is visualized on the lateral aspect of the ultrasound screen. At this point, the adductor muscles (longus, brevis, and magnus) are visualized adjacent to the pectineus (Fig. 3-27). Because the anterior and posterior divisions of the obturator nerve are flat and small nerves, it is easier to identify them in their respective intermuscular fascial planes by sliding the transducer proximally and distally analogous to the trace back technique. Slightly tilting or rotating the transducer may also help improve visualization. If one traces the two divisions of the obturator nerve proximally, they are seen to come together to form the common obturator nerve. Color or Power Doppler ultrasound can also be used to identify the obturator artery that accompanies the common obturator nerve.
FIGURE 3-25 Figure showing the position of the ultrasound transducer relative to the thigh during a transverse scan for the anterior and posterior divisions of the obturator nerve.
4. **Sonoanatomy:** The common obturator nerve or its divisions (anterior and posterior) are not readily identified as discrete nerves on ultrasound imaging, as they are small and flat.
Unlike other peripheral nerves, the anterior and posterior divisions of the obturator nerve appear as two flat and hyperechoic structures in the intermuscular fascial planes between the adductor muscles (Fig. 3-28).

**FIGURE 3-28** Transverse sonogram of the medial compartment of the proximal thigh showing the adductor muscles (longus, brevis, and magnus) and the anterior and posterior divisions of the obturator nerve in the intermuscular plane between the adductor muscles.

5. Clinical Pearls: The anterior division travels in the intermuscular plane between the adductor longus and adductor brevis muscles. The posterior division travels in the plane between the adductor brevis and adductor magnus muscles. The typical appearance on a transverse sonogram would include the pectineus muscle on the lateral aspect of the screen and the three adductors muscles on the medial aspect, with the adductor longus being most superficial, the adductor brevis in the middle, and the adductor magnus deepest, respectively (Figs. 3-27 and 3-28). Small branches of the obturator vessels accompany the divisions of the obturator nerve in the intermuscular plane and can be identified using Color or Power Doppler ultrasound. However, to what extent this is reliable in locating the nerves is yet to be determined, as the position of the obturator vessels relative to the nerves is variable.

**Lateral Cutaneous Nerve of the Thigh**

**Gross Anatomy**

The lateral cutaneous nerve of the thigh, also called the lateral femoral cutaneous nerve of the thigh, innervates the skin on the lateral aspect of the thigh. It is a branch of the lumbar plexus and formed within the psoas muscle by the fusion of the posterior divisions of the L2 and L3 spinal nerves. It exits the psoas muscle from its lateral border, in the retroperitoneum, at about its middle and travels across the iliacus muscle obliquely lying deep to the fascia iliaca (Fig. 3-1). It enters the thigh medial to the anterior superior iliac spine (ASIS) lying under the lateral edge of the inguinal ligament (Figs. 3-29 and 3-30). It then crosses over the sartorius...
muscle in a medial to lateral direction. The course of the lateral cutaneous nerve of the thigh is highly variable. It is found most commonly 10 to 15 millimeters medial to the ASIS but can be located as far medially as 46 millimeters.\textsuperscript{10} Its depth in relation to the soft tissues in the region, the sartorius, and the inguinal ligament is also highly variable. Five different variations have been identified: type A, posterior to the ASIS, across the iliac crest; type B, anterior to the ASIS and superficial to the origin of the sartorius muscle but within the substance of the inguinal ligament; type C, medial to the ASIS, ensheathed in the tendinous origin of the sartorius muscle; type D, medial to the origin of the sartorius muscle located in an interval between the tendon of the sartorius muscle and thick fascia of the iliopsoas muscle deep to the inguinal ligament; and type E, most medial and embedded in loose connective tissue, deep to the inguinal ligament, overlying the thin fascia of the iliopsoas muscle, and contributing the femoral branch of the genitofemoral nerve.\textsuperscript{11}

\textbf{FIGURE 3-29} Anatomical illustration showing the lateral femoral cutaneous nerve entering the thigh under the lateral edge of the inguinal ligament and medial to the anterior superior iliac spine (ASIS).
**FIGURE 3-30** Transverse anatomical section of the upper thigh and lower abdomen a few centimeters distal to the anterior superior iliac spine showing the anatomy related to the lateral femoral cutaneous nerve (the nerve is not seen in this image), which usually lies on the anterior surface of the sartorius muscle or in the groove between the sartorius and the iliacus muscles at this level. IO, internal oblique muscle; TA, transversus abdominis muscle.

**Magnetic Resonance Imaging Anatomy of the Lateral Cutaneous Nerve of the Thigh**

Fig. 3-31

**FIGURE 3-31** Transverse (axial) MRI image of the upper thigh showing the lateral cutaneous nerve of the thigh.

**Lateral Cutaneous Nerve of the Thigh Ultrasound Scan Technique**

1. **Position:**
   a. **Patient:** Supine position
   b. **Operator and ultrasound machine:** The operator may stand on the ipsilateral side of the intervention and face the patient’s head. The ultrasound machine is placed on the same side between the operator and the patient’s head. Alternatively, the operator may choose to position the ultrasound machine depending on his or her “handedness.” Right-handed operators who hold ultrasound transducer with their left hand and carry out needle interventions with their right hand should stand on the right side of the patient and position the ultrasound machine on the opposite side of the patient. This is vice versa for left-handed operators.

2. **Transducer selection:** High-frequency (15-8 or 17-5 MHz) linear array transducer.

3. **Scan technique:** The transducer is placed with one edge on the ASIS. The medial edge of the transducer is rotated slightly caudally such that the transducer is parallel to the inguinal ligament. Slide the transducer medially along the inguinal ligament (Figs. 3-32 to 3-34). The ASIS appears as a hyperechoic line with an acoustic shadow. Immediately
medial to the ASIS is the iliacus muscle. At the level of the inguinal ligament, the lateral cutaneous nerve can be visualized deep to the fascia lata just medial to the ASIS. The transducer can be slid distally approximately 5 cm caudad to the ASIS and rotated to a transverse orientation relative to the femur. At this location, the lateral cutaneous nerve of the thigh is located on the sartorius muscle or in the groove between the sartorius and the iliacus muscles (Fig. 3-35).

**FIGURE 3-32** Figure showing the position of the ultrasound transducer during a transverse scan for the lateral femoral cutaneous nerve at the inguinal region.
FIGURE 3-33 Figure showing the position and orientation of the ultrasound transducer during a transverse ultrasound scan for the lateral femoral cutaneous nerve at the inguinal region. Note the ultrasound transducer is positioned a few centimeters distal and medial to the anterior superior iliac spine.

FIGURE 3-34 Figure highlighting the anatomical structures that are insonated during a transverse ultrasound scan for the lateral femoral cutaneous nerve at the inguinal region.
FIGURE 3-35 Transverse sonogram of the inguinal region at the level of the anterior superior iliac spine showing the lateral cutaneous nerve of the thigh lying on the anterior surface (superficial to) the iliacus muscle.

4. **Sonoanatomy:** The lateral cutaneous nerve of the thigh is a small nerve that may appear as a hypoechoic to hyperechoic structure. At the level of the inguinal ligament, it lies medial to the ASIS and deep to the fascia iliacus. It then courses distally in the groove between the sartorius and iliacus, crossing over the anterior surface of the sartorius (Fig. 3-35) to the lateral aspect of the sartorius muscle.

5. **Clinical Pearls:** The lateral cutaneous nerve of the thigh is a small nerve and can be best visualized using a high-frequency linear transducer. The “trace back” technique is important and useful to confirm the identity of the nerve. The important landmarks here are the medial edge of the ASIS, the groove between the sartorius and iliacus, and the anterior surface of the sartorius. The nerve can usually be located at one of these areas and “traced back” to confirm its identity along the course. Injection of a small volume of normal saline around the nerve can be used to delineate its course (hydrolocation). It is common to see the injectate spread along its course proximally under the inguinal ligament and under the fascia iliaca within the pelvis.

**Saphenous Nerve at the Adductor Canal**

**Gross Anatomy**

Distal to the inguinal crease, the femoral nerve divides into its terminal branches. The saphenous nerve is a branch of the anterior division of the femoral nerve and supplies the skin on the medial aspect of the leg and foot up to the ball of the big toe. It travels with the femoral artery within the anterior fascial compartment of the thigh under the sartorius muscle (subsartorial), and local anesthetic injected into this intermuscular space produces saphenous nerve block. The “subsartorial canal” is also referred to as the adductor canal or Hunter’s canal and is located on the medial aspect of the middle one-third of the thigh (Fig. 3-36). The adductor canal is triangular in cross-section (Figs. 3-37 and 3-38) and extends from the apex
of the femoral triangle, above, to the tendinous opening in the adductor magnus muscle (adductor hiatus), below. The anterior wall of the adductor canal is formed by the vastus medialis muscle; the posterior wall or floor is formed by the adductor longus, above, and the adductor magnus, below; and the roof or medial wall is formed by a strong fibrous membrane underlying the sartorius muscle (Figs. 3-37 and 3-38).

The adductor canal contains the following structures: femoral artery and vein, saphenous nerve, anterior and posterior division of the obturator nerve, and nerve to vastus medialis (Fig. 3-38). The femoral vein lies posterior to the femoral artery in the upper part of the adductor canal and lateral to the artery in the lower part of the canal (Fig. 3-39). The saphenous nerve crosses the femoral artery anteriorly from a lateral to medial direction. The “subsartorial plexus” of nerves lie on the fibrous roof of the adductor canal deep to the sartorius muscle (Fig. 3-38) and are formed by branches from the medial cutaneous nerve of the thigh, saphenous nerve, and anterior division of the obturator nerve. It supplies the neighboring skin and overlying fascia lata. The femoral artery exits the adductor canal through the adductor hiatus and continues as the popliteal artery. At the adductor hiatus, the saphenous nerve leaves the femoral artery and travels along the lower edge of the aponeurosis of the canal and is closely related to the saphenous branch of the descending genicular artery. The saphenous nerve then courses distally along the medial side of the knee deep to the sartorius and pierces the fascia lata, between the tendons of the sartorius and gracilis muscles.

**FIGURE 3-36** Transverse anatomical section of the mid thigh showing the anatomy of the anterior, medial, and posterior compartment of the thigh.
FIGURE 3-37  Transverse anatomical illustration of the midthigh showing the anatomy of the adductor canal.

FIGURE 3-38  Anatomical illustration showing the boundaries and contents of the adductor canal.
FIGURE 3-39  Anatomical illustration showing the course of the saphenous nerve relative to the femoral vessels within the adductor canal.

Computed Tomography Anatomy of the Midfemoral/Adductor Canal Region

Fig. 3-40

FIGURE 3-40  Transverse (axial) CT of the midthigh showing the relation and contents of the adductor canal.

Magnetic Resonance Imaging Anatomy of the Midfemoral/Adductor Canal Region
Midfemoral/Adductor Canal Region Ultrasound Scan Technique

1. **Position:**
   a. **Patient:** Supine position with the ipsilateral hip slightly externally rotated and knee slightly flexed.
   b. **Operator and ultrasound machine:** The operator may choose to position the ultrasound machine based on his or her “handedness.” Right-handed operators who hold ultrasound probes with their left hand and carry out needle interventions with their right hand should stand on the right side of the patient and position the ultrasound machine on the opposite side of the patient. This is vice versa for left-handed operators.

2. **Transducer selection:** High-frequency (15-8 MHz) linear array transducer. A curved array low-frequency (5-2 MHz) transducer can also be used if one wishes to visualize the sciatic nerve, which is located at a depth, at the same time.

3. **Scan technique:** The ultrasound transducer is placed on a medial aspect of the thigh of the middle third of the thigh (midfemoral region) in the transverse orientation (Figs. 3-42 to 3-46). The reference structure to identify is the femoral artery in the transverse view. Thereafter slide the transducer along the medial border of the sartorius to visualize the artery at its most superficial location and just proximal to the point where the femoral artery passes the adductor hiatus to become the popliteal artery. The sartorius is typically triangular/elliptical in shape when imaged transversely. Beneath the sartorius, the femoral artery and veins can be imaged and followed until they pass through the adductor hiatus.

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**FIGURE 3-41** Transverse (axial) MRI image of the midthigh showing the relation and contents of the adductor canal.
FIGURE 3-42  Figure showing the position of the ultrasound transducer relative to the thigh during a transverse ultrasound scan for the saphenous nerve at the adductor canal (midthigh).
FIGURE 3-43 Figure showing the position and orientation of the ultrasound transducer during a transverse ultrasound scan of the adductor canal at the midthigh.

FIGURE 3-44 Figure highlighting the anatomical structures that are insonated during a transverse ultrasound scan of the adductor canal at the midthigh.
**FIGURE 3-45** Figure highlighting the anatomical structures that are imaged during a transverse ultrasound scan at the level of the midthigh using a low-frequency transducer. Note that the sciatic nerve is also included in the highlighted area and can be visualized during the midthigh (midfemoral) scan.

**FIGURE 3-46** Anatomical structures that are visualized during a midfemoral (midthigh) ultrasound scan.

4. **Sonoanatomy:** The saphenous nerve is a small nerve and may not be visualized as a discrete structure in all individuals at the adductor canal. When visualized, it is seen as a
hyperechoic structure that is closely related to the femoral artery (Fig. 3-47).

5. Clinical Pearls: Because the saphenous nerve is a small nerve, the trace back technique is useful for locating it. It can also be followed distally where it lies between the sartorius and the gracilis muscles and with the saphenous branch of the descending genicular artery. When there is difficulty visualizing the saphenous nerve, imaging the most superficial portion of the distal adductor canal and using a periarterial injection deep to the sartorius, medial to the artery is adequate for a successful saphenous nerve block.

Sciatic Nerve at the Parasacral Region

Gross Anatomy

A parasacral sciatic nerve block is the technique of injecting local anesthetic in a fascial plane around the nerves of the sacral plexus before the sciatic nerve is formed. Therefore, it may be considered a sacral plexus block. Currently, the majority of published data describe using peripheral nerve stimulation but recently ultrasound-guided parasacral sciatic nerve block has been described. Because the sacral plexus is located deep within the pelvis in a fascial plane between the piriformis muscle and the pelvic fascia (Figs. 3-2 and 3-3), the block needle has to enter the pelvis through the greater sciatic foramen during a parasacral sciatic nerve block (Fig. 3-48). The internal iliac artery and vein or their branches and the pelvic veins are also closely related to the sacral plexus in the pelvis (Figs. 3-49 to 3-51). The following structures also pass through the greater sciatic foramen: (a) piriformis muscle; (b) structures passing above the piriformis muscle: superior gluteal vessels and nerve; and (c) structures passing below the piriformis: inferior gluteal vessels and nerve, sciatic nerve, posterior cutaneous nerve of thigh, nerve to quadratus femoris muscle, pudendal nerve and vessels, and nerve to obturator internus.
FIGURE 3-48  ■ Anatomical illustration showing the sacral plexus (within the pelvis) formation of the sciatic nerve and how it exits the pelvis through the greater sciatic foramen to enter the gluteal region. Note in this anatomical section one of the components of the sciatic nerve is seen to exit the pelvis by traversing the piriformis muscle to join the other component in the infrapiriformis fossa (a normal anatomical variation).

FIGURE 3-49  ■ Sagittal oblique CT image demonstrating the sciatic nerve between the ilium and ischium (greater sciatic foramen).
FIGURE 3-50  Sagittal oblique CT image depicting the parasacral relations and course of the sciatic nerve in the gluteal region. Note the close proximity of the iliac veins and large bowel to the sacral plexus and sciatic nerve at the level of the greater sciatic foramen.

FIGURE 3-51  Sagittal oblique MRI image at the level of the greater sciatic foramen demonstrating the sacral plexus and the parasacral relation of the sciatic nerve.

Computed Tomography Anatomy of the Sciatic Nerve – Parasacral Region
Figs. 3-49 and 3-50
Magnetic Resonance Imaging Anatomy of the Sciatic Nerve – Parasacral Region
Sciatic Nerve – Parasacral Region Ultrasound Scan Technique

1. **Position:**
   
   a. **Patient:** Semiprone (Sims’) position with the side to be examined uppermost and the upper hip flexed to about 90 degrees.
   
   b. **Operator and ultrasound machine:** The operator sits or stands behind the patient with the ultrasound machine placed directly in front.

2. **Transducer selection:** Low-frequency (5-2 MHz) curved array transducer.

3. **Scan technique:** Various techniques for identifying the sonoanatomy relevant for parasacral sciatic nerve block have been described in the literature. We prefer to start the ultrasound scan by placing the transducer in the transverse orientation between the greater trochanter and ischial tuberosity. Here the sciatic nerve is consistently identified as a hyperechoic oval structure in the subgluteal space between the gluteus maximus muscle posteriorly and the quadratus femoris muscle anteriorly. The ultrasound image is optimized after which the transducer is rotated through 90 degrees to obtain a sagittal view of the sciatic nerve. Then gently slide the transducer cephalad, keeping the sciatic nerve in view until it is seen to lie in the infrapiriformis fossa between the gluteus maximus posteriorly and the gemelli muscles and tendon of obturator internus anteriorly (Figs. 3-52 to 3-54). Dynamic scanning by asking an assistant to rotate the hip (externally and internally), with the knee flexed, will demonstrate a side-to-side gliding motion of the piriformis muscle on the ultrasound image. Color or Power Doppler ultrasound can be used to identify the inferior gluteal artery, which emerges from under the inferior border of the piriformis muscle. The inferior border of the ilium and ischium, with their acoustic shadows, and the greater sciatic foramen can then be delineated in the sagittal sonogram. One can then rotate the transducer to the transverse orientation to obtain a transverse view of the sciatic nerve as it exits the pelvis through the greater sciatic foramen (Figs. 3-55 and 3-56).
FIGURE 3-52 Figure showing the position of the ultrasound transducer during a sagittal scan for the sacral plexus and sciatic nerve at the level of the greater sciatic foramen (parasacral scan).

FIGURE 3-53 Figure highlighting the anatomical structures that are insonated during a sagittal ultrasound scan for the sacral plexus and sciatic nerve at the level of the greater sciatic foramen (parasacral scan).
FIGURE 3-54  Sagittal sonogram of the sciatic nerve as it exits the pelvis through the greater sciatic foramen. Accompanying photograph shows the position and orientation of the ultrasound transducer during a sagittal ultrasound scan for the sacral plexus and sciatic nerve at the level of the greater sciatic foramen (parasacral scan). RPS, retroperitoneal space.

FIGURE 3-55  Figure showing the position of the ultrasound transducer during a transverse scan for the sciatic nerve at the level of the greater sciatic foramen (parasacral scan).
4. **Sonoanatomy:** The sciatic nerve appears as a thick, hyperechoic linear structure in a sagittal sonogram of this region (Figs. 3-57 and 3-58). In some individuals a distinct perineural space, similar to that seen at the subgluteal space or thigh, can be delineated at the parasacral region (Figs. 3-57 and 3-58). Proximally the greater sciatic foramen is seen as an acoustic window between the acoustic shadows of the inferior border of the ilium and the ischium (Fig. 3-57). The pelvic peritoneum can be identified as a hyperechoic linear shadow through this acoustic window, and the sacral plexus nerves appear as hyperechoic linear elements posterior (external) to the peritoneum (Fig. 3-57). The inferior gluteal artery can also be identified using Doppler ultrasound (Fig. 3-59). On a transverse sonogram at the level or just distal to the greater sciatic foramen, the sciatic nerve is seen as a flat-to-oval hyperechoic structure in between the gluteus maximus and gemelli muscles (Fig. 3-60).

**FIGURE 3-56** Transverse sonogram of the sciatic nerve as it exits the pelvis through the greater sciatic foramen. Accompanying photograph shows the position and orientation of the ultrasound transducer during a transverse ultrasound scan for the sciatic nerve at the level of the greater sciatic foramen (parasacral scan). RPS, retroperitoneal space.
**FIGURE 3-57** Sagittal sonogram at the level of the greater sciatic foramen (parasacral scan) showing the sacral plexus and the sciatic nerve as it exits the pelvis to enter the infra-piriformis fossa.

**FIGURE 3-58** Sagittal sonogram showing the sciatic nerve, between the piriformis muscle posteriorly and the gemelli muscles anteriorly, immediately distal to the greater sciatic foramen. Note the hypoechoic perineural space between the sciatic nerve and the piriformis muscle posteriorly. The sciatic nerve is also seen to continue distally to enter the subgluteal space between the gluteus maximus posteriorly and the quadratus femoris anteriorly.
5. **Clinical Pearls:** Because the parasacral sciatic nerve block is a deep block with potential for complications such as pelvic hematoma formation, visceral injury (colon or ureter), inadvertent intravascular injection, transient sciatic neuralgia, we believe it should be considered an advanced regional anesthetic technique and only used when other sciatic nerve block techniques are considered inadequate or inappropriate. Also the presence of an “intermuscular perineural space” through which the sciatic nerve exits the pelvis and
descends caudally deserves further investigation as a site for local anesthetic injection because it can be identified using ultrasound imaging (Figs. 3-57 and 3-58). We believe that local anesthetic injected into this perineural space close to the greater sciatic foramen will not only anesthetize the sacral plexus nerves, but also the sciatic nerve because of cranial and caudal spread of the local anesthetic through the intermuscular “conduit.” This may also be safer than inserting the block needle into the pelvis to anesthetize the sacral plexus nerves during a parasacral sciatic nerve block. Future research to validate this hypothesis in clinical practice is warranted.

Sciatic Nerve – At the Subgluteal Region

Gross Anatomy

Once the sciatic nerve exits the greater sciatic foramen, it enters the subgluteal space below the piriformis muscle. It then descends on the dorsal surface of the ischium, together with the posterior cutaneous nerve of the thigh, lying on the posterior surface of the gemellus superior muscle, tendon of obturator internus, gemellus inferior muscle, and the quadratus femoris muscle (in a cranial to caudal direction) before it enters the hollow between the greater trochanter and the ischial tuberosity (Figs. 3-5 to 3-7). The “subgluteal space” is a well-defined anatomical space between the anterior surface of the gluteus maximus and the posterior surface of the quadratus femoris muscle (Fig. 3-61) and contains the sciatic nerve, posterior cutaneous nerve of the thigh, inferior gluteal vessels and nerve, nerve to the short and long heads of the biceps femoris, the comitans artery and vein of the sciatic nerve, and the ascending branch of the medial circumflex femoral artery (Fig. 3-7).23

![Anatomical illustration showing the sciatic nerve at the subgluteal space between the gluteus maximum muscle posteriorly and the quadratus femoris muscle anteriorly.](http://radiologyme.com/)

**FIGURE 3-61** Anatomical illustration showing the sciatic nerve at the subgluteal space between the gluteus maximum muscle posteriorly and the quadratus femoris muscle anteriorly.

**Computed Tomography Anatomy of the Sciatic Nerve – Subgluteal Region**
FIGURE 3-62 Transverse (axial) CT image demonstrating the subgluteal space at the level of the greater trochanter and ischial tuberosity. Note the subgluteal space between the gluteus maximus muscle posteriorly and the quadratus femoris muscle anteriorly.

Magnetic Resonance Imaging Anatomy of the Sciatic Nerve – Subgluteal Region

FIGURE 3-63 Transverse (axial) MRI image demonstrating the subgluteal space, between the gluteus maximus muscle posteriorly and the quadratus femoris muscle anteriorly, at the level of the greater trochanter and ischial tuberosity. Note the tendons of semitendinosus and biceps femoris at the medial end of the subgluteal space.
Sciatic Nerve at the Subgluteal Region – Ultrasound Scan Technique

1. Position:
   a. Patient: Lateral position with the side to be examined uppermost (nondependent side) and the hip and knees slightly flexed. It is also possible to position the patient in the semiprone (Sims’) position.
   b. Operator and ultrasound machine: The operator sits or stands behind the patient with the ultrasound machine placed directly in front.

2. Transducer selection: Low-frequency (5-2 MHz) curved array transducer.

3. Scan technique: The ultrasound transducer is placed parallel to a line joining the greater trochanter and the ischial tuberosity (Figs. 3-64 to 3-66) to obtain a transverse image of the sciatic nerve in the subgluteal space. It may be necessary to slide the transducer in a cranial to caudal direction to obtain an optimal image of the sciatic nerve. The greater trochanter and the ischial tuberosity are visualized at the edges of the ultrasound image. They appear hyperechoic with a corresponding acoustic shadow and are key landmarks for imaging this region. Rotating the transducer through 90 degrees produces a sagittal image of the sciatic nerve and the subgluteal space.

**FIGURE 3-64** Figure showing the position of the ultrasound transducer during a
transverse scan for the sciatic nerve at the level of the subgluteal space between the greater trochanter and ischial tuberosity.

**FIGURE 3-65** Figure showing the position and orientation of the ultrasound transducer during a transverse scan for the sciatic nerve at the subgluteal space between the greater trochanter and ischial tuberosity.

**FIGURE 3-66** Figure highlighting the anatomical structures that are insonated during a transverse ultrasound scan for the sciatic nerve at the subgluteal space between the greater trochanter and ischial tuberosity.

4. **Sonoanatomy:** The sciatic nerve in the subgluteal region appears as a triangular to oval
hyperechoic structure approximately 1.5 to 2 cm in diameter and lying deep to the gluteus maximus muscle. The sciatic nerve is visualized in a hypoechoic space, the “subgluteal space,” between the epimysium of the gluteus maximus muscle and the quadratus femoris muscle (Fig. 3-67). Although well defined, the subgluteal space can vary in width, is more prominent close to the greater trochanter, and is generally obscured close to the ischial tuberosity (Fig. 3-67). This may be due to the attachment of the tendon of biceps femoris and semitendinosus to the ischial tuberosity (Fig. 3-63). The subgluteal space also extends in a cranial and caudal direction as an intermuscular perineural tunnel or as a conduit for the sciatic nerve. This is clearly visualized on a sagittal sonogram (Fig. 3-68), multiplanar 3-D ultrasound images (Fig. 3-69), or i-slice display (Fig. 3-70) of the subgluteal region.

**FIGURE 3-67** Transverse sonogram demonstrating the hypoechoic subgluteal space between the hyperechoic epimysium of the gluteus maximus muscle and the quadratus femoris muscle. The sciatic nerve is seen as a hyperechoic nodule in the medial aspect of the subgluteal space. Also note the origin of the tendon of biceps femoris from the ischial tuberosity.
FIGURE 3-68  Sagittal sonogram in color mode demonstrating the hypoechoic subgluteal space and sciatic nerve between the hyperechoic epimysium of the gluteus maximus muscle posteriorly and the quadratus femoris muscle anteriorly.
FIGURE 3-69 A multiplanar 3-D view of the sciatic nerve at the subgluteal space, between the greater trochanter and ischial tuberosity. The “reference maker” (green crosshair) has been placed over the sciatic nerve and corresponding views of the sciatic nerve in the transverse, sagittal, and coronal planes are visualized. GT, greater trochanter; IT, ischial tuberosity.
FIGURE 3-70 A transverse i-slice display of the sciatic nerve at the subgluteal space in color (sepia tone) mode. In this figure 16 contiguous sagittal cuts of the sciatic nerve volume, which are 0.9 mm apart, are displayed.

5. **Clinical Pearls:** The sciatic nerve exhibits anisotropy at the subgluteal region and requires slight tilting or rotation of the transducer during the ultrasound scan to clearly delineate the nerve. Color or Power Doppler ultrasound is useful in delineating the inferior gluteal artery, which is close to the sciatic nerve in the subgluteal space.

**Sciatic Nerve at the Infragluteal Region**

**Gross Anatomy**

After the sciatic nerve descends from the subgluteal space, it enters the back of the thigh
lying relatively superficial at the infragluteal region (ie, below the gluteal crease). Here the sciatic nerve is relatively flat in shape and lies in an intermuscular fascial plane between the lower slips of the gluteus maximus and biceps femoris muscle posteriorly and the adductor magnus muscle anteriorly (Figs. 3-71 and 3-72).

**FIGURE 3-71** Transverse anatomical section of the thigh showing the sciatic nerve at the infragluteal location (ie, distal to the inferior border of the gluteus maximus). Note the sciatic nerve is relatively superficial and located between the biceps femoris muscle posteriorly and the adductor magnus muscle anteriorly. Some of the lower slips of the gluteus maximus muscle are also seen posterior to the biceps femoris muscle.

**FIGURE 3-72** Sagittal anatomical section of the thigh showing the sciatic nerve at the infragluteal location.
**Computed Tomography Anatomy of the Sciatic Nerve – Infragluteal Region**

Fig. 3-73

![Diagram of CT image of the thigh showing the relations of the sciatic nerve at the infragluteal location.](image1)

**FIGURE 3-73** ■ Transverse (axial) CT image of the thigh showing the relations of the sciatic nerve at the infragluteal location. FA, femoral artery; FV, femoral vein; PFA, profunda femoris artery; PFV, profunda femoris vein.

**Magnetic Resonance Anatomy of the Sciatic Nerve – Infragluteal Region**

Fig. 3-74

![Diagram of MRI image of the thigh showing the relations of the sciatic nerve at the infragluteal location.](image2)

**FIGURE 3-74** ■ Transverse (axial) MRI image of the thigh showing the relations of the sciatic nerve at the infragluteal location. Note the posterior femoral cutaneous nerve of the leg.
thigh on the posterior aspect of the semitendinosus muscle.

**Sciatic Nerve at the Infragluteal Region – Ultrasound Scan Technique**

1. **Position:**
   a. **Patient:** Lateral position with the side to be examined uppermost (nondependent side) and the hip and knees slightly flexed. It is also possible to position the patient in the semiprone (Sims’) or prone position.
   b. **Operator and ultrasound machine:** The operator sits or stands behind the patient with the ultrasound machine placed directly in front.

2. **Transducer selection:** Because the sciatic nerve is relatively superficial at this level, it is possible to use a high-frequency (12-5 MHz) linear array transducer for the ultrasound scan. We prefer to use a low-frequency (5-2 MHz) curved array transducer because it provides a wider field of view.

3. **Scan technique:** Start by placing the ultrasound transducer parallel to a line joining the greater trochanter and the ischial tuberosity as described earlier for the sciatic nerve at the subgluteal space (Figs. 3-75 to 3-77). Once the sciatic nerve is identified in the transverse sonogram, slide the transducer caudally until it is below the gluteal crease. The sciatic nerve is seen lying superficially between the biceps femoris muscle posteriorly and the adductor magnus muscle anteriorly. It is not uncommon to visualize the lower slips of the gluteus maximus muscle posterior to the biceps femoris muscle in the transverse sonogram.
FIGURE 3-75 Figure showing the position of the ultrasound transducer during a transverse scan for the sciatic nerve at the infragluteal position.
4. **Sonoanatomy:** The sciatic nerve is visualized as a triangular hyperechoic structure between the biceps femoris muscle posteriorly and the adductor magnus muscle anteriorly (Fig. 3-78). Some of the lower slips of the gluteus maximus muscle may also be visualized posterior to the biceps femoris muscle in the transverse sonogram.
FIGURE 3-78 ■ Transverse sonogram showing the sciatic nerve as an oval-to-elliptical hyperechoic structure between the gluteus maximus muscle posteriorly and the adductor magnus anteriorly at the infragluteal position.

5. **Clinical Pearls:** Because the sciatic nerve is relatively superficial at the infragluteal region, it is a recommended site for sciatic nerve block in the obese.

**Sciatic Nerve at the Popliteal Fossa**

**Gross Anatomy**

The popliteal fossa is a diamond-shaped space that lies posterior to the knee joint, lower part of the femur, and upper part of the tibia (Fig. 3-79). It is bound superolaterally by the tendon of biceps femoris, superomedially by the tendon of semitendinosus and semimembranosus, inferolaterally by the lateral head of gastrocnemius, and inferomedially by the medial head of gastrocnemius (Fig. 3-79). The sciatic nerve descends vertically downwards from the infragluteal region to the apex of the superior triangle of the popliteal fossa, lying deep to the biceps femoris and semitendinosus muscle, where it terminates by dividing into its terminal branches, the tibial and common peroneal nerves (Figs. 3-80 to 3-82), at a variable distance (3–7 cm) from the popliteal crease. The tibial nerve is the larger terminal branch of the sciatic nerve. It lies relatively superficial near the popliteal crease, with only overlying subcutaneous tissue, and extends from the superior angle to the inferior angle of the popliteal fossa. During its descent the tibial nerve crosses the popliteal vessels from a lateral to medial side. The common peroneal nerve extends from the superior angle to the lateral angle of the popliteal fossa along the medial border of the biceps femoris muscle. Continuing downwards the common peroneal nerve winds around the posterolateral aspect of the neck of the fibula, pierces the peroneus longus muscle, and then divides into the superficial and deep peroneal nerves.
FIGURE 3-79  Anatomical illustration showing the sciatic nerve at the popliteal fossa.

FIGURE 3-80  Transverse anatomical illustration showing the relations of the tibial and common peroneal nerve at the popliteal fossa.
FIGURE 3-81 Transverse anatomical section of the lower thigh showing the anatomy of the sciatic nerve before its division into the tibial and common peroneal nerve at the popliteal fossa.

FIGURE 3-82 Transverse anatomical section of the lower thigh showing the sciatic nerve after its division into the tibial and common peroneal nerves at the popliteal fossa.

Computed Tomography Anatomy of the Popliteal Fossa
Figs. 3-83 to 3-85
FIGURE 3-83  Transverse (axial) CT image of the lower thigh showing the anatomy of the sciatic nerve before its division into the tibial and common peroneal nerve at the popliteal fossa. Note the large fat-filled perineural space (intermuscular tunnel) surrounding the sciatic nerve.

FIGURE 3-84  Transverse (axial) CT image of the lower thigh showing the anatomy of the sciatic nerve after its division into the tibial and common peroneal nerve at the popliteal fossa. The perineural space is also delineated at this level.
FIGURE 3-85 Coronal CT image of the thigh showing the relations of the sciatic nerve. Note the large fat-filled perineural space (intermuscular tunnel) surrounding the sciatic nerve. Please refer to Figs. 3-82 and Fig. 3-83 for the corresponding transverse CT images.

Magnetic Resonance Imaging Anatomy of the Popliteal Fossa

Figs. 3-86 to 3-88
FIGURE 3-86  Transverse (axial) MRI image of the lower thigh showing the relations of the sciatic nerve before its division into the tibial and common peroneal nerve. The perineural space is clearly delineated and filled with hyperintense fat.

FIGURE 3-87  Transverse (axial) MRI image of the lower thigh showing the relations of the sciatic nerve after its division into the tibial and common peroneal nerve.
Sciatic Nerve at the Popliteal Fossa – Ultrasound Scan Technique

1. **Position:**
   
a. **Patient:** Prone position with the knee slightly bent and ankle supported.

   b. **Operator and ultrasound machine:** The operator sits or stands on the side to be examined and faces the patient’s head. The ultrasound machine is placed on the same side between the operator and the patient’s head. Alternatively, the operator may choose to position the ultrasound machine based on his or her “handedness.” Right-handed operators who hold ultrasound probes with their left hand and carry out needle interventions with their right hand should stand on the right side of the patient and position the ultrasound machine on the opposite side of the patient. This is vice versa for left-handed operators.

2. **Transducer selection:** Because the sciatic nerve or its branches are relatively superficial at the popliteal fossa, a high-frequency (13-5 or 15-8 MHz) linear array transducer is adequate for imaging.

3. **Scan technique:** The transducer is placed in the transverse orientation at the lower thigh (Figs. 3-89 to 3-91). Slowly slide the transducer distally towards the popliteal crease. The sciatic nerve is typically oval in shape in the lower thigh and can be seen to bifurcate into its terminal branches at the popliteal fossa. Close to the popliteal crease, the popliteal artery and vein can be visualized on the posteromedial aspect of the sciatic nerve.
FIGURE 3-89 Figure showing the position of the ultrasound transducer during a transverse scan for the sciatic nerve at the popliteal fossa.
4. Sonoanatomy: The sciatic nerve appears as an oval hyperechoic structure in the mid to lower thigh (Fig. 3-92). It divides into its terminal branches at a variable distance from the popliteal crease (Fig. 3-93). A hypoechoic perineural space surrounds the sciatic nerve at the thigh (Figs. 3-94 and 3-95). This is continuous with the perineural space in the subgluteal (Figs. 3-67 and 3-68) and parasacral (Figs. 3-57 and 3-58) regions and acts like an intermuscular tunnel or conduit through which the sciatic nerve travels from the parasacral region to the popliteal fossa. With high-definition ultrasound imaging it is now possible to delineate an additional hyperechoic layer of connective tissue that is interposed between the epimysium of the surrounding muscle and the outer surface (epineurium) of the sciatic nerve (Figs. 3-95 and 3-96). This represents the “paraneural sheath,” which is distinct from the epineurium and better delineated after local anesthetic injection (Fig. 3-97) and envelopes not only the sciatic nerve but also the common peroneal and tibial nerves separately. Local anesthetic injected during a popliteal sciatic nerve block is seen to compartmentalize into two areas around the sciatic nerve (Fig. 3-97)—that is, subepimyseal (but external to the paraneural sheath) and subparaneural (beneath or deep to the paraneural sheath). The subepimyseal perineural compartment (Fig. 3-96), also referred to as the perineural space, is a well-defined intermuscular space surrounding the sciatic nerve. It is filled with fat and blood vessels and clearly delineated in ultrasound (2-D and 3-D), CT (Figs. 3-83 to 3-85), and MRI images (Figs. 3-86 and 3-87) of the thigh. In contrast the subparaneural compartment is a potential space with a thin layer of fat separating the paraneural sheath from the epineurium of the nerve (Fig. 3-96) and serves like a “plane of cleavage” that provides some degree of mobility and protection to the neural elements housed within.
FIGURE 3-92 Transverse sonogram showing the sciatic nerve as a hyperechoic structure between the hyperechoic epimysium of the biceps femoris muscle posteriorly and the adductor magnus muscle anteriorly at the lower thigh. Also note an additional hyperechoic layer of connective tissue posterior to the sciatic nerve which represents the “paraneural sheath.” The hypoechoic perineural space is also seen posteriorly between the epimysium of the biceps muscle posteriorly and the sciatic nerve.

FIGURE 3-93 Transverse sonogram showing the sciatic nerve after its division into the tibial and common peroneal nerve at the popliteal fossa. Note the relations of the tibial nerve to the popliteal vessels and common peroneal nerve to the biceps femoris muscle (tendon). PA, popliteal artery; PV, popliteal vein.
FIGURE 3-94  Sagittal sonogram showing the sciatic nerve as a hyperechoic structure within a narrow hypoechoic space (perineural space) between the hyperechoic epimysium (short white arrows) of the surrounding muscles at the lower thigh.

FIGURE 3-95  High-definition transverse sonogram of the sciatic nerve at the level of its bifurcation into the tibial and common peroneal nerve at the popliteal fossa. The paraneural sheath (white arrow heads) is interposed between the epimysium (short white arrows) of the surrounding muscles and the outer surface of the sciatic nerve (epineurium), which also appears hyperechoic. The subepimysial (perineural) and subparaneural compartments are seen as hypoechoic areas between the epimysium and the paraneural sheath and between the paraneural sheath and the epineurium, respectively.
FIGURE 3-96  Schematic diagram illustrating the fascial compartments surrounding the sciatic nerve at the popliteal fossa. CPN, common peroneal nerve; TN, tibial nerve.

FIGURE 3-97  Multiplanar 3-D view of the common peroneal (CPN) and tibial (TN) nerve at the popliteal fossa after an ultrasound-guided sciatic nerve block. A rendered 3D volume demonstrating the front, right, and top surfaces of the volume is also presented in Fig. 3-97D. The reference marker has been placed over the tibial nerve (Fig. 3-97A). Spread of the local anesthetic (LA) relative to the sciatic nerve and its divisions or the paraneural sheath is clearly delineated in the multiplanar views.
5. Clinical Pearls: The site where the sciatic nerve bifurcates into its terminal branches at the popliteal fossa is best identified using the “trace back” technique. One can also locate the popliteal artery to identify the tibial nerve as it lies posterior and lateral to the artery.

Sciatic Nerve at the Thigh – Anterior Approach

Gross Anatomy

The anterior approach for sciatic nerve block is technically demanding and generally performed when the patient cannot be positioned in the lateral decubitus position. It produces complete anesthesia of the leg below the knee joint except for the skin on the medial aspect of the leg and foot supplied by the saphenous nerve. The point for needle insertion is approximately 6 to 7 cm distal to the inguinal crease with the patient in the supine position.27 This usually corresponds to the level of the lesser trochanter of the femur in the thigh (Figs. 3-98 to 3-100). In a transverse anatomical section of the thigh at this level, the sciatic nerve lies deep in between the adductor magnus or quadratus femoris muscle anteriorly and the gluteus maximus muscle posteriorly (Figs. 3-22 and 3-98).

**FIGURE 3-98** Transverse anatomical section of the upper thigh at the level of the lesser trochanter.
FIGURE 3-99 Transverse (axial) CT image of the upper thigh at the level of the lesser trochanter. PFA, profunda femoris artery.

FIGURE 3-100 Transverse (axial) MRI image of the upper thigh at the level of the lesser trochanter. PFA, profunda femoris artery.

Computed Tomography Anatomy of the Sciatic Nerve at the Thigh
Fig. 3-99

Magnetic Resonance Imaging Anatomy of the Sciatic Nerve at the Thigh
Fig. 3-100
Sciatic Nerve at the Thigh – Anterior Approach Ultrasound Scan Technique

1. **Position:**
   a. **Patient:** Supine with the leg fully extended and slightly internally rotated.\(^{28}\)
   b. **Operator and ultrasound machine:** The operator may choose to position the ultrasound machine based on his or her “handedness.” Right-handed operators who hold ultrasound probes with their left hand and carry out needle interventions with their right hand should stand on the right side of the patient and position the ultrasound machine on the opposite side of the patient. This is vice versa for left-handed operators.

2. **Transducer selection:** Low-frequency (5-2 MHz) curve array transducer.

3. **Scan technique:** The transducer is placed on the medial aspect of the thigh approximately 6 to 7 cm distal and parallel to the inguinal crease in a transverse orientation (Figs. 3-101 to 3-103). The reference structure to visualize is the femur (lesser trochanter). Once visualized, slide the transducer medially to bring the femur to the lateral edge of the ultrasound image. The sciatic nerve is visualized as a hyperechoic structure between the adductor magnus muscle anteriorly and gluteus maximus muscle posteriorly (Fig. 3-104).

**FIGURE 3-101** Figure showing the position of the ultrasound transducer during a...
transverse scan for the sciatic nerve at the upper thigh during an anterior approach for sciatic nerve block.

**FIGURE 3-102** Figure showing the position and orientation of the ultrasound transducer during a transverse scan for the sciatic nerve at the upper thigh during an anterior approach for sciatic nerve block. GT, greater trochanter; ASIS, anterior superior iliac spine.

**FIGURE 3-103** Figure highlighting the anatomical structures that are insonated during a transverse ultrasound scan for the sciatic nerve at the upper thigh during an anterior approach for sciatic nerve block.
4. **Sonoanatomy:** In a transverse sonogram the sciatic nerve is typically visualized as an elliptical and hyperechoic structure between the adductor magnus and gluteus maximus muscle (Fig. 3-104). This can be confirmed by rotating the transducer to the sagittal orientation in relation to the femur to visualize the hyperechoic laminated appearance of the sciatic nerve.

5. **Clinical Pearls:** The anterior approach for sciatic nerve block is an advanced regional anesthetic technique and can be technically demanding. The sciatic nerve is deep at this level, and there are no reference vascular structures in close vicinity. The sagittal axis may be superior to the transverse axis for visualizing the sciatic nerve at this level.

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**Terminal Nerves in the Leg**

**Gross Anatomy**

The four terminal nerves of the leg below the knee provide sensation and motor function to the foot and ankle (Figs. 3-105 to 3-107). The tibial nerve is a terminal branch of the sciatic nerve. It lies deep to the gastrocnemius and soleus muscles and on the posterior surface of the tibialis posterior muscle (Fig. 3-106). The tibial nerve accompanies the posterior tibial artery (Fig. 3-106) and at the level of the medial malleolus lies medial to the artery and lateral to the flexor hallucis longus tendon under the flexor retinaculum (Figs. 3-108 and 3-109). The saphenous nerve is a terminal branch of the femoral nerve (Fig. 3-110). It typically pierces the deep fascia on the medial aspect of the knee after emerging between the tendons of the sartorius and gracilis. It then travels down the leg superficially along the course of the great saphenous vein (Figs. 3-105 to 3-107, 3-110, and 3-111).

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FIGURE 3-104 ▶ Sonogram demonstrating the sciatic nerve at the upper thigh at the level of the lesser trochanter during an anterior approach for sciatic nerve block.
FIGURE 3-105 Transverse anatomical illustration of the leg at the level of the tibial tuberosity.

FIGURE 3-106 Transverse anatomical illustration of the leg above the middle of the leg.
FIGURE 3-107 Transverse anatomical illustration of the leg above the medial malleolus.

FIGURE 3-108 Transverse anatomical section through the distal leg at the ankle region demonstrating tibial nerve. TA, tibialis anterior; FDL, flexor digitorum longus; FHL, flexor hallucis longus; PB, peroneus brevis; PL, peroneus longus.
FIGURE 3-109  Anatomical illustration of the foot and ankle demonstrating the relations of the tibial nerve on the medial aspect of the ankle.

FIGURE 3-110  Anatomical illustration demonstrating the saphenous and tibial nerves on the medial aspect of the foot.
FIGURE 3-111 Transverse anatomical section through the distal leg at the level of the ankle. The saphenous nerve is located in the same fascial plane as the saphenous vein.

The deep peroneal nerve is a terminal branch of the common peroneal nerve and originates within the substance of the peroneus longus muscle on the lateral aspect of the proximal fibula. The nerve enters the anterior compartment of the leg by piercing the interosseous membrane and descends deep to the extensor digitorum longus muscle (Fig. 3-106). As it descends distally towards the ankle, the nerve lies lateral, then anterior, and finally lateral to the anterior tibial artery (Figs. 3-106, 3-107 and 3-112) as it enters the extensor retinaculum at the ankle.

FIGURE 3-112 Transverse anatomical section through the distal leg at the level of the ankle demonstrating the deep peroneal nerve and the anterior tibial artery. EHL, extensor hallucis longus; EDL, extensor digitorum longus.
The superficial peroneal nerve is also a terminal branch of the common peroneal nerve (Fig. 3-113) and like the deep peroneal nerve originates within the substance of the peroneus longus muscle. It descends first between the peroneus longus and brevis muscle and then between the intermuscular septum of the peroneus brevis and extensor digitorum longus muscle (Fig. 3-114). It then pierces the deep crural fascia and becomes cutaneous in the lower part of the leg at a variable distance from the ankle (Fig. 3-107).^{30}

**FIGURE 3-113** Anatomical illustration of the foot demonstrating the course and divisions of the saphenous, superficial, and deep peroneal nerves.

**FIGURE 3-114** Transverse anatomical section through the distal leg demonstrating the intermuscular plane between the peroneus brevis and the extensor digitorum longus in which the superficial peroneal nerve is located.
The sural nerve (Fig. 3-115) arises from cutaneous branches of the tibial nerve and common peroneal nerve. It descends on the posterior aspect of the leg between the two heads of the gastrocnemius and descends along the lateral edge of the Achilles tendon (Figs. 3-107 and 3-116), lying close to the short saphenous vein (Fig. 3-116), to the space between the lateral malleolus and the calcaneus.

**FIGURE 3-115** Anatomical illustration of the foot demonstrating the course and divisions of the superficial peroneal and sural nerves.

**FIGURE 3-116** Anatomical section through the distal leg at the ankle region demonstrating the sural nerve in the vicinity of the small saphenous vein.

**Computed Tomography Anatomy of the Terminal Nerves of the Leg**
Fig. 3-117

Transverse (axial) CT image of the distal leg demonstrating the tibial nerve and vascular structures on the medial aspect of the ankle. TA, tibialis anterior; EHL, extensor hallucis longus; EDL, extensor digitorum longus; Tib Post, tibialis posterior; FHL, flexor hallucis longus; FDL, flexor digitorum longus.

Magnetic Resonance Imaging Anatomy of the Terminal Nerves of the Leg

Figs. 3-118 and 3-119

FIGURE 3-118 Transverse (axial) MRI image of the distal leg demonstrating the terminal nerves of the leg. EDL, extensor digitorum longus; EHL, extensor hallucis longus; TA, tibialis anterior; TP, tibialis posterior; PB, peroneus brevis; FHL, flexor hallucis longus; FDL, flexor digitorum longus.
FIGURE 3-119 Transverse (axial) MRI image of the ankle region demonstrating the terminal nerves of the leg. EDL, extensor digitorum longus, EHL; extensor hallucis longus; FHL, flexor hallucis longus; FDL, flexor digitorum longus.

Terminal Nerves of the Leg – Ultrasound Scan Technique

1. **Position:**
   a. **Patient:** Supine position. The leg that is examined is positioned according to the nerve to be examined. For the saphenous (Fig. 3-120) and tibial (Fig. 3-121) nerves the ipsilateral knee and hip is slightly flexed and externally rotated. For the superficial peroneal (Fig. 3-122), deep peroneal (Fig. 3-123), and sural (Fig. 3-124) nerves the ipsilateral knee is flexed and the sole of the foot is placed flat on the bed. An assistant may be asked to support the leg during the examination.

FIGURE 3-120 Figure showing the position and orientation of the ultrasound transducer during a transverse ultrasound scan for the saphenous nerve at the distal leg.
FIGURE 3-121 Figure showing the position and orientation of the ultrasound transducer during a transverse ultrasound scan for the tibial nerve at the distal leg.

FIGURE 3-122 Figure showing the position and orientation of the ultrasound transducer during a transverse ultrasound scan for the superficial peroneal nerve at the distal leg. Note an assistant is supporting the leg during the ultrasound scan.
b. **Operator and ultrasound machine:** The operator is positioned at the caudal end of the patient. The ultrasound machine is placed on the ipsilateral side to be examined on the cephalad side.

2. **Transducer selection:** High-frequency (15-8 or 17-5 MHz) linear array transducer.

3. **Scan technique:** To image the tibial nerve, the transducer is placed between the medial malleolus and the Achilles tendon (Fig. 3-121) to obtain a transverse sonographic view of the posterior tibial artery, which is the key sonographic landmark for this nerve block (Fig. 3-125). The structures visualized should be surveyed proximally to confirm the
identity of the flexor hallucis longus and observe the characteristic course of the tibial nerve and tibial artery. The flexor hallucis longus tendon, which lies on the medial and posterior aspect of the tibial nerve, can be confirmed by moving the first toe and observing the movement of the tendon and muscle.

**FIGURE 3-125** Transverse sonogram demonstrating the tibial nerve and its relations at the distal leg.

a. To image the saphenous nerve (Fig. 3-120), the transducer is placed just above the medial malleolus. Apply light pressure over the skin with the transducer during the scan as the long saphenous vein is easily compressible. The long saphenous vein is the key sonographic landmark for this nerve block (Fig. 3-126). In some individuals, the saphenous nerve may not be consistently visualized at this level.

**FIGURE 3-126** Transverse sonogram demonstrating the saphenous nerve and its relations at the distal leg.

b. To image the deep peroneal nerve, the transducer is placed along a line joining the medial malleoli and the lateral malleoli (Fig. 3-123). The anterior tibial artery is confirmed by observing its pulsations and using Color/Power Doppler ultrasound. At
this level, the deep peroneal nerve appears as a small hypoechoic structure lateral to
the artery (Fig. 3-127). The anterior tibial artery is the key sonographic landmark for
this nerve block.

![Transverse sonogram demonstrating the deep peroneal nerve and its
relations at the distal leg. EDL, extensor digitorum longus; EHL, extensor hallucis longus;
TA, tibialis anterior.]

**FIGURE 3-127** Transverse sonogram demonstrating the deep peroneal nerve and its
relations at the distal leg. EDL, extensor digitorum longus; EHL, extensor hallucis longus;
TA, tibialis anterior.

c.To image the superficial peroneal nerve (Fig. 3-122), the transducer is placed
transversely across the fibula just above the lateral malleoli to image the fibula in a
transverse section (Fig. 3-128). The transducer is then moved proximately along the
fibula. During this survey, the fibula is observed to move deeper as the muscle of the
lateral and anterior leg compartments become more pronounced. An intermuscular
septum arises from the edge of the fibula which separates the extensor digitorum
longus and the peroneus brevis/peroneus longus. This is the intermuscular septum that
divides the anterior and lateral compartment of the leg. This is the key sonographic
landmark to identify the superficial peroneal nerve. The superficial peroneal nerve
appears as a honeycomb structure (Fig. 3-128) that lies in the groove within the
intermuscular septum approximately 5 to 10 cm above the lateral malleoli (Fig. 3-
114). It lies below the deep crural fascia of the leg in the midleg and pierces this
fascia to lie superficial to it as the nerve travels down the leg towards the lateral
malleolus.
d. To image the sural nerve, the transducer is placed transversely along a line joining the lateral malleolus and the Achilles tendon (Fig. 3-124). Apply light pressure over the skin with the transducer during the scan, as the short saphenous vein is easily compressible. The short saphenous vein is visualized and confirmed by compression and surveyed proximally along its course. The short saphenous vein is the key sonographic landmark for this nerve block. The sural nerve appears as a honeycomb structure and usually lies posterior to the short saphenous vein between the short saphenous vein and the Achilles tendon (Fig. 3-129) and can be confirmed by tracing it back and forth along its course.

FIGURE 3-128 Transverse sonogram demonstrating the superficial peroneal nerve and its relations at the distal leg.

FIGURE 3-129 Transverse sonogram demonstrating the sural nerve and its relations at the distal leg. Note the short saphenous vein adjacent to the sural nerve.

4. **Sonoanatomy:** The tibial nerve has a typical honeycomb appearance and is located deep and medial to the tibial artery at the level just above the medial malleolus (Fig. 3-125). The saphenous nerve also has a honeycombed appearance in the short axis (Fig. 3-126) but is not consistently visualized in all individuals. The deep peroneal nerve appears as a hyperechoic structure with hypoechoic dots in the short axis (Fig. 3-127). The superficial peroneal nerve appears as one or two fusiform hypoechoic structures in the short axis (Fig. 3-128). The sural nerve appears as a honeycombed structure in the short axis (Fig. 3-129).

5. **Clinical Pearls:** The “trace back” technique is particularly useful for confirming the nerves in the leg. Compared with the traditional ankle block using landmark techniques, ultrasound-guided ankle blocks are generally administered more proximal to the malleoli. Sonographic study of the peripheral nerves at the ankle typically involves the identification of key anatomical landmarks (artery, vein, or intermuscular septum) associated with the nerve and then tracing it proximally until it is best visualized and targeted for nerve blockade. At the level of the malleoli, numerous tendons look similar to the nerves in a sonogram. Muscles can be differentiated from nerves by observing movement on sonography by asking the patient to move his or her toes or ankle. In addition, the tendons will change in appearance as a dynamic scan is performed proximally. The tendons transform into their corresponding muscle proximally. The
nerves are mobile and may “slip” on either side of the vessels with transducer pressure. With respect to the superficial peroneal nerve there are several variations on where the nerve is located, that is, whether it is deep to the crural fascia, where it divides into the medial dorsal cutaneous nerve and the intermediate dorsal cutaneous nerve, and where it pierces the crural fascia to lie superficial to it. These variations may be difficult to appreciate using ultrasound. The use of ultrasound for ankle blocks may improve the success rates of sural and tibial nerve blocks.\textsuperscript{31,32} Also blockade of the saphenous nerve at the ankle may not be necessary for forefoot surgery.\textsuperscript{33}

References


CHAPTER 4

Sonoanatomy Relevant for Ultrasound-Guided Abdominal Wall Nerve Blocks

Introduction

Ultrasound-guided abdominal wall blocks are a recent innovation of the traditional landmark-based techniques of performing abdominal wall field blocks. These blocks include the transverse abdominis plane (TAP) block (lateral/midaxillary and subcostal), rectus sheath block, iliohypogastric and ilioinguinal nerve block, and the quadratus lumborum block (QLB). They are fairly simple to perform, largely devoid of complications, and produce sensory and motor blockade of the abdominal wall.

Gross Anatomy

Muscles of the Anterior Abdominal Wall

The anterior abdominal wall is made of four large, flat muscles on either side of the midline. They are the external oblique muscle (EOM, Figs. 4-1 to 4-3), internal oblique muscle (IOM, Figs. 4-3 to 4-5), transversus abdominis muscle (TAM, Figs. 4-3, 4-6, and 4-7), and the rectus abdominis muscle (RAM, Figs. 4-3 and 4-6). Two other smaller muscles, the cremaster and the pyrimidalis, are also present. The EOM, IOM, and the TAM each end in a fibrous aponeurosis that extends up to the midline (Figs. 4-1, 4-4, and 4-6). The aponeuroses on either side fuse in the midline to form a median band called the linea alba. The RAM is longitudinal in shape, runs vertically on either side of the linea alba (Fig. 4-6), and is enclosed in a fibrous sheath called the “rectus sheath” (see later, Fig. 4-4).
FIGURE 4-1 • Figure showing the innervation of the trunk and the abdominal wall. Note the aponeurosis of the external oblique muscle and the anterior and posterior wall of the rectus sheath (cutout view).

FIGURE 4-2 • Figure showing the origin, insertion, and arrangement of the muscle fibers of the external oblique muscle.
FIGURE 4-3  Figure showing the anatomical arrangement of the muscles of the anterior abdominal wall (external oblique, internal oblique, transversus abdominis, and rectus abdominis) with their aponeurosis, including the rectus sheath. Note the three tendinous insertions on the anterior surface of the rectus abdominis muscle.

FIGURE 4-4  Figure showing the anatomical arrangement of the internal oblique muscle with its aponeurosis.
FIGURE 4-5  Figure showing the origin and insertion of the muscle fibers of the internal oblique deep to the external oblique muscle. Also note the direction of the muscle fibers of the internal oblique muscle (upwards and medially) relative to the external oblique muscle.

FIGURE 4-6  Figure showing the anatomical arrangement of the transversus abdominis muscle. Note the direction of the muscle fibers of the transversus abdominis muscle (transversely).
The EOM originates as eight fleshy slips from the lower eight ribs (Fig. 4-2). The upper slips of the origin of the EOM interdigitate with that of the serratus anterior muscle, and the lower slips of the EOM interdigitate with that of the latissimus dorsi muscle. The fibers of the muscle run downwards, forward, and medially (Fig. 4-2) to end in a broad aponeurosis (Fig. 4-1), which is inserted (from above downwards) to the xiphoid process, pubic symphysis, pubic crest, and the pectineal line of the pubis. The caudal fibers of the muscle are inserted to the anterior two-thirds of the outer lip of the iliac crest (Fig. 4-2). The caudal end of the external oblique aponeurosis is folded on itself to form the inguinal ligament, and above the pubic tubercle there is a small triangular opening called the superficial inguinal ring. Medial to the lateral edge of the rectus abdominis muscle the external oblique aponeurosis contributes to forming the rectus sheath (Fig. 4-6, see later).

The IOM originates from the lateral two-thirds of the inguinal ligament, anterior two-thirds of the intermediate area of the iliac crest (Fig. 4-5), and the thoracolumbar fascia posteriorly. From its origin the fibers of the IOM run obliquely upwards, forwards, and medially, crossing the fibers of the EOM at right angles (Fig. 4-5), to end in an aponeurosis through which it is attached to the xiphoid process, the seventh to ninth costal cartilage, linea alba, pubic crest, and pectineal line. The IOM aponeurosis also contributes to the formation of the rectus sheath (Fig. 4-4, see later).

The TAM has a fleshy origin from the lateral one-third of the inguinal ligament, anterior two-thirds of the inner lip of the iliac crest, thoracolumbar fascia posteriorly, and the inner surface of the lower six costal cartilages. The fibers of the TAM are directed horizontally forwards (Figs. 4-6 and 4-7) and end in an aponeurosis that is attached to the xiphoid process, linea alba, pubic crest, and pectineal line of the pubis. At the lower part of the TAM the lower fibers of the muscle fuse with the lower fibers of the IOM to form the conjoint tendon. The TAM aponeurosis also takes part in the formation of the rectus sheath (Fig. 4-6, see later).

The neurovascular structures of the abdominal wall lie in between the IOM and TAM (Fig. 4-8). This intermuscular plane is also referred to as the transversus abdominis plane (TAP, Figs. 4-9 to 4-11) and is a popular site for ultrasound-guided abdominal wall nerve blocks.
FIGURE 4-8  Figure showing the anatomical course and divisions of a typical thoracolumbar nerve. Note the posterior primary rami and the lateral and anterior cutaneous divisions of the nerve.

FIGURE 4-9  Cross-sectional cadaver anatomical section of the upper abdomen (rendered from the Visible Human Server) showing the relations of the rectus abdominis muscle to the TAP (transversus abdominis plane).
The rectus abdominis muscle (RAM) originates as two heads from the lateral (lateral head) part of the pubic crest and from the anterior pubic ligament (medial head). The fibers of the RAM run vertically upwards to be inserted into the anterior aspect of the chest wall, that is, to the xiphoid process and the fifth to seventh costal cartilages (Fig. 4-12). There are three fibrous bands, also called the tendinous insertions or inscriptions, on the anterior surface of the RAM (Figs. 4-6 and 4-12). The most cephalad tendinous insertion lies opposite the free
end of the xiphoid process, the second opposite the umbilicus, and the third approximately midway between the two (Fig. 4-6). This divides the RAM into six or eight bellies (sections), which is also colloquially called the “six-pack” (Fig. 4-4). The tendinous insertions pass transversely or obliquely across the muscle, are adherent to the anterior wall of the rectus sheath, and traverse only the anterior half of the muscle. The RAM is enclosed in a sheath, the rectus sheath (see later, Fig. 4-6), formed by the aponeurosis of the three flat muscles of the abdomen.

FIGURE 4-12 Sagittal cadaver anatomic section (rendered from the Visible Human Server) showing the rectus abdominis muscle. Note the tendinous insertions on the rectus muscle.

Nerves of the Anterior Abdominal Wall

The skin and musculature of the abdominal wall is innervated by the anterior primary rami of the lower six thoracic nerves (T7-T12, Fig. 4-8) and the first lumbar nerve (L1) through its iliohypogastric and ilioinguinal branches (Fig. 4-1). The anterior primary rami of the lower five intercostal nerves (T7-T11) emerge from their respective intercostal spaces and come to lie in a neurovascular plane between the internal oblique and transversus abdominis muscles (Fig. 4-8). This intermuscular plane is also referred to as the transversus abdominis plane (TAP). The segmental nerves travel anteriorly and medially towards the midline in the TAP, giving off their lateral cutaneous branches at the level of the midaxillary line and pierce the posterior lamina of the internal oblique aponeurosis anteriorly to enter the rectus sheath (Fig. 4-8). While within the rectus sheath the nerves pass behind the rectus abdominis muscle and
lie in front of the epigastric arteries. They then pierce the rectus muscle and the anterior rectus sheath to emerge anteriorly as the anterior cutaneous branches, which supply the overlying skin (Fig. 4-8). The lateral and anterior cutaneous branches supply the skin of the abdomen from the midline to the anterior axillary line. T7 provides sensory supply to the epigastrium, T10 to the umbilicus, and L1 to the groin.

The subcostal nerve is the anterior primary rami of the 12th thoracic nerve and enters the abdomen posteriorly under the lateral arcuate ligament of the diaphragm. It then passes laterally on the anterior surface of the quadratus lumborum muscle and pierces the transversus abdominis muscle to enter the TAP. The remaining part of the course of the subcostal nerve is similar to that of the other thoracolumbar nerves except that it supplies the pyramidalis muscle, and its lateral cutaneous branch supplies the upper and lateral aspect of the gluteal region (Fig. 4-1).

The first lumbar nerve (L1) divides in front of the quadratus lumborum muscle into the iliohypogastric and ilioinguinal nerves after which they pierce the transversus abdominis muscle to enter the TAP (Figs. 4-13 and 4-14). The iliohypogastric nerve then travels anteriorly in the TAP and pierces the internal oblique muscle about 1 inch in front of the anterior superior iliac spine (Fig. 4-1). It then becomes superficial by piercing the external oblique aponeurosis close to the superficial inguinal ring and supplies the skin over the suprapubic region. The lateral cutaneous branch of the iliohypogastric nerve supplies the upper and lateral aspect of the gluteal region (Fig. 4-1). The ilioinguinal nerve has no lateral cutaneous branch but also pierces the internal oblique muscle. It then traverses the inguinal canal with the spermatic cord or the round ligament of the uterus to emerge through the superficial inguinal ring or through the adjacent external oblique aponeurosis to supply the skin of the upper and medial aspect of the thigh and the genitals.

**FIGURE 4-13** Cross-sectional cadaver anatomical section of the lower abdomen (rendered from the Visible Human Server) from the level of the anterior superior iliac spine showing the relations of the TAP (transversus abdominis plane) to the lower abdomen.
FIGURE 4-14 Cross-sectional cadaver anatomical section of the lower abdomen (rendered from the Visible Human Server) from below the level of the anterior superior iliac spine. Note the external oblique muscle is missing because it is an aponeurotic layer at this level.

Lateral (Midaxillary) Transverse Abdominis Plane

Gross Anatomy

The lateral (midaxillary) TAP refers to the neurovascular plane between the internal oblique and transversus abdominis muscle along the lateral abdominal wall (Figs. 4-10 and 4-11). The thoracolumbar nerves (T10-L1) traverse through the lateral (midaxillary) TAP.

Computed Tomography Abdomen Showing the Lateral (Midaxillary) Transverse Abdominis Plane

Fig. 4-15
FIGURE 4-15 Transverse CT of the abdomen showing the anatomical relations of the TAP (transversus abdominis plane) relevant for a lateral (midaxillary) TAP block.

**Magnetic Resonance Imaging Abdomen Showing the Lateral (Midaxillary) Transverse Abdominis Plane**

Fig. 4-16

FIGURE 4-16 Transverse MRI of the abdomen showing the anatomical relations of the TAP (transversus abdominis plane) relevant for a lateral (midaxillary) TAP block.

**Ultrasound Scan Technique**
1. **Position:**
   a. **Patient:** Supine with the abdomen exposed between the subcostal margin and the iliac crest.
   b. **Operator and ultrasound machine:** Right-handed operators who hold the ultrasound transducer with their left hand and carry out needle interventions with their right hand should stand on the right side of the patient and position the ultrasound machine on the contralateral side and directly in front. This is vice versa for left-handed operators.

2. **Transducer selection:** High-frequency (13-8 MHz) linear array transducer.

3. **Scan technique:** The ultrasound transducer is placed in the transverse orientation to the lateral abdominal wall in the midaxillary line between the costal margin and the iliac crest (Fig. 4-17). The aim is to identify the three muscular layers of the lateral abdominal wall with the fascial layers that separate them in the sonogram. It may be necessary to gently slide the transducer in a craniocaudal direction or even gently tilt or rotate the transducer to obtain an optimal ultrasound image.

![Figure 4-17](image)

**FIGURE 4-17** Figure showing the position and orientation of the ultrasound transducer during a transverse scan of the lateral abdominal wall for the lateral (midaxillary) TAP block.

4. **Sonoanatomy:** On a transverse sonogram, the EOM, IOM, and TAM are identified as three longitudinal and hypoechoic structures deep to the skin and subcutaneous tissue (Fig. 4-18). A hyperechoic fascial layer (possibly the epimysium of the individual muscle) is seen between the three muscles (Fig. 4-18). The EOM is the outermost (superficial) layer, the IOM the intermediate, and the TAM is the innermost layer. The thickness of the muscles also varies, but the TAM is in general the thinnest and it also appears darkest (hypoechoic) of the three muscles on the sonogram (Fig. 4-18). The TAP is located between the IOM and TAM (Fig. 4-18). Deep to the TAM are the fascia transversalis and the underlying peritoneum, which also appear hyperechoic (Fig. 4-18). It is difficult to differentiate the fascia transversalis from the peritoneum on a sonogram, but the peritoneum can be identified as a hyperechoic layer by observing peristaltic movement of the bowel loops (Fig. 4-18). The segmental thoracolumbar nerves are small terminal branches and are difficult to define within the TAP using ultrasound. Occasionally the terminal nerves may be seen in the TAP as multiple flat, hyperechoic structures (Fig. 4-19). This is best done by locating the nerves distally in the groin.
(iliohypogastric and ilioinguinal nerve) and then tracing them (trace back technique) back to the TAP.

**FIGURE 4-18** Transverse sonogram of the lateral abdominal wall showing the TAP (transversus abdominis plane) between the hypoechoic internal oblique and transversus abdominis muscles. Also note the hyperechoic fascial layers, which probably represent the epimysium of the muscles, separating the three abdominal muscles.

**FIGURE 4-19** Transverse sonogram of the lateral abdominal wall showing the TAP (transversus abdominis plane) in sepia mode (colorize mode). Note the flat hypoechoic structures, which represent branches of the thoracolumbar nerves, within the TAP (transversus abdominis plane).
5. **Clinical Pearls:** During a lateral (midaxillary) TAP block with an in-plane needle insertion, the point of needle insertion (i.e., how far medial to the transducer) can be determined by noting the depth at which the TAP is located on the ultrasound monitor (depth scale). Normal saline can be used to hydrodissect the TAP to confirm correct needle tip position before the local anesthetic is injected. It is common to see a prominent bulge along the lateral abdominal wall, indicating paralysis of the abdominal muscles, during the postoperative period after a posterior TAP block.

**Subcostal Transverse Abdominis Plane**

**Gross Anatomy**

Subcostal TAP refers to the neurovascular plane between the IOM and the TAM that lies just below the costal margin (Fig. 4-9). The terminal branches of the intercostal nerves (T7-T9) emerge from under the costal margin and enter the subcostal TAP. T7 and T8 nerves pass deep to the costal margin and between the digitations of the TAM to enter the TAP, and T9 and T10 nerves exit from their respective intercostal spaces directly into the TAP.

**Computed Tomography Abdomen Showing the Subcostal Transverse Abdominis Plane**

Fig. 4-20

![CT Image](image.png)

**FIGURE 4-20** Transverse CT of the upper abdomen showing the anatomical relations of the TAP (transversus abdominis plane) relevant for a subcostal TAP block. Note how the transversus abdominis muscle extends deep to and posterior to the rectus abdominis muscle anteriorly.

**Magnetic Resonance Imaging Abdomen Showing the Subcostal Transverse Abdominis Plane**
Fig. 4-21

**FIGURE 4-21** Transverse MRI of the upper abdomen showing the anatomical relations of the TAP (transversus abdominis plane) relevant for a subcostal TAP block.

**Ultrasound Scan Technique**

1. **Position:**
   a. **Patient:** Supine with the abdomen exposed between the costal margin and the iliac crest.
   b. **Operator and ultrasound machine:** For a bilateral subcostal TAP block, right-handed operators who hold the ultrasound transducer with their left hand and carry out needle interventions with their right hand should stand on the left side of the patient and position the ultrasound machine on the contralateral side and directly in front. This is vice versa for left-handed operators.

2. **Transducer selection:** High-frequency (13-8 MHz) linear array transducer.

3. **Scan technique:** The ultrasound transducer is placed immediately below and parallel to the costal margin, typically lateral to the linea semilunaris (Fig. 4-22). The aim is to identify the three muscular layers of the lateral abdominal wall with the fascial layers that separate them on the sonogram.
4. **Sonoanatomy:** At the medial end, the linea semilunaris is seen lateral to the RAM (Figs. 4-23 and 4-24), and the TAM may be the only muscle between the skin and the peritoneum. Laterally and along the midclavicular line the three muscular layers of the abdominal wall and the TAP are clearly delineated and appear similar to the lateral (midaxillary) TAP (Figs. 4-23 to 4-26).

**FIGURE 4-22** Figure showing the position and orientation of the ultrasound transducer during a transverse scan of the anterior abdominal wall for a TAP (transversus abdominis plane) block at the subcostal region.

**FIGURE 4-23** Transverse sonogram of the anterior abdominal wall showing the formation of the linea semilunaris and the transversus abdominis plane (TAP) lateral to the lateral edge of the rectus abdominis muscle (in colorize mode). Also note how the transversus abdominis muscle extends deep to and posterior to the rectus abdominis muscle medially.
FIGURE 4-24 Transverse sonogram of the anterior abdominal wall showing a close-up view of the aponeurotic layers of the three abdominal muscles at the level of the linea semilunaris lateral to the lateral edge of the rectus abdominis muscle.

FIGURE 4-25 Transverse sonogram (panoramic view) of the right subcostal region showing the anatomic relations of the anterior abdominal muscles and the formation of the transversus abdominis plane (TAP).
5. **Clinical Pearls:** During a subcostal TAP block, a multiple injection technique produces greater spread of the injectate compared to a single injection in the TAP lateral to the linea semilunaris. The aim during a multiple injection technique is to hydrodissect the TAP plane such that the injection is deposited progressively more laterally from the linea semilunaris.

**Rectus Sheath**

**Gross Anatomy**

The rectus sheath is an aponeurotic sheath that covers the rectus abdominis muscle (Fig. 4-1). It is made up of an anterior and a posterior wall that are formed by the aponeurosis of the three flat muscles of the abdomen (Figs. 4-27 to 4-29). The anterior wall is complete throughout its length and adherent to the tendinous insertions of the RAM. In contrast, the posterior wall of the rectus sheath is free (not adherent) from the RAM and incomplete below the “arcuate line” (Fig. 4-29). The latter is also referred to as the “linea semicircularis” or “fold of Douglas” and lies about one-third the distance from the umbilicus to the pubic crest, but there are variations. Above the costal margin the anterior wall is formed by the external oblique aponeurosis, and the posterior wall is deficient and the muscle lies directly on the costal cartilages with an intervening layer of fatty tissue (Fig. 4-27). In between the costal margin and the arcuate line the anterior wall is formed by the external oblique aponeurosis and the anterior lamina of the IOM, and the posterior wall is formed by the posterior lamina of the IOM and the aponeurosis of the TAM (Fig. 4-28). Below the arcuate line the anterior wall is formed by the aponeurosis of all the three flat muscles of the anterior abdominal wall, but the posterior wall is deficient and the RAM lies directly on the fascia transversalis, being separated from it by a layer of loose extraperitoneal fatty tissue (Fig. 4-29). The rectus sheath on either side is held together in the midline by a median raphe, the linea alba (Fig. 4-1),
which extends from the xiphoid process to the pubic symphysis.

**FIGURE 4-27** Figure showing the formation of the rectus sheath in transverse section above the costal margin.

**FIGURE 4-28** Figure showing the formation of the rectus sheath in transverse section between the costal cartilage and the arcuate line.

**FIGURE 4-29** Figure showing the formation of the rectus sheath in transverse section below the arcuate line.

**Computed Tomography Abdomen Showing the Rectus Abdominis Muscle**
FIGURE 4-30 Correlative transverse CT (Fig. 4-30A and C), MRI (Fig. 4-30B and D) images of the rectus abdominis muscle from above and below the level of the umbilicus (arcuate line). IEV, inferior epigastric vessels; EIV, external iliac vessels.

Magnetic Resonance Imaging Abdomen Showing the Rectus Abdominis Muscle

Figs. 4-30 and 4-31
FIGURE 4-31  ▪ Sagittal MRI image of the lower abdomen showing the rectus abdominis muscle and the transition zone at the level of the arcuate line on the posterior aspect of the muscle.

Ultrasound Scan Technique

1. Position:
   a. Patient: Supine with the abdomen exposed between the costal margin and the iliac crest.
   b. Operator and ultrasound machine: For a scan of the RAM and rectus sheath, the operator stands on one side of the subject and the ultrasound machine is placed directly opposite on the contralateral side. For a bilateral rectus sheath block, right-handed operators who hold the ultrasound transducer with their left hand and carry out needle interventions with their right hand should stand on the left side of the patient and position the ultrasound machine directly in front on the contralateral side. This is vice-versa for left-handed operators.

2. Transducer selection: High-frequency (13-8 MHz) linear array transducer.

3. Scan technique: For a transverse scan of the RAM and the rectus sheath, the ultrasound transducer is positioned above the umbilicus (ie, above the arcuate line) and to one side of the midline (Fig. 4-32). The aim is to obtain a transverse view of the RAM, which is seen as a hypoechoic oval-to-elliptical structure that is surrounded by its hyperechoic epimysium (Figs. 4-33 and 4-34). For a sagittal scan, the ultrasound transducer is rotated through 90 degrees and positioned midway between the xiphisternum and the umbilicus to obtain a longitudinal view of the RAM (Fig. 4-35).

FIGURE 4-32 ▪ Figure showing the position and orientation of the ultrasound transducer during a transverse scan of the anterior abdominal wall for the rectus abdominis muscle above the arcuate line.
FIGURE 4-33 Transverse (Fig. 4-33A and B) and sagittal (Fig. 4-33C and D) sonograms of the rectus abdominis muscle (RAM) above the arcuate line in colorize mode showing (Fig. 4-33A) the anterior and posterior rectus sheath from both sides fusing in the midline to form the linea alba. In this image the posterior rectus sheath is seen as a well-defined hyperechoic fascial layer from the epimysium of the rectus abdominis muscle (RAM) and the parietal peritoneum (Fig. 4-33B). Close-up view of the medial aspect of the left RAM showing the linea alba and the anterior and posterior layers of the rectus sheath (Fig. 4-33C and D), sagittal views of the RAM, and the anterior and posterior layers of the rectus sheath. Note the hypoechoic space posterior to the RAM into which local anesthetic is injected during a rectus sheath block.
4. **Sonoanatomy**: On a transverse sonogram, the RAM is seen as a hypoechoic oval-to-elliptical structure that is surrounded by a hyperechoic epimysium (Figs. 4-33 and 4-34). Between the costal margin and the arcuate line, the RAM is enveloped by a further layer of fibrous connective tissue, the rectus sheath (details provided earlier), which also appears hyperechoic and can be traced medially to the midline where it is continuous with the linea alba (Fig. 4-34). Below the arcuate line the posterior rectus sheath is deficient.
(Fig. 4-36) and the RAM lies directly on the fascia transversalis, being separated from it by a layer of loose, extraperitoneal fatty tissue (Fig. 4-29). With currently available ultrasound technology, we believe it is not possible to delineate the fascia transversalis on a transverse sonogram.

**FIGURE 4-36** Transverse sonogram of the anterior abdominal wall from below the level of the arcuate line showing the right rectus abdominis muscle (RAM). Note that the anterior rectus sheath is clearly visible but the posterior rectus sheath is deficient at this site.

On a sagittal sonogram the RAM is seen as a cylindrical, hypoechoic structure lying deep to the skin and subcutaneous fat (Figs. 4-37 to 4-40). Interspersed within the RAM are multiple hyperechoic strands (Figs. 4-37 to 4-39) that probably represent intramuscular tendon fibers. The epimysium of the RAM also appears hyperechoic and covers both the anterior and posterior walls of the muscle (Figs. 4-37 to 4-39). The rectus sheath appears as an additional hyperechoic layer lying external to the epimysium of the muscle (Fig. 4-38). The posterior rectus sheath is generally better delineated than the anterior rectus sheath. This may be because the anterior rectus sheath is adherent to the tendinous insertions of the RAM. A hypoechoic space is also clearly visualized between the posterior rectus sheath and the epimysium covering the posterior surface of the RAM (Fig. 4-37). This is the potential space into which local anesthetic is injected during a rectus sheath block. The three tendinous insertions of the RAM may also be seen as hyperechoic areas within the muscle on a sagittal sonogram (Figs. 4-37 and 4-40). The “transition zone” in the posterior aspect of the RAM where the posterior rectus sheath ends can also be clearly delineated (Figs. 4-38 to 4-40). Distal to the transition zone the parietal peritoneum is seen as a hyperechoic structure deep to the RAM and easily recognized by the peristaltic movement of the underlying bowel (Fig. 4-39).
FIGURE 4-37  Sagittal sonogram of the anterior abdominal wall showing the rectus abdominis muscle (RAM) with the anterior and posterior layers of the rectus sheath. Also note the hyperechoic tendinous insertion of the rectus abdominis muscle and the hypoechoic space between the epimysium of the RAM and the posterior rectus sheath.

FIGURE 4-38  Sagittal sonogram of the anterior abdominal wall at the level of the arcuate line showing the “transition zone” where the posterior rectus sheath ends. RAM, rectus abdominis muscle.
FIGURE 4-39 Sagittal sonogram of the anterior abdominal wall showing the intermuscular tendons (hyperechoic) of the rectus abdominis muscle (RAM). Because the ultrasound scan is at the level of the arcuate line, the “transition zone” is clearly visible. The peritoneum is also seen as a hyperechoic structure and distinct from the posterior rectus sheath.

FIGURE 4-40 Sagittal sonogram (panoramic view) of the rectus abdominis muscle (RAM) showing the anatomy of the rectus sheath. Note the posterior rectus sheath is deficient distal to the “transition zone” (ie, distal to the arcuate line). Also one of the tendinous insertions is visible above the arcuate line in this sonogram.

Ilioinguinal and Iliohypogastric Nerve
Gross Anatomy

The gross anatomy of the ilioinguinal and iliohypogastric nerves is described earlier.

Computed Tomography Abdomen – Transverse View at the Level of the Anterior Superior Iliac Spine

Figs. 4-41 and 4-42

FIGURE 4-41 Transverse CT of the lower abdomen at the level of the anterior superior iliac spine (ASIS) showing the location of the iliohypogastric and ilioinguinal nerve in the fascial plane between the internal oblique and the transversus abdominis muscle.

FIGURE 4-42 Transverse CT of the lower abdomen below the level of the anterior
superior iliac spine (ASIS) showing the location of the iliohypogastric and ilioinguinal nerve in the fascial plane between the internal oblique and the transversus abdominis muscle. Note the external oblique muscle is only an aponeurotic layer at this level.

**MRI Abdomen – Transverse View at the Level of the Anterior Superior Iliac Spine**

Figs. 4-43 and 4-44

**FIGURE 4-43** Transverse MRI of the lower abdomen at the level of the anterior superior iliac spine (ASIS) showing the iliohypogastric and ilioinguinal nerve in the fascial plane between the internal oblique and the transversus abdominis muscle.
**Ultrasound Scan Technique**

1. **Position:**
   a. **Patient:** Supine with the lower abdomen exposed.
   b. **Operator and ultrasound machine:** For an ultrasound scan of the ilioinguinal and iliohypogastric nerves, right-handed operators who hold the ultrasound transducer with their left hand and carry out needle interventions with their right hand should stand on the left side of the patient and position the ultrasound machine directly in front on the contralateral side. This is vice-versa for left-handed operators.

2. **Transducer selection:** High-frequency (13-8 MHz) linear array transducer.

3. **Scan technique:** The ilioinguinal and iliohypogastric nerves are best visualized close to the anterior superior iliac spine (ASIS). The ultrasound transducer is positioned close to the ASIS and parallel to a line joining the ASIS and the umbilicus (Fig. 4-45).

**FIGURE 4-45** Figure showing the position and orientation of the ultrasound transducer during a transverse scan of the lower abdomen at the level of the anterior superior iliac spine (ASIS) for the iliohypogastric and ilioinguinal nerves.

4. **Sonoanatomy:** The ilioinguinal and iliohypogastric nerves are identified as two small, rounded hypoechoic structures lying side by side between the internal oblique and transversus abdominis muscles (Fig. 4-46). Below the level of the iliac crest the aponeurosis of the external iliac muscle is seen as a hyperechoic aponeurotic layer (Fig. 4-47). Deep to the transversus abdominis muscle the peritoneum and bowel are also visualized (Fig. 4-47).
FIGURE 4-46 Transverse sonogram of the lower abdomen, at the level of the anterior superior iliac spine (ASIS) showing the iliohypogastric and ilioinguinal nerves between the internal oblique and the transversus abdominis muscles.

FIGURE 4-47 Transverse sonogram of the lower abdomen, from just below the level of the anterior superior iliac spine, showing the iliohypogastric and ilioinguinal nerves between the internal oblique and the transversus abdominis muscles. Also note the external oblique aponeurosis, which is seen as a hyperechoic layer, superficial to the internal oblique muscle.

5. Clinical Pearls: The ilioinguinal and iliohypogastric nerves are best visualized close to the ASIS. Also during an ultrasound-guided ilioinguinal iliohypogastric nerve block, the authors prefer to perform an in-plane technique with the needle inserted from a medial-to-lateral direction and towards the iliac bone. This not only allows the needle to be better
visualized, but also in the event of inadvertent deep needle insertion the iliac bone will prevent further needle advancement. We believe this approach may also prevent serious complications like bowel and visceral perforation because the needle is inserted away from the peritoneum and bowel.

**Quadratus Lumborum Block**

**Gross Anatomy**

Quadratus lumborum block (QLB) is a recently introduced abdominal wall field block in which the local anesthetic is injected into a fascial plane that is deep to the fascia transversalis (the deep fascia of the abdominal wall) and on the anterolateral aspect of the quadratus lumborum muscle (Fig. 4-48). The point of injection is believed to approximate to the landmark-based technique of performing a TAP block at the lumbar triangle of Petit. Several ultrasound-guided techniques for QLB or their variations have been described in the literature (Fig. 4-48), but the optimal technique or the site of injection is still not known. There are also limited clinical data on QLB and in particular the mechanism by which it produces clinical efficacy. Preliminary reports suggest that a QLB acts by a combination of mechanisms: (a) craniocaudal spread of the local anesthetic in the fascial plane anterior to the quadratus lumborum, (b) ipsilateral paravertebral spread, and (c) possibly ipsilateral epidural spread. There is also an anatomical plane of communication between the retroperitoneal space and the thoracic paravertebral space, which may also be involved in the extended lumbothoracic spread of the local anesthetic after a QLB injection.

**FIGURE 4-48** Figure showing the facial planes in the posterior abdomen where the local anesthetic is injected during a quadratus lumborum block (QLB). TAM, transversus abdominis muscle; IOM, internal oblique muscle; EOM, external oblique muscle; QLN, quadratus lumborum muscle; VB, vertebral body; Ao, aorta; IVC, inferior vena cava.
The fascia transversalis of the abdominal wall blends medially with the anterior layer of the quadratus lumborum fascia and the psoas fascia (psoas sheath, Fig. 4-49). The subcostal (T12), iliohypogastric (L1), and ilioinguinal (L1) nerves course anterior to and in close contact with the quadratus lumborum muscle, and the lateral femoral cutaneous nerve of the thigh (L2, L3) crosses the lateral border of the psoas muscle at the level of the inferior border of the L4 vertebra in this fascial plane. The potential space behind the fascia covering the psoas major and quadratus lumborum muscles in the abdomen is continuous cranially with the subendothoracic fascial compartment of the lower thoracic paravertebral spaces in the thorax (Fig. 4-50). This continuity occurs dorsal to the diaphragm through the medial and lateral arcuate ligaments (lumbocostal arch) and the aortic hiatus. This thoracolumbar continuity is the anatomical basis for “extended unilateral anesthesia” after a lower thoracic paravertebral injection and may apply when ipsilateral lumbothoracic spread of contrast or anesthesia occurs after a QLB injection.

**FIGURE 4-49** Figure showing the anatomical relationship of the transversus abdominis plane (TAP), fascia transversalis, and the fascia of the quadratus lumborum (quadratus lumborum fascia) and psoas (psoas fascia/sheath) muscles in the retroperitoneal space. Note the subcostal and ilioinguinal nerves are located on the anterior surface of the quadratus lumborum muscle. Ao, aorta; IVC, inferior vena cava; PM, psoas major muscle; ESM, erector spine muscle; TAM, transversus abdominis muscle; IO, internal oblique muscle; EOM, external oblique muscle.
FIGURE 4-50 Sagittal section showing the fascial relations of the lower thoracic paravertebral space and the retroperitoneal space. Note the path of communication between the subendothoracic compartment of the lower thoracic paravertebral space and the space behind the fascia covering the psoas muscle (psoas fascia/sheath).

A QLB produces multidermatomal ipsilateral anesthesia of the thoracolumbar nerves.\(^ {12}\) A bilateral single injection QLB (20 mL of 0.375% ropivacaine on each side) produces loss of sensation to cold from T7-T12 dermatomes.\(^ {12}\) The segmental anesthesia produced by a QLB is significantly wider than that produced by a lateral (midaxillary) TAP block (with ropivacaine 0.5%, 15 mL per side, T10-T12).\(^ {12}\) Also the duration of analgesia after a bilateral QLB in patients undergoing laparoscopic ovarian surgery is significantly longer than that produced by a bilateral lateral (midaxillary) TAP block.\(^ {12}\) The prolonged duration of analgesia after a QLB has been attributed to the paravertebral spread of the local anesthetic. QLB may also produce ipsilateral sympathetic blockade because paravertebral spread of contrast has been demonstrated.\(^ {10,14}\) Therefore, QLB may be effective in relieving sympathetic mediated visceral pain, which is otherwise not affected by a lateral (midaxillary) TAP block. However, because there is a paucity of data on the use of bilateral QLB for major abdominal surgery, no recommendations can be made at this time, but QLB holds promise as a technique for perioperative pain management. The following section briefly describes the ultrasound scan technique and sonoanatomy relevant for QLB.

**Ultrasound Scan Technique**

1. **Position:**
   a. **Patient:** For a bilateral QLB the patient is placed in the supine position with the abdomen exposed between the costal margin and the iliac crest. The ultrasound scan for a bilateral QLB can also be performed with the patient in the sitting position. For a unilateral QLB it may be preferable to place the patient in the lateral position (Figs. 4-51 and 4-52) because the block needle can then be inserted from the posterior aspect of the ultrasound transducer,\(^ {11}\) which is otherwise not possible when the patient is in
the supine position. In doing so the needle is inserted through the quadratus lumborum muscle (transmuscular QLB)\textsuperscript{11} until the needle tip is in the target site between the psoas and quadratus lumborum muscle (Fig. 4-48).\textsuperscript{11}

**FIGURE 4-51** Figure showing the position of the patient, ultrasound transducer, and the plane of ultrasound imaging during a quadratus lumborum block (QLB) with the patient in the lateral decubitus position. Note the anatomical relationship of the psoas major, quadratus lumborum, and erector spinae muscle to the transverse process and the transversus abdominis plane.

**FIGURE 4-52** Transverse sonogram, acquired with a curvilinear transducer (C5-1 MHz) showing the anatomy relevant for quadratus lumborum block (QLB) at the level of the
transverse process. Note the site for local anesthetic during a QLB I and QLB II injection. Accompanying photograph on the right is demonstrating the position of the patient and the ultrasound transducer during a QLB. EOM, external oblique muscle; IOM, internal oblique muscle; TAM, transversus abdominis muscle; VB, vertebral body; TP, transverse process; ESM, erector spinae muscle; AP, articular process.

b. **Operator and ultrasound machine:** The operator stands on one side of the subject, and the ultrasound machine is placed directly opposite on the contralateral side. For a bilateral QLB, right-handed operators who hold the ultrasound transducer with their left hand and carry out needle interventions with their right hand should stand on the left side of the patient and position the ultrasound machine directly in front on the contralateral side. This is vice versa for left-handed operators.

2. **Transducer selection:** It is preferable to use a curvilinear transducer (5-1 MHz, Fig. 4-51) because it provides better penetration and a wider field of view than a linear transducer (Fig. 4-53). A high-frequency (13-8 MHz) linear transducer, which provides higher-resolution images, can be used in slim individuals (Fig. 4-53).

![FIGURE 4-53](image-url) Transverse sonogram, acquired with a high-frequency (13-8 MHz) linear array transducer showing the anatomy relevant for a quadratus lumborum block (QLB) at the level of the transverse process. The resolution of the muscles and intermuscular facial planes is significantly improved, but the field of view is limited (compare with Fig. 4-52). Also note the sites for local anesthetic injection during a QLB. Accompanying photograph on the right is demonstrating the position of the patient and the ultrasound transducer during a QLB. EOM, external oblique muscle; IOM, internal oblique muscle; TAM, transversus abdominis muscle; RPS, retroperitoneal space; QLM, quadratus lumborum muscle; PM, psoas major muscle; VB, vertebral body; TP, transverse process; ESM, erector spinae muscle; TM-QLB, transmuscular QLB.

3. **Scan technique:** Start the ultrasound scan by placing the transducer in the transverse orientation in the flank immediately above the iliac crest (Figs. 4-51 to 4-53). Then gently
slide the transducer posteriorly, aiming to identify the anterolateral surface of the vertebral body and the transverse process in the transverse sonogram (Fig. 4-52). Once the transverse process is located and the relevant anatomy identified, tilt or slide the transducer slightly caudally to perform the transverse scan through the intertransverse space (Fig. 4-54). The acoustic shadow of the transverse process will no longer be visible and will be replaced by the hyperechoic articular process (Fig. 4-54).

**FIGURE 4-54** Transverse sonogram, acquired with a curvilinear transducer (C5-1 MHz), showing the anatomy relevant for quadratus lumborum block (QLB) at the level of the articular process (AP). Note the site for local anesthetic injection during a QLB I and QLB II. The lumbar plexus nerves are visualized on the posterior aspect of the psoas muscle. Also the spinal canal is visualized through the intervertebral foramen (IVF). EOM, external oblique muscle; IOM; internal oblique muscle, TAM; transversus abdominis muscle; VB, vertebral body; ESM, erector spinae muscle.

4. **Sonoanatomy:** On the transverse sonogram the vertebral body and transverse process of the vertebra appear as hyperechoic structures with a corresponding acoustic shadow (Fig. 4-52). The psoas major, quadratus lumborum, and erector spinae muscles are easily recognized surrounding the transverse process. Also depending on the side scanned, the inferior vena cava (on the right) and aorta (on the left) are visualized anterolateral to the vertebral body (Fig. 4-52). The arrangement of the three muscles around the transverse process, that is, the psoas muscle lying anterior, the erector spinae muscle lying posterior, and the quadratus lumborum muscle lying at the apex (Fig. 4-52), produces a sonographic pattern that has been likened to a “shamrock” with the muscles representing the three leaves.23 Superficial and anterior to these three muscles the external oblique, internal oblique, and transversus abdominis muscles can be identified (Figs. 4-52 to 4-54). In the transverse sonogram through the lumbar intertransverse space the acoustic shadow of the transverse process is no longer visualized, and the intervertebral foramen and spinal canal may also be visualized in addition to the psoas major, quadratus lumborum, and erector spine muscles (Fig. 4-54).

5. **Clinical Pearls:** One must identify the lower pole of the kidney and the peritoneal cavity during the scout scan to avoid deep needle insertion and visceral injury. When performing a QLB scan in individuals with a thick abdominal wall, gentle inward pressure may be
applied with the transducer to compress the abdominal tissues. This maneuver reduces the overall depth to the target and thereby may improve the overall quality of the image.

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CHAPTER 5

Ultrasound Imaging of the Spine: Basic Considerations

Introduction

Ultrasound has revolutionized the practice of regional anesthesia, particularly peripheral nerve blockade, and it has also been used for central neuraxial blocks (spinal and epidural injections).\(^1\)\(^-\)\(^3\) However, the use of ultrasound for central neuraxial blocks is still in its infancy and not as popular\(^4\) as that for peripheral nerve blocks. The reasons for this are not clear, but may be related to the high success rate of landmark-based techniques, limited data on ultrasound for neuraxial blocks, perceived difficulty in performing spinal sonography, limited acoustic window for ultrasound imaging, and poor understanding of spinal sonoanatomy. However, recently published data suggest that ultrasound is beneficial for central neuraxial blocks. Identification of a given lumbar intervertebral level for central neuraxial block using surface anatomical landmarks (Tuffier line) is often imprecise,\(^5\) and ultrasound is more accurate than clinical assessment.\(^6\) It can also be used to accurately measure the depth to the epidural space or thecal sac\(^7\)\(^-\)\(^9\) and predict the ease of performing a neuraxial block.\(^10\) Ultrasound also offers technical advantage by reducing the number of puncture attempts,\(^11\)\(^-\)\(^14\) improves the success rate of epidural access on the first attempt,\(^12\) reduces the need to puncture multiple levels,\(^12\)\(^-\)\(^14\) and improves patient comfort during the procedure.\(^13\) Ultrasound may also be beneficial for central neuraxial blocks in patients with difficult (ie, abnormal or variant) spinal anatomy.\(^15\)\(^,\)\(^16\) Therefore, it is envisioned that the use of ultrasound for central neuraxial blocks will grow in the near future. A sound knowledge of the anatomy of the spine is a prerequisite for understanding the sonoanatomy of the spine. In this chapter, we describe general details of spine anatomy and basic considerations relevant for spinal sonography and central neuraxial blocks.

Basics of Spine Anatomy

The human spine or vertebral column is made up of 33 vertebrae—7 cervical, 12 thoracic, 5 lumbar, 5 sacral, and 4 coccygeal—that are stacked on top of each other (Fig. 5-1). A typical vertebra has unique features (Fig. 5-2), and they differ at different levels (Figs. 5-3 to 5-5). The number of spinal nerves in the thoracic, lumbar, and sacral region corresponds to the number of vertebra, each lying below the corresponding vertebra. In the cervical region there are eight spinal nerves. The first seven spinal nerves lie above the corresponding vertebra, but the eighth cervical nerve lies below the seventh cervical vertebra. In the coccygeal region there is only one coccygeal nerve.
FIGURE 5-1 Human vertebral (spinal) column. (A) Posterior view and (B) lateral view.

FIGURE 5-2 Structure of a typical vertebra with its different components.
FIGURE 5-3  A typical cervical vertebra (C4). Note the triangular spinal canal and the foramen transversarium on the transverse processes. SAP, superior articular process; IAP, inferior articular process; SAF, superior articular facet; IAF, inferior articular facet.
The spine has two primary curves (ie, the thoracic and sacral curve) that are concave anteriorly, present at birth, and due to the shape of the vertebral bodies (Fig. 5-1). There are also two secondary curves—the cervical and lumbar curves (Fig. 5-1)—that are convex anteriorly and develop after birth. The cervical curvature develops after the infant starts to support the weight of the head (usually between 4 and 9 months of age), and the lumbar curvature develops between 12 and 18 months of age once the child assumes the upright posture.

A typical vertebra is made up of two components: the vertebral body and the vertebral arch (Fig. 5-6). The latter is formed by the supporting pedicles and laminae (Fig. 5-6). Seven processes arise from the vertebral arch: one spinous process, two transverse processes, two superior articular processes, and two inferior articular processes (Fig. 5-6). Adjacent vertebra articulate with each other at the facet joints between the superior and inferior articular processes and the intervertebral disc between the vertebral bodies (Fig. 5-7). This produces two gaps between the lamina and the spinous processes (ie, the “interlaminar space” and “interspinous space”). It is through these spaces that the ultrasound energy enters the spinal canal and is therefore relevant for spinal sonography and central neuraxial blocks. The three major ligaments of the spine are the ligamentum flavum, anterior longitudinal ligament, and...
posterior longitudinal ligament (Fig. 5-7). The posterior longitudinal ligament is attached along the length of the anterior wall of the vertebral canal (Figs. 5-7 and 5-8). The ligamentum flavum, also referred to as the “yellow ligament,” is a dense layer of connective tissue that bridges the interlaminar spaces and connects the lamina of adjacent vertebra (Figs. 5-7 to 5-9). It is archlike on cross-section and widest posteriorly in the midline and in the lumbar region. The ligamentum flavum is attached to the anterior surface of the inferior margin of the lamina above, but it splits inferiorly to attach to both the posterior surface (superficial component) and anterior surface (deep component) of the lamina below. The spinous processes are attached at their tips by the supraspinous ligament (Fig. 5-7), which is thick and cordlike, and along their length by the interspinous ligament (Fig. 5-9), which is thin and membranous.

**FIGURE 5-6** The vertebral arch (highlighted in green).

**FIGURE 5-7** The posterior longitudinal ligament.
FIGURE 5-7 ▪ Ligaments of the vertebral column.

FIGURE 5-8 ▪ Ligamentum flavum (yellow ligament) and its attachment to the laminae.

FIGURE 5-9 ▪ Sagittal section of the lumbosacral spine showing the relationship of the spinal cord, conus medullaris, cauda equina, filum terminale, and thecal sac to the vertebral column.
The spinal canal (vertebral canal) is formed by the vertebral arch and the posterior surface of the vertebral body (Fig. 5-6). The openings into the spinal canal are through the intervertebral foramen along its lateral wall and the interlaminar space on its posterolateral wall. Within the spinal canal lies the thecal sac (formed by the dura mater and arachnoid mater) and its contents (spinal cord, cauda equina, and cerebrospinal fluid, Fig. 5-9). The spinal cord extends from the foramen magnum to the conus medullaris, near the lower border of the first lumbar vertebra (Fig. 5-9), finally terminating as the filum terminale. However, there are normal variations in the position of the conus medullaris, and it can extend from T12 to upper third of L3.17 The cauda equina, named after its resemblance to a “horse’s tail,” is made up of lumbar, sacral, and coccygeal nerves that originate in the conus medullaris and descend caudally to exit the spinal canal through their respective intervertebral foramen. The dural sac ends at the level of the second sacral vertebra (S2) (Fig. 5-9), but can vary from the upper border of S1 to the lower border of S4.18 The epidural space is an anatomical space within the spinal canal, but outside the dura mater (extradural). It extends from the level of the foramen magnum cranially to the tip of the sacrum at the sacrococcygeal ligament (Fig. 5-9). The posterior epidural space is of importance for central neuraxial blocks. The only structure of importance in the anterior epidural space for neuraxial blocks is the internal vertebral venous plexus.

**Spinal Sonography – Basic Consideration**

Spinal sonography typically requires the use of low-frequency ultrasound (5-2 MHz) and a curved array transducer because the spine is located at a depth. Low-frequency ultrasound provides good tissue penetration, but it lacks spatial resolution at the depths at which neuraxial structures are imaged (approximately 5–8 cm). The osseous framework of the spine, which envelopes the neuraxial structures, also reflects much of the incident ultrasound signal. Furthermore, the acoustic window for ultrasound imaging (interlaminar and interspinous space) is relatively narrow, and this poses an additional challenge in obtaining high-quality images of the neuraxis. Recent improvements in ultrasound technology, image processing capabilities of ultrasound machines, availability of advanced imaging modalities (tissue harmonic imaging [THI], tissue aberration correction, color B-mode imaging), and the development of new ultrasound scan protocols1 have all contributed to improving our ability to image the neuraxis. Currently it is possible to accurately delineate the neuraxial anatomy relevant for central neuraxial blocks using ultrasound.1,3 Also of note is technology that was once only available in the high-end cart-based ultrasound systems are now available in portable ultrasound devices, making them practical for spinal sonography and ultrasound-guided neuraxial blocks.

**Ultrasound Scan Planes**

There are basically three anatomical planes: median, transverse, and coronal plane (Fig. 5-10). The *median plane* is a longitudinal plane that passes through the midline and bisects the body into equal right and left halves. The *sagittal plane* is also a longitudinal plane but is parallel to the median plane and perpendicular to the ground. Therefore, the *median plane* can also be defined as the sagittal plane that is exactly in the middle of the body (*median sagittal plane*). The *transverse plane*, also known as the axial or horizontal plane, is parallel to the ground. The *coronal plane*, also known as the frontal plane, is perpendicular to the ground.
The spine can be imaged using ultrasound in the transverse (transverse scan, Fig. 5-11) or longitudinal (sagittal scan, Fig. 5-12) plane and with the patient in the sitting, lateral decubitus, or prone position. The latter is useful in patients presenting for chronic pain interventions when fluoroscopy may also be used in conjunction with ultrasound. The transverse and sagittal scan planes complement each other during an ultrasound examination of the spine. Coronal plane images are displayed exclusively during multiplanar three-dimensional (3-D) ultrasound imaging, and they are rendered images from the acquired 3-D volume. During a transverse scan of the lumbar spine, the ultrasound beam can be insonated at the level of the spinous process (transverse spinous process view, TSPV, Fig. 5-11A) or through the interspinous space (transverse interspinous view, TISV, Fig. 5-11B). A sagittal scan can be performed through the midline (median sagittal scan) or through a paramedian (paramedian sagittal scan, PMSS) plane. The latter is more frequently used (less bone), and during a paramedian sagittal scan (PMSS) the ultrasound beam is insonated lateral to the midline (paramedian), and ultrasound images are acquired from the level of the lamina (paramedian sagittal lamina view, Fig. 5-12A), articular process (paramedian sagittal articular process view, Fig. 5-12B), or transverse process (paramedian sagittal transverse process view, Fig. 5-12C). The neuraxial structures are better visualized through a paramedian sagittal plane than through the median sagittal or median transverse plane. The ultrasound visibility of neuraxial structures is further improved when the spine is imaged in the paramedian sagittal oblique axis (Fig. 5-13). During a paramedian sagittal oblique scan (PMSOS), the transducer is positioned 2 to 3 cm lateral to the midline (paramedian) in the sagittal plane, and it is also tilted slightly medially, that is, towards the midline (Fig. 5-14). The purpose of the medial tilt is to ensure that the majority of the ultrasound energy (signal)
enters the spinal canal through the widest part of the interlaminar space. The same applies, and is probably more important, during a paramedian sagittal scan of the thoracic spine (Fig. 5-15).

**FIGURE 5-11** Axis of scan – transverse scan (A) at the level of the spinous process and (B) at the level of the interspinous space.

**FIGURE 5-12** Axis of scan – paramedian sagittal scan (A) at the level of the lamina, (B) at the level of the articular process, and (C) at the level of the transverse process.
FIGURE 5-13  Axis of scan. (A) Paramedian sagittal scan at the level of the lamina and (B) paramedian sagittal oblique scan at the level of the lamina.

FIGURE 5-14  Axis of scan – paramedian sagittal oblique scan of the lumbar spine. Note the medial direction of the ultrasound beam (blue color). PMSS, paramedian sagittal scan (red color); PMSOS, paramedian sagittal oblique scan. VB, vertebral body; IVC, inferior vena cava; ESM, erector spinae muscle.
FIGURE 5-15  ■ Axis of scan – thoracic spine. (A) Paramedian sagittal scan and (B) paramedian sagittal oblique scan.

Sonoanatomy of the Osseous Elements of the Spine

The bony framework of the spine, which wraps around the neuraxial structures, does not lend itself to optimal conditions for ultrasound imaging because it reflects the majority of the incident ultrasound energy, except for what gets through to the spinal canal through the interspinous and interlaminar spaces. This creates a narrow acoustic window for imaging (Fig. 5-16) and is narrower in the thoracic region than in the lumber spine (Fig. 5-16). Age-related changes in the spine also cause narrowing of the acoustic window, making spinal sonography more challenging in the elderly. Being able to accurately define the osseous anatomy of the spine in a spinal sonogram is, in our opinion, the first step towards learning how to interpret ultrasound images of the spine. Let’s consider that the spine is made up of bone and soft tissue. If one is able to identify individual osseous elements of the spine, then one should be able to identify the gaps in the bony framework (ie, the interlaminar space or the interspinous space) through which the ultrasound beam is insonated to visualize the neuraxial structures within the spinal canal. It is also through these same gaps that a spinal or an epidural needle is inserted during an ultrasound-guided central neuraxial block.
FIGURE 5-16 Sagittal sonogram of the lumbar and thoracic spine demonstrating the acoustic window between the acoustic shadows of the laminae. Note the acoustic window is larger in the lumbar spine.

The water-based spine phantom is a simple model to study the osseous anatomy of the spine.\textsuperscript{1,3,20} It is prepared by immersing a commercially available spine model in a water bath (Fig. 5-17) and imaging it in the transverse and sagittal plane through the water using a low-frequency curved array transducer (Fig. 5-18). The water-based spine phantom, although originally developed to study the osseous anatomy of the lumbosacral spine,\textsuperscript{1,3,20} can also be used for the thoracic (Fig. 5-18) and cervical spine. Ultrasonography is often a case of “pattern recognition,” and this is also true for spinal sonography. Each osseous element of the spine produces a characteristic (signature) sonographic pattern that is comparable with that seen in vivo (Figs. 5-19 to 5-24).\textsuperscript{1,3} Because water produces an anechoic (black) background, the hyperechoic reflections from the bone are clearly visualized. Also because one can see the spine model through the water, it is possible to validate the sonographic appearance of a given osseous element by performing the scan with a marker (eg, a needle) in contact with it (Fig. 5-20A). The water-based spine phantom is also relatively cheap, easily prepared, requires little setup time, and can be repeatedly used without it deteriorating or decomposing.

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like animal tissues do.

**FIGURE 5-17** The water-based lumbosacral spine phantom. Note the lumbosacral spine is immersed in a water bath and is imaged through the water using a curved linear transducer.

**FIGURE 5-18** Water-based thoracic spine phantom. Note the acute angulation of the spinous processes in the midthoracic area (seen on the ultrasound monitor).
FIGURE 5-19 Sonograms from the water-based lumbosacral spine phantom showing (A) the transverse spinous process (SP) view, (B) the median sagittal spinous process view, and (C) the transverse interspinous view. An inset image has been placed next to image C to illustrate the resemblance of the sonographic appearance of the transverse interspinous view to a cat’s head (refer to text for details). TS, transverse scan; SP, spinous process; ISS, interspinous space; TP, transverse process; AP, articular process; VB, vertebral body; SC, spinal canal.
FIGURE 5-20  Paramedian sagittal sonogram of the (A) lamina, (B) articular process, and (C) transverse process from the lumbosacral water-based spine phantom. A graphic overlay has been placed over the lamina in (A) to illustrate the “horse head sign” and over the articular process in (B) to illustrate the “camel hump sign.” SS, sagittal scan; AP, articular process; TP, transverse process. Note a needle has been placed over the lamina, which is used to validate the structure imaged.

FIGURE 5-21  Sonograms from a water-based lumbosacral spine phantom showing (A) median sagittal view of the sacrum, sacral hiatus, and coccyx and (B) transverse view of the
sacral hiatus. SS, sagittal scan; TS, transverse scan.

**FIGURE 5-22** Paramedian sagittal sonogram of the lumbosacral junction (L5-S1 gap) from the water-based lumbosacral spine phantom.
FIGURE 5-23  Paramedian sagittal sonogram of thoracic spine at the level of the lamina. A simulated epidural needle is shown being inserted towards the interlaminar space in (B) as one would do with a paramedian thoracic epidural. PMSOS, paramedian sagittal oblique scan.
FIGURE 5-24  Sonograms from a water-based cervical spine phantom. Note the bifid spinous process of C2 in (B), the C1 spinous process is hypoplastic relative to C2 and recessed in (D), lamina in (E), and articular process in (F). TS, transverse scan; PMSS, paramedian sagittal scan; PMSOS, paramedian sagittal oblique scan.

With a lumbosacral water-based spine phantom the spinous processes produce an inverted Y-shaped pattern in the transverse spinous process view (Fig. 5-19A), but in a median sagittal scan they appear as crescent-shaped structures with their concavity facing anteriorly (Fig. 5-19B). The gaps between the spinous processes represent the interspinous spaces (Fig. 5-19B). The transverse interspinous view produces a sonographic pattern that resembles a cat’s head (Fig. 5-19C) with the ears of the cat representing the articular processes, the head representing the spinal canal, and the whiskers the transverse processes. We refer to this as the cat’s head sign. On a paramedian sagittal scan the lamina resembles the head and neck of a horse (Fig. 5-20A) and is referred to as the horse-head sign. 3 The articular processes appear as one continuous hyperechoic wavy line with no intervening gaps (Fig. 5-20B), resembling a camel’s hump (camel hump sign). The transverse processes are also crescent-shaped (Fig. 5-20C), but much smaller than the spinous process, and their acoustic shadows produce a sonographic pattern referred to as the trident sign. 21 The sacrum is recognized as a large hyperechoic structure with a large acoustic shadow anterior to it on a sagittal sonogram (Fig. 5-21). 3 The gap between the lamina of L5 and the sacrum is the L5-S1 gap (lumbosacral interlaminar space, Fig. 5-22). 3 Representative ultrasound images of the lamina of the thoracic spine (Fig. 5-23), and the spinous process (Fig. 5-24), lamina, and articular pillars (Fig. 5-24) of the cervical spine are presented in Figs. 5-23 and 5-24. Other models that are useful in understanding the osseous anatomy of the spine are the CIRS lumbar training phantom (Figs. 5-25 and 5-26) 3 and gelatin-agar spine phantom (Figs. 5-27 to 5-29). 22 Because the former can be imaged using computerized tomography (CT), 3-D reconstruction
of high-definition CT scan data (3-D volume data set) can also be used to study the osseous anatomy (Figs. 5-25 and 5-26).

**FIGURE 5-25** The CIRS lumbar training phantom (A) shown being imaged using ultrasound (C and D). Also shown is a 3-D reconstructed image of the volume CT data set of the CIRS phantom (B).
FIGURE 5-26 Rendered CT images of the CIRS lumbar training phantom. (A) Median sagittal section showing the spinous processes, interspinous space (ISS), and the L5-S1 gap. (B) Transverse interspinous section showing the articular processes (AP), facet joints (FJ), transverse process (TP), and spinal canal. (C) Paramedian sagittal section showing the laminae and interlaminar spaces (ILS). (D) Paramedian sagittal section at the level of the articular processes.
FIGURE 5-27 Gelatin-agar spine phantom. (A) Lumbosacral spine model secured to the base of the plastic box. (B) Spine phantom after being embedded in the gelatin-agar mixture. (C) Performing ultrasound scan of the gelatin-agar spine phantom. (D) Simulated in-plane needle insertion in the gelatin-agar spine phantom.
FIGURE 5-28 Ultrasound scan of the gelatin-agar spine phantom (A). Transverse sonogram of the spinous process (B) and through the interspinous space (D). Paramedian sagittal oblique scan of the L3-L4-L5 level (C).

FIGURE 5-29 Paramedian sagittal sonogram from the gelatin-agar spine phantom. (A) L5-S1 gap, (B) the laminae, (C) articular processes, and (D) the transverse processes at L3-L4 and L4-L5 levels. A graphic overlay has been placed over the L4 lamina in image B to illustrate the sonographic pattern resembling the head and neck of a horse, and an inset has been placed in image C to illustrate the camel hump–like appearance of the articular processes. SC, spinal canal; AC, anterior complex; ILS, interlaminar space; LF, ligamentum flavum; AP, articular process; TPn transverse process.

References


CHAPTER 6

Sonoanatomy Relevant for Ultrasound-Guided Injections of the Cervical Spine

Introduction

Injections of the cervical spine are frequently used for pain management in chronic pain medicine. The concentration of bony structures and nerves in the cervical spine, each of which can be a cause of pain, as well as vessels, requires an intimate knowledge of the anatomy. The relevant procedures in the cervical spine include facet joint and medial branch blocks, selective nerve root injection, third occipital nerve block, epidural steroid injection, and stellate ganglion block. In this chapter we discuss the anatomy relevant for these procedures.

Basic Cervical Spine Anatomy

The cervical spine (Figs. 6-1 to 6-3) is a column of seven vertebrae supporting the skull and neck structures. The atlanto-occipital and atlantoaxial joints are unique. The former is an ellipsoid joint, and the atlantoaxial joint is a rotatory joint. The atlantoaxial joint is bordered by the C2 dorsal root ganglion and vertebral artery. The cervical vertebrae are identified by the presence of the foramen transversarium (transverse foramen) for the vertebral artery.
**FIGURE 6-1** Cervical spine – lateral view.

**FIGURE 6-2** Cervical spine – anterior view. VB, vertebral body.
Typical Cervical Vertebra (C3 to C6)

The third to sixth cervical vertebrae are considered typical cervical vertebra (Fig. 6-4), whereas the first, second, and seventh cervical vertebrae are atypical with certain unique features (Figs. 6-5 and 6-6). The general characteristics of a typical cervical vertebra are described next. The upper five cervical vertebrae (C3 to C7) each have a concave superior surface and are convex on the inferior surface. They articulate with the adjacent vertebrae via uncovertebral joints (joints of Luschka). These are thought to be due to degenerative tears in the annulus of the intervertebral disc, leading to creation of the uncovertebral joint. Uncovertebral joint osteophytes can contribute to narrowing of the exit foramina. The spinal canal (vertebral canal) in the cervical spine is larger than the size of the body. It is also triangular shaped because the pedicles are directed backwards and laterally (Fig. 6-4). The superior and inferior vertebral notches are usually equal sized. The laminae are relatively long and narrow and thinner above than below. The superior and inferior articular processes form the articular pillars and project laterally at the junction of the pedicle and transverse process. The superior articular facets are directed backwards and upwards, whereas the inferior articular facets are directed forwards and downwards (Fig. 6-1). The transverse process of each vertebra is pierced by the foramen transversarium (Fig. 6-4) to allow for the passage of the vertebral arteries on their upward course to the foramen magnum (Fig. 6-7). Each transverse process has an anterior and a posterior tubercle with the groove for the spinal nerve between them (Figs. 6-1 and 6-2). The anterior tubercle of the sixth cervical vertebra is large and called the “carotid tubercle” (tubercle of Chassaignac). The posterior tubercles of C3 to C5 are located lower and laterally (Figs. 6-1 and 6-2). The spinous processes of C3 to C6 can be bifid (Figs. 6-3 and 6-8), and the two divisions can be of unequal size. The first bifid spinous process is C2, and this landmark is used to identify the remaining cervical vertebrae. The facet joints are oriented at 45 degrees to the axial plane and allow sliding of one articular facet on another (Figs. 6-9 and 6-10).
FIGURE 6-4 A typical cervical vertebra (C4 - fourth cervical vertebra). SAF, superior articular facet; SAP, superior articular process; VB, vertebral body; IAF, inferior articular facet; IAP, inferior articular process.
FIGURE 6-5  □ Atlas (superior, anterior, and lateral view). Note the kidney-shaped SAFs. SAF, superior articular facet; IAF, inferior articular facet.

FIGURE 6-6  □ Axis (superior, anterior, and lateral view). SAF, superior articular facet; VB, vertebral body; IAF, inferior articular facet; AAF, anterior articular facet; IAP, inferior articular process; PAF, posterior articular facet.
**FIGURE 6-7** Cervical spine (anterior view) showing the relationship of the cervical spinal nerves and the vertebral artery to the transverse processes of the vertebra. Note the transverse processes of the C7 vertebra lack an anterior tubercle and the relationship of the vertebral artery to the C7 spinal nerve and the transverse processes.

**FIGURE 6-8** Cross-sectional cadaver anatomic section through the C2 vertebral body showing the bifid spinous process of C2. This is an anatomical landmark used to identify the C2 vertebra as it is the first cervical vertebra with a bifid spinous process. The spinous process may be tilted to the right or left. Gentle left and right angulation of the probe in the longitudinal sagittal plane may be required to visualize these spinous processes.
FIGURE 6-9 Paramedian sagittal cadaver anatomic section through the cervical spine demonstrating the lamina of the cervical vertebrae. VB, vertebral body.

FIGURE 6-10 Cross-sectional cadaver anatomic section through the cervical spine demonstrating the facet joints. Note that the facet joints are orientated at about 45 degrees to the horizontal plane in transverse section.

The cervical spinal canal measures about 14 to 20 mm in the mediolateral dimension and 15 to 20 mm in the anteroposterior dimension. The spinal nerves (formed by the anterior and posterior nerve roots) exit through the neural foramina. These foramina are largest at C2 to C3 and progressively decrease in size to the C6 to C7 levels. The spinal nerve and ganglion take up about 33% of the foraminal space. The foramen is bordered anteromedially by the uncovertebral joints and posterolaterally by the facet joints. The pedicles border the exit foramina superior and inferiorly. The spinal nerves exit above their corresponding vertebral bodies. The C1 nerve exits above the C1 vertebra (atlas). The next spinal nerve is C2, exiting above the C2 vertebra (axis). Following this naming convention, the last cervical nerve root is C8, and it exits between the C7 and T1 vertebrae (Figs. 6-11 and 6-12).
FIGURE 6-11 Cross-sectional cadaver anatomic section through the cervical spine demonstrating the exiting C5 nerve root. The C5 nerve root exits the neural foramen and is in close relation to the vertebral artery posteriorly. Both these structures are bound by the larger anterior tubercle and the smaller posterior tubercle. TP, transverse process.

FIGURE 6-12 Sagittal cadaver anatomic section of the exit neural foramina demonstrating the C5 nerve root exiting between the transverse processes (TP) of C4 superiorly (C4 TP) and C5 (C5 TP) inferiorly. The bulk of sternocleidomastoid muscle lies anteriorly and may be traversed during procedures in the cervical spine.

The anterior spinal artery is located in the central sulcus of the cord, with paired posterior arteries running on the posterolateral aspect of the cord dorsally. The anterior spinal artery is an important artery: it supplies the anterior two-thirds of the cervical spinal cord. The artery
receives blood supply from the paired anterior spinal branches that arise from the cervicomedullary junction portion of the vertebral arteries. This anatomy is relevant for epidural steroid injections. The radicular arteries also supply the nerve roots and spinal cord. These radicular arteries arise from the aorta. In the lower cervical spine, they arise from the vertebral arteries and run in an anteromedial direction with respect to the neural foramina. In the lower cervical spine, large radiculomedullary branches contribute blood supply to the anterior spinal artery as well. Branches of the ascending and deep cervical arteries anastomose with the vertebral artery branches and contribute to the anterior spinal artery. The ascending cervical artery arises from the thyrocervical trunk or subclavian artery.

The posterior subclavian artery also gives off the deep cervical artery and the superior intercostal artery. The deep cervical artery gives spinal branches from levels C7 to T1, known as the cervical radiculomedullary arteries. As mentioned earlier, these arteries can contribute supply to the anterior spinal artery. These radiculomedullary arteries are found along the length of the intervertebral foramina and can be compromised during injection, potentially leading to damage to the anterior spinal artery. The posterior third of the cervical spinal cord is supplied by small paired posterior spinal branches.

**Atlas (C1)**

The atlas is the first cervical vertebra (Fig. 6-5) and forms the joint that connects the spine to the skull (Fig. 6-13). It is ring shaped and lacks both a vertebral body and spinous process (Fig. 6-5). It also lacks a true facet joint and has two arches: anterior and posterior. The posterior arch is usually quite small. A thick anterior arch, lateral masses, and transverse processes on either side make up the rest of the atlas ring. It also has a rudimentary posterior tubercle. On each lateral mass is a facet (zygapophyseal) joint. The superior articular facets are kidney shaped (Fig. 6-5), concave, and face upwards and inwards (imagine your hands cupping water from a running tap). The inferior articular facets are flat and face downwards and outwards. The transverse processes project laterally from each lateral mass and are longer than all the others (Figs. 6-2 and 6-3).

**FIGURE 6-13** Median sagittal cadaveric anatomic section through the cervical spine demonstrating C1 in relation to the occiput and the rest of the cervical vertebrae. Note how
closely the dura and the cervical spinal cord are to the spinous processes. The vertebral bodies (VB) are labeled as anterior complex to demonstrate that sonographically, the individual components (including the posterior longitudinal ligament complex) are difficult to distinguish individually. SP, spinous process.

**Axis (C2)**

The second cervical vertebra (Fig. 6-6) is recognized by the presence of the dens (odontoid process), which is a strong toothlike process that projects upwards from the body (Fig. 6-6). The dens is believed to represent the body (centrum) of the atlas, which has fused with the body of the axis. The odontoid process articulates with the atlas to form the rotatory atlantoaxial joint. The joint is strengthened by periarticular ligaments (the apical, alar, and transverse ligaments). The axis is made up of a vertebral body, pedicles, lamina, and transverse and spinous processes. The atlas articulates with the axis (Fig. 6-2) at the superior articular facets of C2. In order to meet the inferior articular processes of C1, the C2 superior articular facets face upwards and outwards. There is an extensive and densely packed network of blood vessels around the dens. These are supplied by the paired anterior and posterior ascending arteries (which arise from the vertebral arteries at the C3 level, carotid wall vessels, and the ascending pharyngeal arteries).

The transverse ligament secures the odontoid process to the posterior atlas and acts to prevent subluxation of C1 on C2. Accessory ligaments arise posterior to the transverse ligament and insert on the lateral aspects of the atlantoaxial joint. The apical ligament, part of the accessory ligaments mentioned earlier, connect the anterior lip of the foramen magnum to the tip of the dens. Paired alar ligaments also attach the tip of the dens to the anterior foramen magnum. The tectorial membrane is a cranial continuation of the posterior longitudinal ligament, attaching to the anterior lip of the foramen magnum. A broad accessory atlantoaxial ligament connects C1 and C2 and connects to the occiput. They contribute to craniocervical stability. The lack of bony borders at the atlantoaxial joint results in wider acoustic windows at this level, but this is countered by the tortuous course of the ascending vertebral arteries.

**Seventh Cervical Vertebra (C7)**

This is also known as the “vertebral prominence” because it has a long and prominent spinous process (Fig. 6-1) that is palpable from the skin surface. The spinous process is also thick, nearly horizontal, and is not bifid but ends in a tubercle. The transverse process of C7 is relatively large and lacks an anterior tubercle (Fig. 6-7). The foramen transversarium on the transverse processes of C7 are small but may be duplicated or even absent.

**Computed Tomography Anatomy of the Cervical Spine**

Figs. 6-14 to Fig. 6-21
**FIGURE 6-14** Transverse CT section through the cervical spine demonstrating the facet joints at the C5 to C6 level. The inferior articular pillar of the C6 (vertebra inferior to the joint) is located anterior to the joint space. The superior articular pillar of the C5 (vertebra superior to the joint) is located posterior to the joint space.

**FIGURE 6-15** Transverse CT section through the cervical spine demonstrating the facet joints at the C6 to C7 level. Note the relatively horizontal orientation of the facet joint as opposed to the obliquity of the C5 to C6 facet superiorly.
FIGURE 6-16 Transverse CT section through the cervical spine. The lamina on the posterolateral aspect of the vertebra flows into the transverse process. The longus colli muscle lies on the anteromedial aspect of the transverse process.

FIGURE 6-17 Transverse CT section through the body of the seventh cervical spine demonstrating its large and prominent spinous process (vertebra prominence). VB, vertebral body.
FIGURE 6-18  Sagittal CT section of the cervical spine demonstrating the posterior arch of C1 and the corresponding laminae of the vertebrae inferiorly.

FIGURE 6-19  Sagittal CT section of the cervical spine more laterally in the cervical spine demonstrating the overlapping articular pillars that form the facet joints. In the same cut, transverse processes may also be visualized on CT. The transverse processes may be obscured on ultrasound by the bony reflections of the facet joints.
FIGURE 6-20  Sagittal CT section of the cervical spine in the midline demonstrating the spinous processes aligned with the occiput. The tips of the spinous processes are echogenic on ultrasound. Starting with the broad echogenic base of the occiput, these echogenic points can be used to identify the levels of the cervical spine. Note that the spinous process of C1 is hypoplastic relative to C2 and recessed. It is important to identify this recess to avoid mislabeling C2 as the first cervical vertebra on ultrasound.

FIGURE 6-21  Sagittal CT section of the cervical spine demonstrating the relationships of the articular pillars, facet joints, and the vertebral artery within the foramen transversarium. Also note the oblique angulation of the facet joints in the sagittal plane. In order for successful facet joint injection, the needle should be parallel to the angulation of the joint.
Magnetic Resonance Anatomy of the Cervical Spine

Figs. 6-22 to 6-38

FIGURE 6-22 Sagittal T2-weighted MRI section of the cervical spine demonstrating the posterior arch of C1 and the corresponding laminae of the vertebrae inferiorly. Note the slight overlap of the laminae, which is seen on ultrasound as a “horse head” configuration. Cerebrospinal fluid (hyperintense signal) bathes the small nerve roots in the spinal canal.

FIGURE 6-23 Sagittal T2-weighted MRI section of the cervical spine more laterally in the cervical spine demonstrating the overlapping articular pillars that form facet joints.
FIGURE 6-24 Sagittal MRI section of the cervical spine demonstrating the vertebral artery within the foramen transversarium. The exiting nerve roots are well demonstrated as ovoid hypointense foci as they are seen en face. The nerve roots are closely related to the vertebral artery.

FIGURE 6-25 Sagittal MRI section of the cervical spine in the midline demonstrating the spinous processes aligned with the occiput. The tips of the spinous processes are echogenic on ultrasound. Starting with the broad echogenic base of the occiput, these echogenic points can be used to identify the levels of the cervical spine. Note that the spinous process of C1 is hypoplastic relative to C2 and recessed. It is important to identify this recess to avoid mislabeling C2 as the first cervical vertebra on ultrasound. MRI demonstrates the relationship of the cervical spine relative to the dura, with surrounding cerebrospinal fluid.
FIGURE 6-26  Sagittal MRI section of the cervical spine demonstrating the broad base of the occiput. Note that the spinous process of C1 is hypoplastic relative to C2 and recessed. It is important to identify this recess to avoid mislabeling C2 as the first cervical vertebra on ultrasound.

FIGURE 6-27  Sagittal oblique MRI section of the cervical spine demonstrating the
epidural space and the dura posteriorly. The epidural space in the cervical spine is a potential space (unlike the lumbar spine, where fat fills the epidural space).

**FIGURE 6-28** Transverse MRI section through the cervical spine demonstrating the laminae of C2. The cervical spinal cord is well visualized centrally, with nerve roots exiting on either side of the cord, extending beyond through the exit foramina.

**FIGURE 6-29** Transverse MRI section through the cervical spine demonstrating the facet joints. The facets are angled posteriorly at this level and gradually assume a more horizontal orientation in the lower cervical spine. The vertebral body and anterior and posterior longitudinal ligaments are collectively referred to as the anterior complex in sonography as they are not separately distinguishable.
FIGURE 6-30 Paramedian sagittal MRI of the cervical spine demonstrating the almost vertical oblique course of the cervical nerve roots of C4 and C5 as they plunge toward the interscalene groove. The large overlying sternocleidomastoid muscle is demonstrated.

FIGURE 6-31 Paramedian sagittal MRI section of the cervical spine demonstrates the C5 nerve root beyond the exit foramen. It runs between the transverse processes of C4 and C5 en route to the interscalene groove (between the anterior and middle scalene muscles).
FIGURE 6-32 Transverse MRI section through the cervical spine demonstrating the exiting C5 nerve root. The C5 nerve root exits the neural foramen and is in close relation to the vertebral artery posteriorly. Both these structures are bound by the larger anterior tubercle and the smaller posterior tubercle.

FIGURE 6-33 Transverse MRI section through the cervical spine demonstrating the facet joints at the C5 to C6 level. The inferior articular pillar of the C6 (vertebra inferior to the joint) is located anterior to the joint space. The superior articular pillar of the C5 (vertebra superior to the joint) is located posterior to the joint space. Note that at C5 to C6, the facets remain oblique relative to the horizontal plane. They take a more horizontal course from the C6 to C7 and C7 to T1 levels.
FIGURE 6-34  Transverse MRI section through the cervical spine demonstrating the prominent anterior tubercle of C6 (Chassaignac’s tubercle). This is a sonoanatomical landmark to identify C6 and the exiting C6 nerve root immediately posterior to the tubercle. The longus colli muscle lies anteromedial to the Chassaignac tubercle in close relationship with the carotid artery on its lateral aspect.

FIGURE 6-35  Transverse MRI section through the cervical spine demonstrating the C6 to C7 facet joints. In comparison with the C5 to C6 level, the facets are orientated in a more horizontal plane.
FIGURE 6-36 Transverse MRI section through the cervical spine at the C6 to C7 foramen demonstrating the exiting C7 nerve root running immediately posterior to the vertebral artery. The nerve root is en route between the anterior and middle scalene to form the brachial plexus. Note the presence of the internal jugular vein (IJV), carotid artery, and the vertebral artery.

FIGURE 6-37 Transverse MRI section through the cervical spine demonstrating the C7 transverse processes. The anterior complex (vertebral body) is flanked by the vertebral arteries on both sides.
Ultrasound for Cervical Facet Joint Injection

Ultrasound Scan Technique

1a. **Patient position:**
   a. **Lateral approach:** The patient is placed in the lateral decubitus position. The head is placed on a pillow so that the shoulders are square to the examination couch. Hair should be tied and lifted clear from the side of the neck to prevent contamination during the procedure (Fig. 6-39).
FIGURE 6-39 Position of the patient and ultrasound transducer during a paramedian sagittal scan of the cervical facet joints. The transducer is placed about 1 to 2 cm away from the midline and angulated medially toward the facet joints. A similar position is used for performing third occipital nerve blocks (refer to text).

b. **Posterior approach:** The posterior approach has the distinct advantage of allowing the patient to be placed prone and both joints being accessible without having to change position. It can be uncomfortable to the patient if multiple levels are blocked, so this position is suited for faster access to both sides of the neck (Fig. 6-40).

FIGURE 6-40 Position of the patient and ultrasound transducer during a paramedian sagittal scan of the cervical facet joints. The transducer is placed about 1 to 2 cm away from the midline and angulated medially toward the facet joints. The posterior approach allows more room to maneuver the needle and probe. It also allows simultaneous access to both sides of the spine, but is generally more uncomfortable for patients.
1b. **Position of operator and ultrasound machine:**

The operator sits or stands facing the patient’s back in the lateral position or on the side of the patient for the posterior approach. It is more comfortable for the operator if the nondominant hand anchors the transducer and the dominant hand manipulates the needle.

2. **Transducer selection:**

Due to the density of muscular structures around the cervical spine, a curvilinear probe (5–2 MHz) is used for imaging and blocks in the cervical spine (facet blocks and occipital nerve blocks). The in-plane resolution of the images is reduced compared with a linear probe, but this is often necessary due to the depth of the facet joints in relation to the skin. The probe footprint is often large, and maneuvering the transducer into the correct position requires practice. Although visualization of small (2 mm and below) structures is compromised by using a curvilinear probe traditionally, processing techniques such as spatial compound imaging and tissue harmonic imaging on new ultrasound machines enable us to examine tissues at those depths with reasonable clarity. Beam steering technology (which is an offshoot of compound imaging) enhances needle visualization, and color B-mode imaging (such as indigo or sepia hue) aids the human eye for image visualization when image contrast is poor.

3. **Scanning technique for facet joint blocks:**

A sagittal plane scan is performed in the midline, using the spinous processes to identify the level to inject. Align the transducer in a craniocaudal direction with respect to the cervical spine, starting at the occiput and sliding inferiorly. C1 has a very small or absent spinous process (Figs. 6-41 and 6-42), and the first bifid spinous process will be C2. The transducer can be slid inferiorly until the desired level for the injection is reached. Having identified the level, the transducer should be shifted slightly laterally along the lamina by about 1 to 2 cm from the midline. From there, a slight lateral shift of the transducer will reveal facet joints, which appear with a characteristic “saw sign.” The probe may have to be angled medially to produce a slightly paramedian sagittal oblique image. The needle is inserted in a posterior-to-anterior plane and followed in real time (Fig. 6-43).

![FIGURE 6-43](image)

**FIGURE 6-43** Paramedian sagittal sonogram of the cervical spine lateral to the laminae demonstrating the overlying echogenic “hills” of the facet joints.
FIGURE 6-41  Median sagittal sonogram of the cervical spine. The broad echogenic base of the occiput is immediately followed by the recessed spinous process of C1. The C2 spinous process is larger and appears as a step superficially relative to the C1 vertebra.

FIGURE 6-42.  Coned (zoomed) sagittal view of the cervical spine. The occiput and C1 articulation is clearly demonstrated.

4. Sonoanatomy of the facet joint:
On ultrasound, cervical segments can be identified with respect to the occiput by counting the echogenic points, which represent the spinous processes. The first echogenic point located inferior to the occiput is the C1 cervical vertebra. The C2 vertebra is located immediately inferior to that and has a characteristic bifid appearance. This presents as two
echogenic points on ultrasound performed in the transverse plane. The spinous processes in the cervical spine can appear bifurcated and can be asymmetrical. They can also deviate to the right or left (Figs. 6-8 and 6-13).

The occipitoatlantal and atlantoaxial joints may be demonstrated once these levels are identified. The articular processes are echogenic, and the facet joint is represented as a hypoechoic gap between the articular processes. The needle can then be inserted from inferior to superior in plane to the transducer. This approach allows the needle to be inserted parallel to the facet joint (Fig. 6-43).

The facet joints are angled at about 45 degrees to the transverse plane in the cervical spine. They start to assume a more vertical position in the upper thoracic spine. The superior articular process faces more posteromedial in the upper cervical levels, and it becomes more posterolateral at the lower cervical level (Figs. 6-44 and 6-45). The facet joints are synovial joints. Each facet joint has a fibrous capsule and is lined by synovial membrane. The joint capsules are lax in the lower cervical spine, allowing the spine to glide smoothly during movement (Figs. 6-9, 6-14, 6-29, and 6-46).

FIGURE 6-46 Transverse sonogram clearly demonstrating the facet joint of C5 to C6. Sometimes, this joint is obscured by osteophyte formation.
FIGURE 6-44  Transverse sonogram of the cervical spine at the C2 articular pillars level. With the probe orientated in a transverse plane and angulated superiorly between the spinous processes, the spinal cord and anterior complex can be visualized.

FIGURE 6-45  Transverse sonogram at the C2 to C4 articulation demonstrating the facet joints on either side of the central canal containing the spinal cord. The echogenic lines denoting the apposing articular surfaces can be seen. Whereas an in-plane injection technique is frequently used with cross-sectional imaging, ultrasound-guided facet injections are usually performed in the longitudinal plane relative to the patient.

The facet joint capsules contain dense mechanoreceptors, which play a role in proprioception and pain sensation. This is thought to neuromodulate the cervical spine and prevent excessive joint movement. The facet joints are innervated by articular
branches derived from the medial branches of the cervical ventral and dorsal rami. The atlanto-occipital and atlantoaxial joints are innervated by the anterior rami of the first and second cervical spinal nerves. The C2 to C3 facet joint is innervated by the two branches of the posterior ramus of the third cervical spinal nerve: a communicating branch and the third occipital nerve (Fig. 6-9).

The C3 to C7 dorsal rami arise from their respective spinal nerves and pass dorsally over the root of the corresponding transverse processes. The medial branches of the cervical dorsal rami run transversely across the centroid of the corresponding articular pillars (Fig. 6-47). They are bound to the periosteum by investing fascia and secured by the tendon of semispinalis capitis. The articular branches arise as the nerve approaches the posterior aspect of that articular pillar, one innervating the zygapophyseal joint above and the other innervating the joint below. Hence each typical cervical facet joint below C2 and C3 has dual innervation from the medial branch above and below.

**FIGURE 6-47** Coned down (zoomed) ultrasound view of the facet joints and articular pillars. Echogenic medial branch rami are visualized in apposition to the echogenic bone cortex. These superficial structures are well visualized and can be targeted for radiofrequency ablation and injection.

The medial branches of the C3 dorsal ramus differ in their anatomy. A deep medial branch passes around the waist of the C3 articular pillar, similar to other typical medial branches, and supplies the C3 to C4 zygapophyseal joint. The superficial medial branch of C3 is large and known as the third occipital nerve (TON). It curves around the lateral and then the posterior aspect of the C2 to C3 zygapophyseal joint, giving articular branches to the joint. Beyond the C2 to C3 zygapophyseal joint, the TON becomes cutaneous over the suboccipital region. Another anatomical exception is the course of the medial branch of C7. The C7 medial branch passes more cranial, closer to the foramen of C7, crossing the triangular superior articular process of C7 vertebrae.

5. **Clinical Pearls:**

Do not introduce too much craniocaudal rocking movement of the transducer as it increases the chances of losing one’s position. Axial scans of the cervical spine to identify
the facet joints are usually not practiced routinely. The reason is that rotating the transducer to produce an axial image increases the chances of losing one’s position along the cervical vertebrae, requiring a recount. Furthermore, visualization of the facet joint in the axial plane does not facilitate needle positioning, as the sonographic technique uses a craniocaudal approach (as opposed to a lateral-to-median approach).

The skin entry point of the needle is usually about 2 to 3 cm inferior to the end of the probe, rather than at the probe itself. This allows the needle to enter at a shallower angle and to be inserted parallel to the facet joint. Confirmation of injectate can be done by watching out for a hyperechoic flush (representing a small pocket of air trapped within the needle). However, once the air has been expelled, it can be difficult to visualize the injectate. Turning on the Color Doppler function on the ultrasound machine allows flow to be visualized, and injection can be done under continuous Doppler monitoring.

Ultrasound for Third Occipital Nerve Block

Gross Anatomy of the Third Occipital Nerve

As described in the facet joint section, the joints are innervated by articular branches derived from medial branches of the cervical dorsal rami. The C3 to C7 dorsal rami arise from the corresponding spinal nerves and travel dorsally over the transverse processes posteriorly. Now, the C3 medial branches have a different anatomy. A deep medial branch passes around the waist of the C3 articular pillar to supply the C3 to C4 facet (similar to the other levels caudally). The superficial medial branch of C3 (the TON) curves laterally and around the posterior aspect of the C2 to C3 facet. It supplies branches to the joint prior to traveling dorsal to the semispinalis obliquus capitis muscle. So, each facet joint is innervated by the medial branch at the levels inferior and superior to it (dual innervation), with the exception of C2 to C3, which is innervated by a single nerve (TON). The TON is the only nerve that crosses over the facet joint. The TON measures about 2 mm in diameter (range of 1–3 mm) and is located about 2 cm (range 1.4–2.7 cm) from the skin.

Ultrasound Scan Technique

1. Position:
   a. Patient: The patient is placed in the lateral decubitus position, similar to a lateral facet injection position (Fig. 6-39). The head is placed on a pillow so that the shoulders are square to the examination couch. Hair should be tied and lifted clear from the side of the neck to prevent contamination during the procedure.
FIGURE 6-48 Position of the patient and ultrasound transducer during a scan for selective nerve root injection. The high-frequency linear array transducer is placed in a transverse oblique plane with respect to the long axis of the cervical spine, allowing visualization of the nerve root.

b. **Operator and ultrasound machine:** The operator sits or stands facing the patient’s back in the lateral position. It is more comfortable for the operator if the nondominant hand anchors the transducer and the dominant hand manipulates the needle.

2. **Transducer selection:**

   A high-frequency (15–12 MHz) linear transducer is generally used. This allows visualization of the greater occipital nerve at the level of the obliquus capitis inferior muscle. Imaging techniques like beam steering technology and compound and harmonic imaging are available on most new ultrasound machines. These generally improve visualization of the anatomy and the needle. A lower-frequency curvilinear transducer (3–5 MHz) can be used in obese patients, but nerve visualization will be more difficult compared with the linear transducer. The footprint of the curvilinear transducer is also bigger than the linear transducer. Circumstances will usually dictate the appropriate transducer to use.

3. **Scanning technique and sonoanatomy:**

   Starting in the midline of the posterior spine, the probe can be slid anteriorly and laterally to the level of the mastoid process. This will allow identification of the occipital bone and the C1 and C2 transverse processes. Turning on the Color Doppler function at this level is useful to identify aberrant branches of the vertebral artery. The probe can be slid inferiorly and posteriorly, and the articular pillars of C2 and C3 will come into view. The TON runs perpendicular to the probe at this point and is located dorsal to the C2 to C3 articulation. Sonographically, the fibrillar ovoid nerve can be seen overlying the C2 to C3 facet joint. The TON crosses the C2 to C3 articular pillars about 1 mm from the bone, and the operator can identify the typical fibrillar pattern of the nerve on ultrasound by angling the probe slightly back and forth. The facets can also be confirmed by visualizing the echogenic “hills” representing the facet joints caudally. The medial branch nerves are located in the troughs or valleys of these echogenic “hills” (Figs. 6-43 and 6-47).

Another technique to detect the TON involves placing the transducer in an oblique
transverse orientation, with the cranial end of the transducer anchored to the occipital bone. The caudal end of the transducer can then be tilted inferiorly (keeping the cranial end anchored to the mastoid), until the semispinalis obliquus capitis muscle comes into view in the longitudinal plane. The third occipital nerve can be seen as an ovoid fibrillar structure overlying the muscle. This corresponds to the traditional suboccipital landmark used in palpation-based injection techniques.

4. Clinical Pearls:
The ultrasound technique is a modification of the blind palpation technique. The nerve is blocked at a more proximal level, prior to branching of the nerve, increasing the treated area. Using Doppler prior to injection is important to identify aberrant vessels in the suboccipital area.

Ultrasound for Selective Nerve Root Block

Ultrasound Scan Technique

1. Position:
   a. Patient:
      i. Lateral approach: The patient is placed in the lateral decubitus position (Fig. 6-48). The head is placed on a pillow so that the shoulders are square to the examination couch. Hair should be tied and lifted clear from the side of the neck to prevent contamination during the procedure.
      ii. Posterior approach: The posterior approach has the distinct advantage of allowing the patient to be placed prone and both sides being accessible without having to change position. It can be uncomfortable to the patient if multiple levels are blocked, so this position is suited for faster access to both sides of the neck.
   b. Position of operator and ultrasound machine:
      The operator sits or stands facing the patient’s back in the lateral position or on the side of the patient for the posterior approach. It is more comfortable for the operator if the nondominant hand anchors the transducer and the dominant hand manipulates the needle.

2. Transducer selection:
   For selective nerve root blocks, a high-frequency (15–12 MHz) linear array transducer can be used. The linear footprint is smaller than the curvilinear transducer and can be placed at the base of the neck for the lower cervical nerve roots. Imaging techniques like beam steering technology and compound and harmonic imaging are generally available on most new ultrasound machines and improve visualization of the anatomy and the needle point.

3. Scanning technique:
   Locating the correct cervical vertebral level has been described in the section on facet joint injection. This involves identifying the C1 vertebra (with a small or nonexistent spinous process) and the C2 vertebra inferiorly (the first bifid cervical spinous process, Fig. 6-8). The levels are then labeled sequentially from C2 (Fig. 6-41). Another technique of identifying the cervical vertebral levels on a lateral image is to count upwards (cephalad direction) from C6. The C6 vertebral anterior tubercle is the largest in the cervical spine (Chassaignac’s tubercle). The transducer is maintained in the same axial orientation and gently moved upwards. The anterior tubercles of the respective cervical vertebrae are identified and counted. The vertebral artery must be identified at the same
time and documented. The vessel runs anteriorly at C7 before it enters the foramen transversarium from C6 in about 90% of cases (Fig. 6-7). In the remaining cases, the vertebral artery enters the foramen transversarium at C5 or at a higher vertebral level. The ultrasound transducer is positioned to obtain an oblique axial image of the cervical spine. The landmark structures are the transverse processes and their anterior and posterior tubercles, resulting in a camel hump sign. The nerve root is visualized as an oval hypoechoic punctate structure between the tubercles (Figs. 6-49 and 6-50). Subsequently, a 22-G needle can be introduced in a posterior-to-anterior direction. The needle is slowly advanced toward the oval hypoechoic target located between the “camel humps.” This approach is extraforaminal, but it provides a margin of safety given the density of radicular arteries in the foramen itself.

**FIGURE 6-49** Transverse sonogram demonstrating the exited C5 nerve root between the anterior and posterior tubercles of the C5 transverse process. The nerve will proceed between the anterior and middle scalene muscles with the other brachial plexus roots. The overlying sternocleidomastoid muscle is hypoechoic with fibrofatty striations.
FIGURE 6-50 Transverse sonogram demonstrating the exited C6 nerve root between the anterior and posterior tubercles. The nerve will proceed between the anterior and middle scalene muscles, with the other brachial plexus roots. The overlying sternocleidomastoid muscle is hypoechoic, with fibrofatty striations.

The anterior tubercle at C7 is hypoplastic. Hence, there is no bony landmark to indicate the anteriormost extent of the nerve root. More importantly, the vertebral artery at C7 runs in close proximity to the exited nerve root. It takes a vertical course toward the subclavian artery, and the C7 nerve root eventually runs laterally as part of the brachial plexus (Fig. 6-51). Due to the inherent risks of cervical spine procedures, monitoring with fluoroscopy is still advisable.6–12

FIGURE 6-51 Transverse sonogram demonstrating the exited C7 nerve root. The anterior
tubercle of C7 is hypoplastic and barely seen.

4. Sonoanatomy:
   The cervical spinal nerves exit primarily through the lower part of the foramen (Figs. 6-11, 6-12, 6-31, and 6-52). Epiradicular veins generally occupy the upper part of the foramen. Radicular arteries also lie in close approximation to the cervical spine nerves within the foramen. Hoeft showed that radicular branches from the vertebral artery course over the anteromedial aspect of the foramen and the branches arising from the ascending or deep cervical arteries run medially throughout the foramen. These arteries are at risk for inadvertent injury during transforaminal injections.

![Figure 6-52](image)

**FIGURE 6-52** Sagittal sonogram demonstrating the exited C5 nerve root running lateral to the transverse process. The C4 transverse process superiorly is demonstrated on the left of the image.

The C3 to C6 vertebrae constantly demonstrate an anterior (usually bigger) and a posterior tubercle with the groove for the spinal nerve between them. The posterior tubercles of C3 to C5 are situated lower and lateral to the anterior ones. The transverse processes lie beside the vertebral bodies slightly directed downward and anteriorly. The transverse processes in the cervical spine are relatively short, with the exception of the atlas and C7. The transverse processes at C1 project more laterally than all the others. The anterior tubercle at C2 is not well developed, resulting in a small transverse process. This feature can be used to differentiate C1 from C2 vertebrae on the axial plane. The anterior tubercle at C6 is usually the largest (tubercle of Chassaignac). This is an important sonographic landmark as the prominent anterior tubercle allows identification of C6 and location of the stellate ganglion in relation to the longus colli muscles. The transverse process of C7 has no anterior tubercle. This is an important characteristic to note as it helps to identify the vertebra. More importantly, injections performed around C7 should be done with caution, as the vertebral artery course is more variable than the other levels of the cervical spine (Figs. 6-8, 6-28, 6-34, 6-37, 6-53, and 6-54).
FIGURE 6-53 Transverse cadaver anatomic section through the cervical spine demonstrating the prominent anterior tubercle of C6 (Chassaignac’s tubercle). This is a sonoanatomical landmark to identify C6 and the exiting C6 nerve root immediately posterior to the tubercle. The longus colli muscle lies anteromedial to the Chassaignac tubercle.

Cervical ribs of various lengths and size may also occur and are usually bilateral when present. They can indent or impinge on the brachial plexus nerve roots. The foramen transversarium at C1 to C7 contain vertebral arteries and sympathetic nervous plexus.
from C6 upwards. Intervertebral foramina are largest at C2 and C3 (Figs. 6-55 and 6-56).

**FIGURE 6-55** Sagittal cadaver anatomic section of the cervical spine showing the vertebral artery immediately posterior to the transverse processes of C4 and C5. The relative positions of the vertebral bodies and cervical spinal cord are also demonstrated. The large belly of the sternocleidomastoid muscle is located anteriorly.

**FIGURE 6-56** Anterior sagittal sonogram of the cervical spine at the level of the C4 and C5 transverse processes demonstrating the hypoechoic nerve roots. The vertebral arteries within the foramen transversarium are well demonstrated with Color Doppler mode.

5. **Clinical Pearls:**
Although ultrasound guidance is useful in identification of the vertebral and inferior thyroid arteries, spinal radicular arteries are often too small in caliber to visualize consistently with ultrasound. Hence, using a smaller volume of injectate and continuous sonographic and Doppler monitoring are suggested. Epidural extension of the injectate through a transforaminal approach can result in a wider area of pain relief.

Ultrasound for Stellate Ganglion (Cervical Sympathetic Chain) Block

Gross Anatomy

The cervical sympathetic chain is composed of the superior, middle, intermediate, and inferior cervical ganglia. In 80% of cases, the inferior cervical ganglion is fused with the first thoracic ganglion, forming the stellate (cervicothoracic) ganglion. It measures approximately 2.5 cm in length, 1 cm in width, and 0.5 cm in anteroposterior depth. The ganglion is usually found between the inferior border of the C7 transverse process to T1 (especially if the lower cervical and upper thoracic ganglia remained separate) or adjacent to the pleural dome. It is contained within the fascial plane of the prevertebral fascia, overlying the longus colli muscles, on either side of the cervical vertebrae. The postganglionic fibers from the stellate ganglion and seventh and eighth cervical nerves to the first thoracic nerve provide sympathetic innervation to the upper limbs. The preganglionic fibers travel in a cephalad direction to the superior and middle cervical ganglia through the cervical sympathetic trunk. Hence, injection of local anesthetic at the level of the stellate ganglion blocks the sympathetic supply to a larger area (the head, neck, and upper limbs) than injection of the cervical sympathetic trunk (which results in sympathetic blockade of the head and neck regions only).

The vertebral artery is relatively free floating at the C7 level prior to entering the foramen transversarium at C6 as it ascends the neck. This is true in about 90% of cases. It can enter the foramen transversarium at C5 or higher instead in the remaining 10% of cases and is vulnerable to injury. The inferior thyroid artery is also exposed at the base of the neck. It arises from the thyrocervical trunk of the subclavian artery (running anterior to the vertebral artery and the longus colli muscle) and has a tortuous and variable course. These vascular structures can be visualized with Color Doppler and avoided during ultrasound-guided injections.

Ultrasound Scan Technique

1. Position:
   a. Patient: The patient is placed in a supine position, with the neck slightly extended (Fig. 6-57). A high-resolution linear transducer (17–9 MHz) is placed slightly lateral to the midline at the base of the neck.
FIGURE 6-57 Position of the patient and the ultrasound transducer during a cervical sympathetic (stellate ganglion) block. The stellate ganglion is best visualized with the patient’s neck gently extended. The transducer is orientated in a transverse oblique plane relative to the long axis of the cervical spine.

b. **Position of operator and ultrasound machine:** With the patient supine, the operator sits or stands on the side to be blocked. The ultrasound display should be placed diametrically opposite the operator. The operator can also sit or stand cephalad to the patient (at the head end). This gives access to both sides of the neck without the need to shift position. This position helps if the side to be blocked is ipsilateral to the operator’s dominant hand (ie, right stellate ganglion for right-handed individuals). It is more comfortable for the operator if the nondominant hand anchors the transducer and the dominant hand manipulates the needle.

2. **Transducer selection:**
   For cervical sympathetic chain blocks, a high-frequency (15–12 MHz) linear array transducer can be used. The linear footprint is smaller than the curvilinear probe and can be placed at the base of the neck. Imaging techniques like beam steering technology and compound and harmonic imaging are generally available on most new ultrasound machines. These improve visualization of the anatomy and the needle.

3. **Scanning technique:**
   The ultrasound transducer is placed in transverse orientation with respect to the cervical spine, in a paramedian position, at the base of the neck, above the prominence of the medial clavicle. From there, the probe is angled in a craniocaudal direction gently until the anterior tubercle of C6 (Chassaignac’s tubercle) transverse process comes into view. At this point, Color Doppler should be used to identify the important vessels and esophagus described later. A lateral-to-medial approach can be planned through the sternocleidomastoid muscle or lateral to it. The needle track must avoid the vascular structures and should run posterior to the vessels. The fluoroscopic technique of touching bone with the needle followed by gentle retraction can also be followed here. With ultrasound, the needle can be finessed into the space between the prevertebral fascia superficial to the muscle and reduce the amount of injection into the muscle. Usually 5 to 10 mL of local anesthetic is adequate (as opposed to larger quantities when the injection
was performed without imaging guidance). Injection should be monitored with Color Doppler.

4. Sonoanatomy:

On axial sections, the twin anechoic circular structures denoting the internal jugular vein and carotid artery are visible. The vein is differentiated from the artery by their compressibility. On computed tomography (CT) and magnetic resonance imaging (MRI), differentiation is based on relative locations of the vessels with respect to each other (the internal jugular vein is superficial to the carotid artery) and by scrolling in a craniocaudal direction. The thickness of the overlying sternocleidomastoid can be gauged in cross-section. The longus colli muscle runs anterior to the cervical transverse process at this level. It appears as an ovoid hypoechoic structure in transverse section, with fibrous tissue giving rise to internal striations (Fig. 6-58). These fibrous strands are also associated with fatty tissue, which adds to the striated hyperechoic appearance. On CT fibrous strands present as hypodense streaks within the muscle. On T1-weighted MRI images, the muscles appear hypointense with the fatty-fibrous strands appearing hyperintense in signal. This relationship is preserved on T2-weighted sequences. Whereas palpation and fluoroscopy are techniques used to perform stellate ganglion blocks, ultrasound confers the additional advantage of real-time visualization of the inferior thyroid, vertebral, cervical, and carotid arteries. Structures like the thyroid gland and esophagus can also be demonstrated with ultrasound and avoided during the procedure. The esophagus has a variable course at the level of the cricoid cartilage at the C6 vertebral level. It tends to project to the left side of the neck. The esophagus in transverse section presents as an ovoid structure with an irregular lumen (representing the mucosal folds). On both CT and MRI, the esophagus can be followed craniocaudally on sequential slices. It has a characteristic appearance similar to that seen on ultrasound. Care should be taken to identify the esophagus, especially during left-sided stellate ganglion blocks. The needle should not traverse the esophagus, to avoid bacterial contamination.

![Figure 6-58](image)

**Figure 6-58** Transverse sonogram of the cervical spine demonstrating the longus colli muscle. Note it is surrounded by the internal jugular vein, the carotid artery, the transverse cervical artery, and the vertebral artery.
5. Clinical Pearls:

The esophagus can be distinguished from the other structures in the neck by observing peristaltic movements when the patient is asked to swallow. It is important to ensure the inferior (caudal) flow of injectate from C6 to T1 to ensure that the stellate ganglion is appropriately targeted. Recall that the ganglion is usually located at C7 to T1 levels and that the injection is performed at C6 due to a slightly better safety profile (the vertebral artery is usually contained in the foramen transversarium at this level). If the injectate only stays at C6, then the middle cervical sympathetic ganglion is treated and not the stellate ganglion. The traditional practice of stellate ganglion block avoided bilateral injections. The reasons for this included potential for local anesthetic toxicity with the use of high volumes of local anesthetic (and hence higher plasma concentration) and recurrent laryngeal nerve palsy (up to 10% of cases). With real-time ultrasound monitoring, flow of the injectate between the carotid sheath, thyroid, and esophagus may be detected, and needle positioning can be adjusted if necessary.

References

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Introduction

Ultrasound imaging of the thoracic spine can be challenging due to peculiarities in its anatomy. The osseous framework of the thoracic spine makes up for a narrow acoustic window with limited ultrasound visibility of the spinal canal and neuraxial structures.\textsuperscript{1,2} Ultrasound visibility of the thoracic spine also varies depending on the plane\textsuperscript{1} of the ultrasound imaging and which part of the thoracic spine is being imaged.\textsuperscript{1} Ultrasound visibility progressively decreases as one moves up the thoracic spine.\textsuperscript{1} Currently data are limited on the use of ultrasound to guide or assist thoracic epidural injections.\textsuperscript{3,4} This chapter briefly outlines the anatomy, the technique of ultrasound imaging, and sonoanatomy of the thoracic spine relevant for thoracic epidural injection.

Basic Anatomy of the Thoracic Spine

The thoracic spine is made up of a column of 12 vertebrae (Fig. 7-1) that makes up the midsection of the vertebral column. The thoracic vertebrae are identified by the presence of articular facets on the lateral surface of the vertebral bodies for articulation with the head of the ribs (Figs. 7-1 to 7-4). There are also facets on the transverse processes of all, except the 11th and 12th vertebrae, for articulation with the tubercle of the ribs (Fig. 7-1). The thoracic vertebrae are intermediate in size between the cervical and lumbar vertebrae, with the lower thoracic vertebrae being a lot larger than the upper thoracic vertebrae (Fig. 7-4) and the upper thoracic vertebrae (T1–T2) being similar in size to the cervical vertebrae (Fig. 7-2). The thoracic spine has a primary curvature, which is concave anteriorly, but also has a lateral curvature that is slightly concave to the left, most likely from greater use of the right upper extremity and pressure from the aorta.
FIGURE 7-1 Thoracic spine (lateral view). VB, vertebral body.

FIGURE 7-2 Second thoracic vertebra (superior, anterior, and lateral view). TP, transverse process; VB, vertebral body; SC, spinal canal; SAP, superior articular process; IAP, inferior articular process; IVN, inferior vertebral notch.
FIGURE 7-3  Sixth thoracic vertebra (superior, anterior, and lateral view). TP, transverse process; SVN, superior vertebral notch; SC, spinal canal; SAP, superior articular process; IAP, inferior articular process.
FIGURE 7-4 Twelfth thoracic vertebra (superior, anterior, and lateral view). TP, transverse process; SC, spinal canal; SAP, superior articular process; IAP, inferior articular process; SVN, superior vertebral notch; VB, vertebral body.

Typical Thoracic Vertebrae

The 2nd to 8th thoracic vertebrae are considered typical thoracic vertebrae (Figs. 7-2 and 7-3), whereas the remaining five vertebrae (1st, 9th, 10th, 11th, and 12th) are atypical as they have certain unique features. The body of a typical thoracic vertebra is heart-shaped (Fig. 7-3) with its anteroposterior and lateral diameters being roughly the same (Fig. 7-3). Also the distance between the two lamina of the vertebra is greater than the width of the vertebral body (Fig. 7-3). On either side of the vertebral body are two costal (superior and inferior) facets (Fig. 7-3). The superior costal facets are larger, located on the superior border of the vertebra near the pedicle, and articulate with the head of the numerically identical rib (Figs. 7-2 and 7-3). The inferior costal facets are smaller in size, they are located near the inferior border of the vertebra and in front of the inferior vertebral notch, and they articulate with the next lower rib. The spinal canal is relatively small and circular (Fig. 7-3) and contains the spinal cord and meninges.

The pedicles of the thoracic vertebra are short and directed backwards (Fig. 7-2). The superior vertebral notch is shallow, whereas the inferior vertebral notch is large and deep (Figs. 7-1 and 7-5). The laminae are broad and thick, overlap the one from the adjacent vertebrae (Fig. 7-6), and are connected to the pedicle anteriorly (Fig. 7-5). The interlaminar spaces are also narrow, and using ultrasound they measure approximately 0.9 cm at the lower thoracic spine to 0.8 cm and 0.6 cm at the mid- and upper thoracic spine, respectively.1 The transverse processes are large and are directed laterally and backwards (Figs. 7-3 and 7-6) from the junction of the lamina and pedicle (Fig. 7-5). The costal facets on the anterior surface of the transverse process of the upper six vertebrae are concave (Fig. 7-3), facing forward, and articulate with the tubercle of the corresponding rib. The inferior articular processes are fused to the laminae, and their articular facets are directed forwards and slightly downwards and medially (Fig. 7-5). The superior articular processes in contrast project from the junction of the pedicle and laminae and are directed backwards and slightly laterally and upwards. The articulation of the rib to the transverse process anteriorly results in the neck of the rib being hidden anteriorly by the transverse process at the vertebral levels T1 to T4, but from there on until T9 the neck of the rib progressively projects above the transverse process.5 The spinous processes are long and directed backwards, downwards (Figs. 7-1, 7-6 and 7-7), and often slightly obliquely. Therefore even in a perfectly normal spine, the tips of the spinous processes may be slightly deviated from the midline (ie, paramedian in location, Fig. 7-7). The spinous processes are longest between T2 and T9 levels and overlap each other like “tiles on a roof.” This creates an acute angle for epidural needle insertion or insonation of the ultrasound beam if one were to do so through the midline. The spinous processes are less oblique above T2 and below T9. The spinous processes of T11 and T12 are directed backwards as with the lumbar spinous processes. The orientation of the T10 spinous process varies, with it being only slightly caudally directed to resemble that of the T11 and T12.
FIGURE 7-5 Lateral view of the sixth thoracic vertebra. VB, vertebral body; TP, transverse process; IAP, inferior articular process.

FIGURE 7-6 Articulation of the thoracic vertebrae and the rib with the transverse process (costotransverse junction) in the midthoracic region. Note the acute angulation of the spinous processes and the posteriorly directed transverse processes.
FIGURE 7-7 Different views of the thoracic spine that were rendered from a single 3-D volume CT data set. Note that although there is no scoliosis in this patient, the spinous processes of the vertebrae are slightly deviated from the midline (Fig. 7-7F).

The ligamentum flavum is attached to the upper border and the upper part of the anterior surface of the laminae. The transverse process gives attachment to the following ligaments (Fig. 11-3): (i) lateral costotransverse ligament at the tip, (ii) superior costotransverse ligament to the lower border, (iii) the inferior costotransverse ligament to the anterior surface, (iv) intertransverse ligament to the superior and inferior borders, and (v) the levator costae to the posterior surface (T1–T11). The spinous processes give attachment to the supraspinous and interspinous ligaments. Also the superior and inferior borders of the vertebral bodies give attachment in front and behind to the anterior and posterior longitudinal ligaments, respectively. There are also several muscles attached to the spine of the thoracic vertebrae, including the latissimus dorsi, trapezius, rhomboids, and many deep muscles of the back.

**Gross Anatomy of the Upper Thoracic Spine (T1–T4)**

Figs. 7-8 and 7-9
FIGURE 7-8 Cross-sectional cadaver anatomic section through the third thoracic vertebra demonstrating the relationship of the spinous process of the T2 vertebra with the posterior elements of the T3 thoracic vertebra. Also note the posteriorly directed transverse process and the costotransverse articulation. VB, vertebral body; CE, cervical esophagus.

FIGURE 7-9 Paramedian sagittal cadaver anatomic section through the thoracic spine demonstrating the lamina and the interlaminar spaces of the thoracic vertebrae. VB, vertebral body.

Computed Tomography Anatomy of the Upper Thoracic Spine (T1–T4)
Figs. 7-10 to 7-13
FIGURE 7-10 Transverse CT section through the lower part of the body of the second thoracic vertebra. VB, vertebral body.

FIGURE 7-11 Transverse CT section through the interspinous space of the T2 to T3 thoracic vertebrae. VB, vertebral body; TP, transverse process.
**FIGURE 7-12** Median sagittal CT section of the upper thoracic spine (T1–T4). VB, vertebral body; ISS, interspinous space.

**FIGURE 7-13** Paramedian sagittal CT section of the upper thoracic spine. ILS, interlaminar space; VB, vertebral body.

**Magnetic Resonance Imaging Anatomy of the Upper Thoracic Spine (T1–T4)**

Figs. 7-14 to 7-17

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FIGURE 7-14  Transverse MRI section of the upper thoracic spine through the base of the T3 spinous process. VB, vertebral body; CSF, cerebrospinal fluid.

FIGURE 7-15  Transverse MRI section of the upper thoracic spine through the interspinous space of the T2 to T3 vertebrae. VB, vertebral body; CSF, cerebrospinal fluid.
FIGURE 7-16 Median sagittal MRI section of the upper thoracic spine (T1–T4). VB, vertebral body; ISS, interspinous space.

FIGURE 7-17 Paramedian sagittal MRI section of the upper thoracic spine (T1–T4). VB, vertebral body; ILS, interlaminar space.

Gross Anatomy of the Midthoracic Spine (T5–T8)

Figs. 7-18 and 7-19
**FIGURE 7-18** Cross-sectional cadaver anatomic section through the midthoracic spine (7th thoracic vertebra). VB, vertebral body.

**FIGURE 7-19** Paramedian sagittal cadaver anatomic section of the midthoracic spine. Note the acute caudal angulation of the laminae and the narrow interlaminar spaces. VB, vertebral body.

**Computed Tomography Anatomy of the Midthoracic Spine (T5–T8)**

Figs. 7-20 to 7-23
FIGURE 7-20 Transverse CT section of the midthoracic spine through the base of the T6 spinous process. VB, vertebral body.

FIGURE 7-21 Transverse CT section of the midthoracic spine through the T6 to T7 interspinous space. VB, vertebral body; TP, transverse process.
FIGURE 7-22  Median sagittal CT section of the midthoracic spine (T5–T8). Note the acute caudal angulation of the spinous processes and the narrow interspinous spaces (ISS).

FIGURE 7-23  Paramedian sagittal CT section of the midthoracic spine. Note the narrow interlaminar spaces (ILS).

Magnetic Resonance Imaging Anatomy of the Midthoracic Spine (T5–T8)

Figs. 7-24 to 7-27
FIGURE 7-24  Transverse MRI section of the midthoracic spine through the base of the T6 spinous process. VB, vertebral body.

FIGURE 7-25  Transverse MRI section of the midthoracic spine through the T6 to T7 interspinous space. VB, vertebral body.
FIGURE 7-26 Median sagittal MRI section of the midthoracic spine. Note the sharp acute caudal angulation of the spinous processes and the narrow interspinous spaces. VB, vertebral body.

FIGURE 7-27 Paramedian sagittal MRI section of the midthoracic spine. VB, vertebral body.

Gross Anatomy of the Lower Thoracic Spine (T9–T12)

Figs. 7-28 and 7-29
**FIGURE 7-28** Cross-sectional cadaver anatomic section through the lower thoracic spine (11th thoracic vertebra). VB, vertebral body.

**FIGURE 7-29** Paramedian sagittal cadaver anatomic section of the lower thoracic spine (T9–T12). Note the acute caudal angulation of the laminae and the narrow interlaminar spaces. VB, vertebral body; ITS, intrathecal space.

**Computed Tomography Anatomy of the Lower Thoracic Spine (T9–T12)**

Figs. 7-30 to 7-33
FIGURE 7-30 ▪ Transverse CT section of the lower thoracic spine through the base of the T10 spinous process. VB, vertebral body.

FIGURE 7-31 ▪ Transverse CT section of the lower thoracic spine through the T10 to T11 interspinous space. VB, vertebral body; TP, transverse process.
FIGURE 7-32  Median sagittal CT section of the lower thoracic spine (T9–T12). Note the spinous process of T11 and T12 are broad, directed backwards, and similar to the lumbar spinous processes.

FIGURE 7-33  Paramedian sagittal CT section of the lower thoracic spine. ILS, interlaminar spaces.

Magnetic Resonance Imaging Anatomy of the Lower Thoracic Spine (T9–T12)
Figs. 7-34 to 7-37
**FIGURE 7-34** Transverse MRI section of the lower thoracic spine through the T10 to T11 interspinous space. VB, vertebral body; CSF, cerebrospinal fluid.

**FIGURE 7-35** Transverse MRI section of the lower thoracic spine through the T10 spinous process. VB, vertebral body; CSF, cerebrospinal fluid.
Ultrasound Imaging of the Thoracic Spine – Basic Considerations

Because of the peculiarities of the anatomy of the thoracic spine, as described earlier, we will be considering ultrasound imaging of the thoracic spine under three sections: (a) upper (T1–T4), (b) middle (T5–T8), and (c) lower (T9–T12) (Fig. 7-38). Ultrasound imaging of the
Thoracic spine can be performed in the transverse or sagittal plane. Because the depth from the skin to the lamina and epidural space in the mid- and lower thoracic regions—where the majority of thoracic epidural catheters are placed in clinical practice—is relatively shallow (median distance approx. 3.3–4 cm), the use of a high-frequency linear (12–8 MHz) transducer may suffice for ultrasound imaging. However, although the ultrasound images are generally of high resolution, the field of view with a high-frequency linear transducer is narrow and it gets progressively narrower with increasing depth of imaging. Therefore, it is desirable to use a curvilinear transducer, which emits a divergent beam and provides both high-quality images and a wide field of view (Fig. 7-39). The authors prefer to use a high-frequency (9–4 MHz) curvilinear transducer for imaging the thoracic spine, but a low frequency (5–2 MHz) is perfectly fine.

**FIGURE 7-38** Thoracic spine and its division into the upper (T1–T4), mid (T5–T8), and lower (T9–T12) thoracic regions.
Ultrasound visibility of the neuraxial structures decreases progressively as one moves up the thoracic spine, with ultrasound visibility being best in the lower thoracic region. The acute angulation of the spinous processes and the overlapping laminae in the midthoracic region make it difficult to image the neuraxis through the median plane in the transverse axis (median transverse scan). Ultrasound visualization of the spinal canal and neuraxial structures is better through the paramedian sagittal plane than through the median transverse plane. Therefore, the thoracic spine is generally imaged via the paramedian plane (Fig. 7-40) and through the interlaminar spaces. The laminae of the thoracic vertebrae are hyperechoic and relatively flat compared to the “horse head–like appearance” of the laminae in the lumbar spine (Fig. 5-20). Due to the narrow interlaminar spaces in the thoracic spine, the acoustic window for ultrasound imaging is significantly narrower than that in the lumbar region (Fig. 7-42). Therefore, ultrasound visibility of the neuraxial structures in the thoracic spine is not as good as in the lumbar region. For optimal imaging, it is also necessary to tilt the ultrasound transducer slightly medially, that is, insonate the beam slightly medially (paramedian sagittal oblique scan, Fig. 7-40), so that the majority of the ultrasound energy enters the spinal canal through the widest part of the interlaminar space, similar to that in the lumbar region.
FIGURE 7-40 Axis of scan – thoracic spine. (A) paramedian sagittal scan and (B) paramedian sagittal oblique scan.

FIGURE 7-41 Water-based thoracic spine phantom with a sagittal sonogram showing the lamina and interlaminar spaces.
The spinal cord, which lies within the thoracic spinal canal, can be clearly defined in newborns and young infants\(^8\) using ultrasound (Figs. 7-43 and 7-44) but cannot be delineated in adults with currently available ultrasound technology. The central canal is also seen as an echogenic line in the center of the spinal cord in young infants (Fig. 7-43).\(^8\) Various factors may contribute to the inability to visualize the spinal cord in adults: (a) a narrow acoustic window for imaging, (b) attenuation of the ultrasound beam, (c) the spinal cord is inherently hypoechoic, and (d) the spinal cord is surrounded by anechoic cerebrospinal fluid (Fig. 7-44).\(^8\) Therefore, in the thoracic region one has to rely on recognizing the osseous structures of the vertebral arch, interspinous and interlaminar spaces, ligamentum flavum, and the anterior complex (AC).\(^3\) The latter represents the composite echo created by the posterior surface of the vertebral body, posterior longitudinal ligament, and the anterior dura. Also because it is often difficult to define the ligamentum flavum and posterior dura as two separate structures in a thoracic sonogram, they are collectively referred to as the ligamentum flavum–dura matter complex,\(^1\) or the posterior complex (PC).\(^3\)
FIGURE 7-43  Sagittal sonogram of the thoracic spine in a neonate to illustrate the hypoechoic spinal cord, hyperechoic central canal, hyperechoic anterior and posterior dura, and the epidural spaces. CSF, cerebrospinal fluid.

FIGURE 7-44  Transverse sonogram of the thoracic spine in a neonate to illustrate the hypoechoic spinal cord, the thecal sac, dentate ligaments, dura (anterior and posterior), and the epidural space. CSF, cerebrospinal fluid.

Ultrasound Imaging of the Upper Thoracic Spine (T1–T4)

1. Position:
a. **Patient:** The patient is positioned comfortably in the sitting position with the arms hanging down and resting on the thigh or on a pillow or support in front. The patient is also asked to slightly flex the head anteriorly. However, if the patient is unable to sit or is unwell, then the patient can be positioned in the lateral decubitus position with the head flexed anteriorly.

b. **Operator and ultrasound machine:** The operator stands behind the patient, and the ultrasound machine is placed directly in front of the patient.

2. **Transducer selection:** Due to the thick musculature of the nape of the neck and relatively greater depth from the skin to the neuraxial structures, curvilinear transducers are best for imaging the upper thoracic spine. The authors prefer to use a high-frequency (9–4 MHz) curvilinear transducer, but it is feasible to use a low-frequency (5–2 MHz) curvilinear transducer for the ultrasound scan.

3. **Scanning technique:** The upper thoracic spine can be imaged in the transverse ([Fig. 7-45](#)) or sagittal ([Fig. 7-46](#)) planes. During the median transverse scan, the aim is to obtain a transverse spinous process view (TSPV, [Fig. 7-47](#)) or a transverse interspinous view (TISV, [Fig. 7-48](#)). Because the spinous processes in the upper thoracic region are not inclined as steeply as in the midthoracic region, especially above the T3 levels, it may be feasible to obtain a TISV. Below this level it gets increasingly difficult to obtain a TISV. For a sagittal scan the ultrasound transducer is placed 2 to 3 cm lateral to the midline and gently tilted medially (paramedian sagittal oblique scan, PMSOS) until the thoracic lamina and the interlaminar spaces are visualized ([Fig. 7-49](#)).

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**FIGURE 7-45** Position and orientation of the ultrasound transducer during a transverse scan of the upper thoracic spine with the subject in the sitting position.
FIGURE 7-46 Position and orientation of the ultrasound transducer during a paramedian sagittal oblique scan of the upper thoracic spine with the subject in the sitting position.

FIGURE 7-47 Transverse sonogram demonstrating the spinous process view of the upper thoracic spine.
4. **Sonoanatomy of the upper thoracic spine:** On a median TSPV the spinous process is visualized as a hyperechoic structure with an acoustic shadow anteriorly (Fig. 7-47). Laterally the lamina and transverse process or the inferior articular processes of the thoracic vertebra with their corresponding acoustic shadow are visualized. Because the spinal canal and neuraxis are obscured by the acoustic shadow of the spinous process and lamina in this view, it is only useful for locating the midline if the spinous processes are not palpable. If one now slides the transducer slightly caudally and/or gently inclines the
ultrasound beam cranially, the acoustic shadow of the spinous process disappears and the median TISV is obtained (Fig. 7-48). On a median TISV the transverse processes are visualized as linear hyperechoic shadows, one on each side of the midline, and they are also directed slightly backwards and outwards (Fig. 7-48). The AC is visualized anteriorly as a hyperechoic shadow (Fig. 7-48). The outlines of the spinal canal can be recognized, but the spinal cord is not visualized for reasons described earlier (Fig. 7-48).

On a PMSOS of the upper thoracic region the lamina and interlaminar spaces are clearly visualized posteriorly (Fig. 7-49). The intervening gaps between the lamina of the adjacent vertebrae are the interlaminar spaces, and they are relatively narrow (width approximately 0.6 mm)\(^1\) compared to that at the lower thoracic (width approximately 0.9 mm)\(^1\) or lumbar spine (Fig. 7-42). This results in a narrow acoustic window for imaging, and thus ultrasound visibility of the neuraxial structures is also limited when compared to that at the mid or lower thoracic region.\(^1\) Nevertheless it may still be possible to visualize the ligamentum flavum, epidural space, posterior dura, spinal canal, and AC from a posterior-to-anterior direction within the acoustic window (Fig. 7-49).

**Ultrasound Imaging of the Midthoracic Spine (T5-T8)**

1. **Position:**
   a. **Patient:** Sitting (Figs. 7-50 and 7-51) or lateral decubitus (Fig. 7-52) position.

**FIGURE 7-50** Position and orientation of the ultrasound transducer during a transverse scan of the midthoracic spine with the subject in the sitting position.
FIGURE 7-51 Paramedian sagittal oblique sonogram of the midthoracic spine with the subject in the sitting position.

FIGURE 7-52 Paramedian sagittal oblique sonogram of the midthoracic spine with the patient in the lateral position.

b. **Operator and ultrasound machine:** The operator sits or stands behind the patient, and the ultrasound machine is positioned directly in front of the patient.

2. **Transducer selection:** Curved array transducer. The authors prefer to use a high-frequency (9–4 MHz) curvilinear transducer, but a low-frequency (5–2 MHz) curvilinear transducer will suffice.

3. **Scanning technique:** Ultrasound imaging is more demanding in the midthoracic region than at the lower thoracic region due to the acute caudal angulation of the spinous processes.
processes and the overlapping lamina. The narrow interspinous and interlaminar spaces (approximately 0.8 cm) create a narrow acoustic window for imaging with variable quality of ultrasound images of the neuraxis. The midthoracic spine can be imaged in the transverse (Fig. 7-50) or sagittal (Figs. 7-51 and 7-52) axis. The median transverse scan (median TSPV, Fig. 7-53) is not very useful, as it provides little information relevant for neuraxial blockade other than identifying the midline and measuring the depth to the lamina. Also acquiring a median TISV (Fig. 7-54) at the midthoracic region is challenging, and in some individuals it may be impossible. Because the paramedian sagittal axis provides better visualization of the neuraxis than the transverse axis, it is the preferred route for imaging. Also for optimal paramedian sagittal imaging one has to perform a PMSOS (Fig. 7-52) as described earlier.

**FIGURE 7-53** Transverse sonogram demonstrating the spinous process view of the midthoracic spine.
4. **Sonoanatomy of the midthoracic spine:** On a median TSPV the spinous process, lamina, transverse processes, the costotransverse junction, and the ribs produce a sonographic pattern that we describe as the “flying swan sign” due to its resemblance to a swan in flight. The posteriorly directed transverse processes are also easily recognized, and they are symmetrically located. One must note that due to the acute angulation of the spinous processes in the midthoracic region, when one performs a median transverse scan to obtain a median TSPV, the osseous elements in the sonogram look congruous, but the spinous process shadow is from the vertebra one level higher than that from which the shadows of the laminae and transverse processes arise (Fig. 7-55). The exact clinical significance of this observation for central neuraxial blocks is not clear.
On a PMSOS in the midthoracic region the laminae and interlaminar spaces are clearly visualized posteriorly (Fig. 7-56). The laminae appear relatively flat (Figs. 7-56 and 7-57), and the interlaminar spaces are also relatively narrow (width approximately 0.8 mm). However, despite the narrow acoustic window, it may be possible to define the ligamentum flavum, epidural space, posterior dura, spinal canal, and AC from a posterior-to-anterior direction within the acoustic window (Fig. 7-56). Age-related changes in the vertebral column and/or ossification of the ligamentum flavum can make visualization of the neuraxial structures difficult in the elderly.
FIGURE 7-56 Paramedian sagittal oblique sonogram of the midthoracic spine.

FIGURE 7-57 Correlative sagittal (A) CT, (B) sonogram, (C) cadaver anatomic, and (D) MRI (T1 weighted) images of the midthoracic spine. ILS, interlaminar space; SC, spinal canal; VB, vertebral body; LF, ligamentum flavum; PD, posterior dura; AC, anterior complex; ITS, intrathecal space.
Ultrasound Imaging of the Lower Thoracic Spine (T9–T12)

1. Position:
   a. Patient: Sitting (Fig. 7-58) or lateral decubitus position.

   ![Position and orientation of the ultrasound transducer during a transverse scan of the lower thoracic spine with the subject in the sitting position.](image)

   **FIGURE 7-58** Position and orientation of the ultrasound transducer during a transverse scan of the lower thoracic spine with the subject in the sitting position.

   b. Operator and ultrasound machine: The operator stands behind the patient, and the ultrasound machine is positioned directly in front of the patient.

2. Transducer selection: Curved array transducer. The authors prefer to use a high-frequency (9–4 MHz) curvilinear transducer (Figs. 7-58 and 7-59), but a low-frequency (5–2 MHz) curvilinear transducer is perfectly adequate.
3. **Scanning technique:** Ultrasound imaging is less demanding in the lower thoracic region than at the upper and midthoracic regions due to the wider acoustic window for ultrasound imaging. Ultrasound imaging at the lower two to three thoracic intervertebral levels is similar to imaging the lumbar spine. The lower thoracic spine can be imaged in the transverse (Fig. 7-58) or sagittal (Fig. 7-59) axis, and because of the relatively larger acoustic window it is possible to acquire high-quality images of the neuraxis (Figs. 7-60 to 7-62).

**FIGURE 7-59** Position and orientation of the ultrasound transducer during a paramedian sagittal oblique scan of the lower thoracic spine with the subject in the sitting position.

**FIGURE 7-60** Transverse sonogram demonstrating the transverse spinous process view of the midthoracic spine.
FIGURE 7-61 Transverse sonogram demonstrating the transverse interspinous view of the midthoracic spine.

FIGURE 7-62 Paramedian sagittal oblique sonogram of the lower thoracic spine. The white linear streak in the middle of the acoustic window probably represents one of the cauda equina nerves.

4. **Sonoanatomy of the lower thoracic spine:** On a median TSPV the spinous process, lamina, and transverse processes produce a typical acoustic shadow (Fig. 7-60). Although this view is not useful for visualizing the neuraxial structures, it is useful for locating the midline. Laterally the parietal pleura and underlying lung are visualized and recognized by the characteristic “lung-sliding sign” (Fig. 7-60). On a median TISV the spinal canal and anterior complex are clearly defined in the midline with the transverse processes laterally (Fig. 7-61). The posterior dura or the posterior complex may also be visualized in a median TISV in some individuals. The PMSOS provides better visibility of the neuraxial structures (Fig. 7-62), relevant for central neuraxial blocks, than the median TISV. One can clearly recognize the wide interlaminar spaces and the posterior and anterior complexes (Fig. 7-62). Outlines of the cauda equina fibers may also be rarely visualized (Fig. 7-62).

**Identification of Thoracic Intervertebral Spaces Using Ultrasound**

Accurate identification of a given thoracic intervertebral level using anatomical landmarks is inaccurate. Ultrasound has been used to identify a given thoracic intervertebral space by “counting up” from the L5 to S1 junction. Identification errors can be expected with this method because lumbosacral transitional anomalies (lumbarization of S1 or sacralization of L5) are present in approximately 4% to 21% of the general population. Therefore to enhance accuracy, others have elected to include identification of the 12th rib and its
articulation with the T12 vertebra as a secondary ultrasound landmark to the “counting up” method.\textsuperscript{1,14} It is not known if this combined method improves accuracy because an accessory L1 rib can also be present in approximately 2% of individuals.\textsuperscript{15} An alternative sonographic method, which has been used to identify the level of thoracic paravertebral injection, relies on identifying the first rib.\textsuperscript{16} However, a limitation of this method is that the presence of a cervical rib can affect its accuracy. Therefore, although various sonographic methods have been described, they have inherent inaccuracies. More importantly, none of these methods have been tested against a gold-standard imaging modality such as computed tomography (CT) or magnetic resonance imaging (MRI). Despite these limitations it is our opinion that for day-to-day practice of thoracic epidural catheter placement, the sonographic methods described earlier are clinically useful because sonographic methods are generally more accurate than methods that solely reply on anatomical landmarks.\textsuperscript{11}

**Clinical Pearls**

Currently there are limited published data on ultrasound imaging of the thoracic spine or on the use of ultrasound for thoracic epidural catheter placement. Based on published data, it is most frequently used to preview the anatomy of the spine before thoracic epidural catheter placement.\textsuperscript{4} During the preprocedural or scout scan, ultrasound can be used to identify the midline, determine the presence of any underlying spinal abnormality (eg, scoliosis,\textsuperscript{17} underlying spinal instrumentation), determine the degree of axial rotation of the thoracic spine in scoliosis,\textsuperscript{17} accurately measure the depth to the lamina or posterior dura,\textsuperscript{4} and determine the optimal site for epidural needle placement. During a median transverse (for midline approach) or PMSOS (for a paramedian approach), the angle of insonation that produces the best ultrasound visualization of the neuraxial structures or the anterior complex closely mirrors the angle or trajectory for needle insertion. Currently there are no published data on the use of ultrasound to guide or assist real-time epidural needle placement in the thoracic region. In the authors’ experience ultrasound can be used to assist epidural catheter placement in the thoracic region, especially in patients with obesity or difficult backs, by guiding the tip of the epidural needle to the target interlaminar space before the traditional loss-of-resistance method is used to confirm correct epidural needle placement. This may translate into reduced needle passes and higher success rates on the first attempt. Future research to establish the utility of ultrasound for thoracic epidural catheter placement is warranted.

**References**


CHAPTER 8
Ultrasound Imaging of the Lumbar Spine for Central Neuraxial Blocks

Introduction

Central neuraxial blocks (CNBs), which include spinal, epidural, and combined spinal epidural (CSE) injections, are frequently performed in the lumbar region for anesthesia and analgesia and for managing chronic pain.1 Traditionally, they are performed using a combination of surface anatomic landmarks, the operator’s tactile perception of “loss of resistance” during needle advancement through the ligamentum flavum, and/or visualizing the efflux of cerebrospinal fluid. Anatomic landmarks (eg, the spinous processes) are useful but they are not always easily palpable in patients with edema, obesity,2 underlying spinal deformity, or previous back surgery. The “Tuffier’s line,” which is a line joining the highest points of the iliac crests, is another surface anatomical landmark that is widely used to estimate the location of the L4 to L5 interspace; however, the correlation is inconsistent.3 Even in the absence of spine abnormalities, estimation of a specific intervertebral level may not be accurate in many patients4,5 and may result in needle placement one or two spinal levels higher than intended.4–7 This inaccuracy is exaggerated in the obese and in the upper spinal levels.4,6,8 Furthermore, using surface anatomical landmarks alone, it is not possible to predict the ease or difficulty of needle placement prior to skin puncture. Unanticipated technical difficulty, multiple attempts at needle placement, and failure of CNB are therefore prevalent in clinical practice.9,10

Recently, ultrasound imaging of the spine11–13 has emerged as a useful tool to overcome many of the shortcomings of the traditional approach to CNBs, and it has been used with great success. Ultrasound is most frequently used as a preprocedural tool,11 but can also be used to guide the epidural or spinal needle in real time during CNBs.14 Advantages of the preprocedural scan include being able to accurately locate the midline,15 identify a given lumbar interspace, predict the depth to the epidural space, detect any vertebral rotational defects (eg, in scoliosis), and identify patients with a potentially difficult CNB.11,16 In expert hands the use of ultrasound for epidural needle insertion reduces the number of puncture attempts,17–22 improves the success rate of epidural access on the first attempt,18 reduces the need to puncture multiple levels,18–20 and improves patient comfort during the procedure.19 This chapter briefly outlines the anatomy, the technique of ultrasound imaging, and sonoanatomy relevant for CNBs in the lumbar region.

Basic Lumbar Spine Anatomy

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The lumbar spine makes up the lower back and is made up of five vertebrae, numbered L1 to L5 (Figs. 8-1 and 8-2). It connects with the thoracic spine above and with the sacrum below at the lumbosacral joint. L1 to L4 are typical lumbar vertebrae because they share common characteristics, but L5 is atypical because it has certain peculiarities. The lumbar vertebral body is designed to bear weight, and therefore the size of the lumbar vertebrae increases from L1 to L5. The lumbar spine also has a curvature, being slightly convex anteriorly, and this is referred to as lordosis.

**FIGURE 8-1** Lumbosacral spine – lateral view.

**FIGURE 8-2** Lumbar spine – lateral view.

**Typical Lumbar Vertebra**
A typical lumbar vertebra (L1–L4) is identified by its large vertebral body and the absence of costal facets on the body (Fig. 8-3). The body of a typical lumbar vertebra is wider in the transverse axis than in the anteroposterior axis (Fig. 8-3). The height of the vertebral body is also greater anteriorly than posteriorly, and this difference contributes to the forward convexity of the lumbar spine. The vertebral foramen is triangular in shape (Fig. 8-3) and larger than that in the thoracic region but smaller than that in the cervical region. The pedicles are short and strong and directed posteriorly from the upper part of the body (Figs. 8-2 and 8-3). This results in an inferior vertebral notch that is significantly deeper than the superior vertebral notch (Figs. 8-2 and 8-3). The laminae are short and thick, directed backwards and medially, and form the posterior part of the vertebral arch. The spinous process is thick, wide, and quadrilateral in shape, and directed backwards (Figs. 8-1 to 8-3). The transverse processes are thin and directed laterally and slightly backwards (Fig. 8-4). The width of the transverse process increases from L1 to L3 after which it decreases as one moves caudally. In a typical lumbar vertebra, the superior articular processes lie farther apart from each other than the inferior articular processes (Fig. 8-4). The superior articular processes face backwards and medially, whereas the inferior articular process faces laterally and forward (Figs. 8-3 and 8-4).

**FIGURE 8-3** A typical (fourth) lumbar vertebra—superior, anterior, and lateral views. TP, transverse process; SAP, superior articular process; SC, spinal canal; SVN, superior vertebral notch; VB, vertebral body; IAP, inferior articular process.
FIGURE 8-4 Posterior articulation of the lumbar vertebra. Note the superior and inferior articular processes and the facet joints on either side of the midline.

Fifth Lumbar Vertebra (L5)

The body of the L5 vertebra is the largest of all the lumbar vertebrae. Its anterior surface is wider than its posterior surface (Fig. 8-5), and this difference results in the sharp lumbosacral angulation (Fig. 8-1). The pedicles are short and directed backwards and laterally (Fig. 8-5). The superior articular processes face more backwards than medially, and the inferior articular process also looks more anteriorly than laterally when compared to the other lumbar vertebrae (Fig. 8-5). The distance between the inferior articular processes are also equal to or more than the distance between the superior articular processes. The transverse process of L5 is short, thick, pyramidal in shape, and attached to the entire thickness of the pedicle (Fig. 8-5). The spine of L5 is also relatively short and has a rounded tip.
The adjacent lumbar vertebrae articulate with each other at the facet joints between the superior and inferior articular processes and the intervertebral disc between the vertebral bodies (Fig. 5-7). This results in two gaps—the “interspinous space” and the “interlaminar space”—between the adjacent spinous processes and the laminae of the vertebrae, respectively (Fig. 8-4). These gaps allow the ultrasound energy to enter the spinal canal and thereby act as acoustic windows for ultrasound imaging during spinal sonography. The reader should refer to Chapter 5 for a detailed description of the anatomy of the interlaminar and interspinous spaces, major ligaments that support the lumbar vertebra (ie, ligamentum flavum, supraspinous and interspinous ligament, and the anterior and posterior longitudinal ligament), spinal canal, and the epidural space in the lumbar region.

**Gross Anatomy of the Lumbar Spine**

Figs. 8-6 to 8-11
FIGURE 8-6 Cross-sectional cadaver anatomic section through the L4 vertebral body and transverse process illustrating the attachment of the ligamentum flavum to the laminae, posterior epidural space, and the relationship of the articular process to the transverse process. ESM, erector spinae muscle; QLM, quadratus lumborum muscle; PM, psoas major muscle; VB, vertebral body.

FIGURE 8-7 Cross-sectional cadaver anatomic section from just inferior to the L4 transverse process and through the lower part of the L4 vertebral body illustrating the lamina of the lumbar vertebra, the articular processes, and the intervertebral foramina. VB, vertebral body; IVF, intervertebral foramen; QLM, quadratus lumborum muscle; ESM, erector spinae.
muscle.

**FIGURE 8-8** Median sagittal cadaver anatomic section of the lumbar spine showing the spinous processes (L3–L5), interspinous spaces, ligamentum flavum, posterior epidural space, and the thecal sac. Also note the cauda equina (CE) within the thecal sac. ITS, intrathecal sac; VB, vertebral body.

**FIGURE 8-9** Paramedian sagittal cadaver anatomic section of the lumbar spine at the level of the lamina. The laminae have been shaded in green, and a graphic overlay has been placed over the L3 lamina to illustrate the horse head–like appearance of the lamina of the lumbar vertebra. ESM, erector spinae muscle; ILS, interlaminar space; ITS, intrathecal space; VB,
vertebral body; IVD, intervertebral disc.

**FIGURE 8-10** Paramedian sagittal cadaver anatomic section of the lumbar spine at the level of the articular processes. A graphic overlay has been placed over the articular processes of the L4 vertebra to illustrate the camel hump–like appearance formed by the articulations of the superior and inferior articular processes and the facet joints. VB, vertebral body.

**FIGURE 8-11** Paramedian sagittal cadaver anatomic section of the lumbar spine at the level of the transverse processes. Note the large fleshy muscle (ie, the psoas major muscle) lying anterior to the transverse processes. Also the lumbar plexus nerves can be identified within the substance of the psoas muscle. ESM, erector spinae muscle; TP, transverse process; NR, nerve root.
Computed Tomography Anatomy of the Lumbar Spine

Figs. 8-12 to 8-18

**FIGURE 8-12** Transverse CT image of the lumbar spine at the level of the spinous process. IVC, inferior vena cava; VB, vertebral body; ITS, intrathecal space; PM, psoas major muscle; QLM, quadratus lumborum muscle; ESM, erector spinae muscle.

**FIGURE 8-13** Transverse CT image of the lumbar spine at the level of the articular process. IVC, inferior vena cava; VB, vertebral body; ESM, erector spinae muscle; ITS, intrathecal space; PM, psoas major muscle; QLM, quadratus lumborum muscle.
FIGURE 8-14 ■ Median sagittal CT image of the lumbosacral spine. Note the L5 to S1 gap between the spinous processes of L5 and S1 vertebra posteriorly. SP, spinous process; VB, vertebral body.

FIGURE 8-15 ■ Paramedian sagittal oblique (rendered) CT section of the lumbosacral spine at the level of the lamina. Note the wide interlaminar space (L5–S1 gap) between the lamina of L5 and the sacrum. ITS, intrathecal space; VB, vertebral body.
FIGURE 8-16 Paramedian sagittal CT image of the lumbosacral spine at the level of the lamina. Note the relatively narrow interlaminar and intrathecal space (ITS) when compared to that in Fig. 8-15 (same subject). VB, vertebral body.

FIGURE 8-17 Paramedian sagittal CT image of the lumbar spine at the level of the articular processes. Note how the articular processes articulate to form the facet joints. VB, vertebral body.
FIGURE 8-18  Paramedian sagittal CT image of the lumbosacral spine at the level of the transverse processes. TP, transverse process; NR, nerve root.

Magnetic Resonance Imaging Anatomy of the Lumbar Spine

Figs. 8-19 to 8-26

FIGURE 8-19  Transverse T1-weighted magnetic resonance image of the lumbar spine through the interspinous space. Note the attachment of the ligamentum flavum to the laminae and the wide posterior epidural space. IVC, inferior vena cava; PM, psoas major muscle; VB, vertebral body; QLM, quadratus lumborum muscle; ESM, erector spinae muscle; ITS, intrathecal space.
FIGURE 8-20 Transverse T1-weighted magnetic resonance image of the lumbar spine at the level of the spinous process. Note the relationship of the articular processes to the intervertebral foramen and the lumbar nerve root. VB, vertebral body; LPVS, lumbar paravertebral space; ITS, intrathecal space; PM, psoas major muscle; QLM, quadratus lumborum muscle; SP, spinous process.

FIGURE 8-21 Zoomed magnetic resonance image of the lumbar epidural and intrathecal space. Note the attachment of the ligamentum flavum to the laminae, the posterior epidural space, and the cauda equina nerves within the hyperintense cerebrospinal fluid. VB, vertebral body.
FIGURE 8-22 Median sagittal magnetic resonance image of the lumbar spine demonstrating the spinous processes (SP), interspinous spaces, posterior epidural space, and the thecal sac. The hyperintense oval structures on the surface of the skin posteriorly are cod liver oil capsules that were used as skin markers to identify the lumbar interspinous spaces.

FIGURE 8-23 Sagittal magnetic resonance image of the lumbar spine at the level of the lamina.
FIGURE 8-24 Sagittal oblique (rendered) T1-weighted magnetic resonance image of the lumbar spine at the level of the lamina. Note the wide interlaminar and intrathecal spaces when compared to that in Fig. 8-23 (same subject).

FIGURE 8-25 Sagittal magnetic resonance image of the lumbosacral spine at the level of the lumbar articular processes. VB, vertebral body. IVD, intervertebral disc.
Ultrasound Imaging of the Lumbar Spine

The lumbar spine is imaged using a low-frequency (5–2 MHz) curved array transducer and in the transverse or sagittal plane. During a median transverse scan (Figs. 8-27 to 8-38) the “transverse spinous process view” (Figs. 8-27 to 8-29) and “transverse interspinous view” (Figs. 8-34 to 8-36) are acquired. During a median sagittal scan (Figs. 8-39 to 8-41) the lumbar spinous processes and the interspinous spaces are visualized. The lumbar spinous processes appear as crescent-shaped structures (Figs. 8-40 and 8-41) and occupy most of the median plane (i.e., there is a lot of bone). Therefore, the acoustic window for imaging is relatively narrow in the midline (Fig. 8-41). Also any clinical condition that causes narrowing of the interspinous spaces (e.g., in the elderly) further compromises the acoustic window. Consequently ultrasound imaging through the median plane provides a limited view of the neuraxial structures (Fig. 8-41). In contrast there is less bony obstruction in the paramedian sagittal plane, particularly at the level of the lamina, which creates a large acoustic window for imaging through the interlaminar spaces. Sonographic views of the neuraxis are also more detailed through the paramedian sagittal plane (Figs. 8-42 to 8-67). Therefore it is the preferred route for spinal sonography and for real-time ultrasound-guided CNBs. For a detailed ultrasound examination of the lumbar spine, it must be imaged in both the transverse and sagittal planes because the information obtained from either plane complements the other.
**FIGURE 8-27** Position and orientation of the ultrasound transducer during a transverse scan of the lumbar spine with the subject in the lateral position.

**FIGURE 8-28** Transverse sonogram of the lumbar spine with the transducer positioned directly over the lumbar spinous process (i.e., the transverse spinous process view). Note the acoustic shadow of the spinous process and lamina completely obscures the spinal canal and the neuraxial structures. SP, spinous process; ESM, erector spinae muscle.
FIGURE 8-29  Transverse sonogram of the lumbar spine illustrating the transverse spinous process view. Photographs on the right illustrate the position and orientation of the ultrasound transducer with the subject in the lateral position.

FIGURE 8-30  Multiplanar 3-D CT images of the lumbar spinous process that were rendered from a volume CT data set of the CIRS lumbar training phantom. (A) Transverse view, (B) sagittal view, and (C) coronal view.
FIGURE 8-31 Correlative transverse (A) CT, (B) ultrasound, (C) cadaver anatomic, and (D) MRI images of the lumbar spinous process and lamina. SP, spinous process; SC, spinal canal; VB, vertebral body; ESM, erector spinae muscle; QLM, quadratus lumborum muscle; PM, psoas major muscle; ITS, intrathecal space; PD, posterior dura; CE, cauda equina; ITS, intrathecal space.

FIGURE 8-32 Multiplanar 3-D ultrasound images of the lumbar spinous process with the reference marker (white crosshair) placed over the tip of the spinous process. (A) Transverse
view, (B) sagittal view, (C) coronal view, and (D) slice plane. SP, spinous process; ITS, intrathecal space; ISS, interspinous space.

**FIGURE 8-33** Multiplanar 3-D ultrasound images of the lumbar spinous process with the reference marker (white crosshair) placed over the base of the spinous process. (A) Transverse view, (B) sagittal view, (C) coronal view, and (D) slice plane. SP, spinous process; ITS, intrathecal space; ISS, interspinous space.

**FIGURE 8-34** Transverse sonogram of the lumbar spine with the ultrasound beam being insonated through the lumbar interspinous space (ie, the transverse interspinous view). The photographs on the right illustrate the position and orientation of the ultrasound transducer with the subject in the lateral position.
FIGURE 8-35 Transverse sonogram of the lumbar spine – coned (zoomed) transverse interspinous view. The epidural space, posterior dura, intrathecal space, and the anterior complex are visible in the midline, and the articular process (AP) is visible laterally on either side of the midline. Note how the articular processes on either side are symmetrically located.

FIGURE 8-36 Transverse sonogram of the lumbar spine – transverse interspinous view. Note the posterior epidural space is clearly delineated in this sonogram. ESM, erector spinae muscle; ITS, intrathecal space; VB, vertebral body.
FIGURE 8-37  Multiplanar 3-D CT images of the lumbar spine that were rendered from a volume CT data set of the CIRS lumbar training phantom. The reference marker (crosshair) has been placed at the L3 to L4 interspinous space. (A) Sagittal view, (B) transverse view, and (C) coronal view.
FIGURE 8-38 Correlative transverse (A) CT, (B) ultrasound, (C) cadaver anatomic, and (D) high-definition coned (zoomed) ultrasound images of the lumbar interspinous view. Note how the inferior and superior articular processes of the vertebrae make up the facet joints on either side of the midline. TP, transverse process; FJ, facet joint; SC, spinal canal; IAP, inferior articular process; SAP, superior articular process; ESM, erector spinae muscle; ES, epidural space; ITS, intrathecal space; LF, ligamentum flavum; CE, cauda equina; PM, psoas major muscle; QLM, quadratus lumborum muscle; PD, posterior dura; AP, articular process; VB, vertebral body; AC, anterior complex; AD, anterior dura.

FIGURE 8-39 Position and orientation of the ultrasound transducer during a median sagittal scan of the lumbar spine with the subject in the lateral position.

FIGURE 8-40 Median sagittal sonogram of the lumbar spine showing the crescent-shaped hyperechoic reflections of the spinous processes. The interspinous space is interposed.
between the spinous processes in the midline.

**FIGURE 8-41** Correlative median sagittal (A) CT, (B) ultrasound, (C) cadaver anatomic section, and (D) magnetic resonance images of the lumbar spine. SP, spinous process; ISS, interspinous space; VB, vertebral body; SC, spinal canal; IVD, intervertebral disc; LF, ligamentum flavum; PD, posterior dura; ES, epidural space; ITS, intrathecal space; CE, cauda equina.

**FIGURE 8-42** Position and orientation of the ultrasound transducer during a paramedian sagittal scan of the lumbar spine with the subject in the lateral position.
FIGURE 8-43  Paramedian sagittal sonogram of the lumbar spine. Note the narrow intrathecal space in this sonogram. ESM, erector spinae muscle.

FIGURE 8-44  Position and orientation of the ultrasound transducer during a paramedian sagittal oblique scan of the lumbar spine with the subject in the lateral position.
**FIGURE 8-45** Figure illustrating how to identify a given lumbar intervertebral space by performing a paramedian sagittal scan. (A) Locate the L5 to S1 gap and (B) slide the transducer cephalad until the lamina of L3, L4, and L5 are identified.

**FIGURE 8-46** Paramedian sagittal sonogram of the lumbosacral junction. The dip or gap between the posterior surface of the sacrum and the lamina of L5 is the L5 to S1 gap. ESM, erector spinae muscle; LF, ligamentum flavum; ITS, intrathecal space. The photographs on the right illustrate the position and orientation of the ultrasound transducer to locate the L5 to S1 gap with the subject in the lateral position.
FIGURE 8-47  Paramedian sagittal oblique scan of the lumbar spine at the level of the lamina showing the L3 to L4 and L4 to L5 interlaminar spaces. Note the hypoechoic epidural space (few millimeters wide) between the hyperechoic ligamentum flavum and the posterior dura. The intrathecal space is the anechoic space between the posterior dura and the anterior complex in the sonogram. The hyperechoic reflections anterior of the anterior complex are from the intervertebral disc (IVD). The cauda equina nerve fibers are also seen as hyperechoic longitudinal structures within the thecal sac. The photograph on the right illustrates the position and orientation of the ultrasound transducer during a paramedian sagittal oblique scan of the lumbar spine with the subject in the lateral position.

FIGURE 8-48  Paramedian sagittal oblique sonogram of the lumbar spine demonstrating the L3 to L4 and L4 to L5 interlaminar spaces. The posterior epidural space is clearly delineated between the hyperechoic ligamentum flavum and the posterior dura in this sonogram. Also note the cauda equina nerves within the thecal sac at the L4 to L5 level.
**FIGURE 8-49** Paramedian sagittal oblique sonogram of the lumbar spine at the L3 to L5 level demonstrating color Doppler signals from the vasculature within the erector spinae muscle (ESM).

**FIGURE 8-50** Panoramic view of a paramedian sagittal oblique scan of the lumbosacral spine.
FIGURE 8-51  Multiplanar 3-D CT images of the lumbar spine that were rendered from a volume CT data set of the CIRS lumbar training phantom. The reference marker (crosshair) has been placed over the L4 lamina. (A) Transverse view, (B) sagittal view, and (C) coronal view.
FIGURE 8-52 Paramedian sagittal oblique sonogram of the lumbar spine at the level of the laminae (L3–L5) from (A) the water-based spine phantom and (B) volunteers and a representative anatomical section from (C) a representative cadaver anatomical section from the Visible Human Server. In the latter, the lamina has been shaded in green (C). Note the marker (needle) in contact with the lamina in the water-based spine phantom (A). This was done to ensure that the lamina was being scanned and also helped in validating its sonographic appearance. A graphic overlay has been placed over the lamina in (A) to illustrate the “horse head sign.” AC, anterior complex; CE, cauda equina; ES, epidural space; ESM, erector spinae muscle; ILS, interlaminar space; ITS, intrathecal space; IVD, intervertebral disc; LF, ligamentum flavum; PD, posterior dura; SC, spinal canal; VB, vertebral body.

FIGURE 8-53 Correlative paramedian sagittal (A) CT, (B) ultrasound, (C) cadaver anatomic section, and (D) magnetic resonance images of the lumbar spine. ILS, interlaminar space; ESM, erector spinae muscle; ES, epidural space; SC, spinal canal; VB, vertebral body; IVD, intervertebral disc; LF, ligamentum flavum; ITS, intrathecal space; CE, cauda equina; PD, posterior dura; AC, anterior complex.
FIGURE 8-54 Correlative paramedian sagittal (A) sonogram and (B) T2-weighted magnetic resonance images of the neuraxis via the L4 to L5 interlaminar space. LF, ligamentum flavum; ES, epidural space; ITS, intrathecal space; CE, cauda equina.
FIGURE 8-55 Multiplanar 3-D ultrasound images of the lumbar spine with the reference marker (green crosshair) placed over the lamina. (A) Transverse view, (B) sagittal view, and (C) coronal view. AP, articular process; ITS, intrathecal space.
FIGURE 8-56 Paramedian sagittal sonogram of the lumbar spine showing the articular processes. The photographs on the right illustrate the position and orientation of the ultrasound transducer during a paramedian sagittal scan of the lumbar spine at the level of the articular processes of the vertebra with the subject in the lateral position.

FIGURE 8-57 Paramedian sagittal sonogram of the lumbar spine at the level of the articular processes of the vertebra. A graphic overlay has been placed in this image to illustrate the camel hump–like appearance of the articular processes.
FIGURE 8-58 Multiplanar 3-D CT images of the lumbar spine that were rendered from a volume CT data set of the CIRS lumbar training phantom. The reference marker (crosshair) has been placed over the articular process (AP) of the L4 vertebra. (A) Sagittal view, (B) transverse view, and (C) coronal view.
**FIGURE 8-59** Paramedian sagittal sonogram of the articular process from the (A) water-based spine phantom, (B) volunteer, and (C) a representative cadaver anatomical section. A graphic overlay has been placed in (B) to illustrate the camel hump–like appearance of the articular processes. AP, articular process; ESM, erector spinae muscle; FJ, facet joint; VB, vertebral body.

**FIGURE 8-60** Correlative sagittal (A) CT, (B) ultrasound, (C) cadaver anatomic section, and (D) magnetic resonance images of the lumbar spine at the level of the articular processes (AP). IAP, inferior articular process; SAP, superior articular process; VB, vertebral body; IVD, intervertebral disc; ESM, erector spinae muscle; FJ, facet joint.
FIGURE 8-61  Multiplanar 3-D ultrasound images of the lumbar spine with the reference marker (white crosshair) placed over the articular process of the vertebra. (A) Transverse view, (B) sagittal view, and (C) coronal view. AP, articular process; ITS, intrathecal space.

FIGURE 8-62  Paramedian sagittal sonogram of the lumbar spine at the level of the transverse processes. Note the hyperechoic reflections of the transverse processes with their acoustic shadows that produce the “trident sign.” The psoas major muscle is seen in the acoustic window between the transverse processes and is recognized by its typical hypoechoic and striated appearance. Hyperechoic longitudinal striations within the substance of the psoas muscle may represent intramuscular tendons of the psoas muscle. The
photographs on the right illustrate the position and orientation of the ultrasound transducer during a paramedian sagittal scan of the lumbar spine at the level of the transverse processes of the vertebra with the subject in the lateral position. ESM, erector spinae muscle; TP, transverse process; PM, psoas major muscle; RPS, retroperitoneal space.

**FIGURE 8-63** Paramedian sagittal sonogram of the lumbar spine at the level of the transverse processes. The acoustic shadows of the transverse processes produce the “trident sign.” In this sonogram the lumbar plexus is visualized as a hyperechoic shadow in the posterior part of the psoas muscle between the L3 and L4 transverse process (TP). Intramuscular tendons of the psoas muscle are also seen within the substance of the psoas muscle and should not to be confused with the lumbar plexus nerves. ESM, erector spinae muscle.
FIGURE 8-64 Multiplanar 3-D CT images of the lumbar spine that were rendered from a volume CT data set of the CIRS lumbar training phantom. The reference marker (crosshair) has been placed over the transverse process of the L4 vertebra. (A) Transverse view, (B) sagittal view, and (C) coronal view.
**FIGURE 8-65** Correlative sagittal (A) CT, (B) ultrasound, (C) cadaver anatomic section, and (D) magnetic resonance images of the lumbar spine at the level of the transverse processes (TP). PM, psoas muscle; ESM, erector spinae muscle; RPS, retroperitoneal space; NR, nerve root; LP, lumbar plexus.

**FIGURE 8-66** Multiplanar 3-D ultrasound images of the lumbar spine with the reference marker (green crosshair) placed over the transverse process of the vertebra. (A) Transverse view, (B) sagittal view, and (C) coronal view. AP, articular process; PM, psoas major muscle; TP, transverse process; ESM, erector spinae muscle.
Transverse Ultrasound Imaging of the Lumbar Spine

For a transverse scan of the lumbar spine, the ultrasound transducer is positioned in the midline and initially over the spinous process (transverse spinous process view, TSPV, Figs. 8-27 to 8-29) with the patient in the sitting, lateral, or prone position. On a TSPV, the spinous process and the lamina on either side are seen as hyperechoic reflections anterior to which there is an acoustic shadow that completely conceals the underlying spinal canal and thus the neuraxial structures (Figs. 8-28 and 8-29). Therefore, the TSPV is not suitable for imaging the neuraxial structures but can be used to identify the midline when the spinous processes cannot be palpated (eg, in patients with edema over the back or obese patients). From this position, by sliding the transducer slightly cranially or caudally, a transverse scan of the lumbar spine through the interspinous/interlaminar space (transverse interspinous view, TISV, Figs. 8-34 to 8-38) is obtained.\(^{12,15}\) A slight tilt of the ultrasound transducer cranially or caudally may be needed to align the ultrasound beam with the interspinous space and optimize the TISV. In the TISV, the posterior dura, thecal sac, and the anterior complex can be visualized (from a posterior-to-anterior direction) within the spinal canal in the midline, and the articular processes and the transverse processes are visualized laterally (Figs. 8-34 to 8-36).\(^{12,15}\) The osseous elements produce a sonographic pattern that resembles a “cat’s head,” with the spinal canal representing the head, the articular processes representing the ears of the cat, and the transverse processes representing the whiskers (Figs. 8-35 to 8-38). The ligamentum flavum is rarely visualized in the TISV (Figs. 8-35 and 8-36), possibly due
to anisotropy caused by the archlike attachment of the ligamentum flavum to the lamina (Fig. 8-38). The epidural space is also less frequently visualized in the TISV (Fig. 8-6) than in the paramedian sagittal oblique scan (PMSOS). In the TISV the depth of the posterior dura from the skin can be easily measured using the internal caliper of the ultrasound system. The TISV can also be used to examine for rotational defects of the vertebra, such as in scoliosis. Normally, both the lamina and the articular processes on either side are symmetrically located (Figs. 8-35 and 8-36). However, if there is asymmetry, then a rotational deformity of the vertebral column should be suspected and a difficult CNB should be anticipated.

Sagittal Ultrasound Imaging of the Lumbar Spine

For a sagittal scan (Figs. 8-39 to 8-67) the patient is positioned in the sitting, lateral (Fig. 8-39), or prone position with the lumbosacral spine maximally flexed. The transducer is placed 1 to 2 cm lateral to the spinous process (paramedian sagittal scan, PMSS) at the lower back with its orientation marker directed cranially (Fig. 8-39). For optimal imaging the transducer is also tilted slightly medially during the scan (paramedian sagittal oblique scan, PMSOS, Fig. 8-44) so that majority of the ultrasound signal enters the spinal canal through the widest part of the interlaminar space.

The sagittal scan routine begins by locating the sacrum as a flat hyperechoic structure with a large acoustic shadow anteriorly (Figs. 8-45 to 8-47, details in Chapter 9). When the transducer is gently manipulated in a cranial direction, a gap is seen between the sacrum and the lamina of the L5 vertebra, which is the L5 to S1 interlaminar space, also referred to as the L5 to S1 gap (Fig. 8-46). The L3 to L4 and L4 to L5 interlaminar spaces can now be located by moving the transducer cranially and counting upward (Figs. 8-45 and 8-47). The erector spinae muscles are hypoechoic and lie superficial to the laminae. The lamina appears hyperechoic and is the first osseous structure visualized (Figs. 8-47 and 8-48). Because bone impedes the penetration of ultrasound, there is an acoustic shadow anterior to each lamina. The sonographic appearance of the lamina produces a pattern that resembles the head and neck of a horse (the “horse head sign”) (Fig. 8-52). The interlaminar space is the gap between the adjoining lamina (Fig. 8-48) and is the “acoustic window” through which the neuraxial structures are visualized within the spinal canal. The ligamentum flavum appears as a hyperechoic band across adjacent lamina (Figs. 8-47 to 8-50). The posterior dura is the adjoining hyperechoic structure anterior to the ligamentum flavum, and the epidural space is the hypoechoic area (a few millimeters wide) between the ligamentum flavum and the posterior dura (Figs. 8-47 and 8-48). The ligamentum flavum and posterior dura may also be seen as a single linear hyperechoic structure, which is referred to as the “posterior complex” or “ligamentum flavum-posterior dura complex.” The posterior dura is generally more hyperechoic than the ligamentum flavum. The thecal sac with the cerebrospinal fluid is the anechoic space anterior to the posterior dura (Fig. 8-53). The cauda equina, which is located within the thecal sac, may also be seen as multiple horizontal, hyperechoic shadows within the anechoic thecal sac. Pulsations of the cauda equina are also identified in some individuals. The anterior dura is also hyperechoic, but it is often difficult to differentiate it from the posterior longitudinal ligament and the posterior surface of the vertebral body because they are of similar echogenicity (isoechoic) and closely apposed to each other. What results is a single, composite, hyperechoic reflection anteriorly, which is referred to as the “anterior complex” (Figs. 8-53 and 8-54).

If the transducer is now slid laterally from the level of the lamina, the paramedian sagittal articular process view (Figs. 8-56 and 8-57) is seen. The articular processes of the vertebrae appear as one continuous, hyperechoic wavy line with no intervening gaps (Figs. 8-56 to 8-
This produces a sonographic pattern that resembles multiple camel humps—the “camel hump sign” (Fig. 8-59). A sagittal scan lateral to the articular processes brings the transverse processes of the L3 to L5 vertebrae into view and produces the paramedian sagittal transverse process view (Figs. 8-62 and 8-63). The transverse processes (Figs. 8-62 to 67) are recognized by their crescent-shaped, hyperechoic reflections and fingerlike acoustic shadows anteriorly (Figs. 8-62 and 8-63). This produces a sonographic pattern that is referred to as the “trident sign” because of its resemblance to the trident (Latin tridens or tridentis) that is often associated with Poseidon, the god of the sea in Greek mythology, and the Trishula of the Hindu God Shiva.

References


CHAPTER 9
Ultrasound Imaging of Sacrum and Lumbosacral Junction for Central Neuraxial Blocks

Introduction

Ultrasound imaging of the sacrum\textsuperscript{1,2} and lumbosacral (L5–S1) interlaminar space\textsuperscript{3–7} is frequently performed to identify the sonoanatomy relevant for central neuraxial blocks, that is, spinal and epidural (lumbar and caudal) injection.\textsuperscript{1–7} Because the lumbosacral interlaminar space and sacrum are relatively superficial structures, they lend themselves well to ultrasound imaging.\textsuperscript{3–5,7} This chapter briefly outlines the anatomy, technique of ultrasound imaging, and sonoanatomy of the sacrum and lumbosacral interlaminar space relevant for central neuraxial blocks.

Basic Anatomy of the Sacrum

The sacrum is a large, triangular bone formed by the fusion of the five sacral vertebrae (Figs. 9-1 and 9-2). It makes up the posterior aspect of the bony pelvis and articulates with the corresponding hip bones laterally at the sacroiliac junctions. Because it is triangular in shape it has a base, an apex, and four surfaces (right and left lateral surfaces, dorsal and ventral or pelvic surface). Anatomically the pelvic surface of the sacrum faces downwards and forward, whereas the dorsal surface faces backwards and slightly upwards. The sacrum is divided by a row of foramina on either side of the midline into a median section and a pair of lateral masses (Fig. 9-1). The median section is traversed by the sacral canal, which contains adipose tissue, cauda equina nerves (including the filum terminale), epidural space, spinal meninges (dura and arachnoid), and the thecal sac. The thecal sac ends at the level of the S2 but can vary from S1 to S3. The sacral canal also contains the epidural venous plexus, which generally ends at the level of the S4 but may extend more caudally. The lateral masses are formed by fusion of the transverse processes posteriorly and the costal elements anteriorly. The base is formed by the superior surface of the body of the S1 vertebra, which is large, lumbar in type, and articulates with the L5 vertebra at the lumbosacral junction. The vertebral foramen of the S1 vertebra is triangular in shape and continuous cranially with the lumbar spinal canal and caudally with the sacral canal. The spine of the S1 vertebra forms the first spinous tubercle. The apex of the sacrum is formed by the body of the S5 vertebra (inferior surface) that articulates with the coccyx (Figs. 9-1 and 9-2).
The pelvic surface of the sacrum (Fig. 9-1), although not visualized during ultrasound imaging, is concave and directed downwards and forward. Four transverse ridges on the median area indicate the lines of fusion of the bodies of the four sacral vertebrae (Fig. 9-1). These transverse ridges connect the four pelvic sacral foramina on either side of the midline and are continuous with the sacral canal through the intervertebral foramen. The pelvic sacral foramen decrease in size in a craniocaudal direction consistent with the decrease in size of the sacral vertebra. In contrast the dorsal surface (Fig. 9-2), which can be visualized using ultrasound, is convex, irregular in appearance, narrower than the pelvic surface, and directed backwards and slightly upwards (Fig. 9-2). The median area bears the median sacral crest with three to four spinous tubercles representing the fused spines of the upper four sacral
vertebrae (Fig. 9-2). A ridge joining the articular tubercles forms the intermediate sacral crest. Four dorsal sacral foramina lie lateral to the intermediate sacral crest (Fig. 9-2) and communicate with the sacral canal through the intervertebral foramina (Fig. 9-3). The lateral sacral crest lies lateral to the dorsal sacral foramina. Below the fourth sacral tubercle there is an inverted U-shaped defect on the posterior aspect of the sacrum: the “sacral hiatus” (Fig. 9-2). This results from a failure of fusion of the laminae of the fourth and fifth sacral vertebrae. The inferior articular processes of the fifth sacral vertebra form the sacral cornua and lie lateral to the sacral hiatus (Fig. 9-2). The sacral hiatus is roofed by a firm elastic membrane, the sacrococcygeal ligament, which is an extension of the ligamentum flavum. The terminal end of the filum terminale exits through the sacral hiatus and traverses the dorsal surface of the S5 vertebra and sacrococcygeal joint to end at the coccyx. The fifth spinal nerve also exits through the sacral hiatus lying medial to the sacral cornua.

**FIGURE 9-3** Sagittal section of the sacrum showing the sacral canal and the sacral foraminae.

**Gross Anatomy of the Sacrum**

Fig. 9-4
FIGURE 9-4 Transverse (upper images) and sagittal (lower images) cadaver anatomic sections of the sacrum at the level of the sacral hiatus that was rendered from the Visible Human Server male data set.

Computed Tomography Anatomy of the Sacrum

Figs. 9-5 to 9-7
FIGURE 9-5 Transverse CT image of the sacrum. Note the sacral canal and the sacroiliac joints. ESM, erector spinae muscle.

FIGURE 9-6 Median sagittal CT image of the sacrum. Inset image is a transverse CT section of the sacrum at the level of the sacral hiatus.

FIGURE 9-7 3-D CT reconstruction demonstrating the dorsal surface of the sacrum. Note the large L5 to S1 interlaminar space, dorsal sacral foramina, and the sacral hiatus.

Magnetic Resonance Imaging Anatomy of the Sacrum

Figs. 9-8 and 9-9
FIGURE 9-8 Transverse MRI image of the midsection of the sacrum. Note the cauda equina nerves within the fat-filled sacral canal. SIJ, sacroiliac joint.

FIGURE 9-9 Median sagittal MRI image of the sacrum. The superficial and deep components of the sacrococcygeal ligament are seen in this image. Inset image is a transverse MRI section of the sacrum at the level of the sacral hiatus.

Ultrasound Imaging of the Sacrum for Caudal Epidural Injection – Basic Considerations
The caudal epidural space is the continuation of the lumbar epidural space and can be accessed via the sacral hiatus. Ultrasound imaging of the sacrum and sacral hiatus can be performed in the transverse or sagittal axis (Fig. 9-10).\textsuperscript{1,2,5} Because the sacral hiatus is a superficial structure, it can be imaged using a high-frequency linear transducer (12–5 MHz).\textsuperscript{1,2,5} Ultrasound imaging of the sacrum for a caudal epidural injection produces a typical sonographic appearance of the osseous structures that are illustrated in Fig. 9-11.

**FIGURE 9-10** Figure illustrating the position of the ultrasound transducer during a (A) transverse and (B) sagittal scan of the sacrum.

**FIGURE 9-11** Sonograms of the sacral hiatus (A, sagittal view and B, transverse view)
Ultrasound Imaging of the Sacrum for Caudal Epidural Injection

1. **Position:**
   
   a. **Patient:** The patient is positioned in the lateral decubitus position for a caudal epidural injection (Fig. 9-12). When fluoroscopy is used in conjunction with ultrasound for the caudal epidural injection, as in chronic pain medicine, then the patient may be positioned in the prone position with a pillow under the abdomen.

   ![A Transverse sonogram of the sacrum at the level of the sacral hiatus that was acquired with the patient in the (B) lateral position.](image)

   **FIGURE 9-12** (A) Transverse sonogram of the sacrum at the level of the sacral hiatus that was acquired with the patient in the (B) lateral position.

   b. **Operator and ultrasound machine:** The operator stands behind the patient, and the ultrasound machine is placed directly in front of the patient.

2. **Transducer selection:** High-frequency linear transducer (12–5 MHz).

3. **Scanning technique:** Ultrasound scan for the sacral hiatus is commenced by placing the ultrasound transducer at the lower end of the sacrum and over the coccyx. Thereafter the transducer is gradually moved cranially until the sacral cornua and hiatus are visualized (Fig. 9-12).

4. **Sonoanatomy:** The sacral hiatus is covered by the sacrococcygeal ligament. Its lateral margins are formed by the two sacral cornua. On a transverse sonogram of the sacrum at the level of the sacral hiatus, the sacral cornua are seen as two hyperechoic reversed U-shaped structures, one on either side of the midline (Figs. 9-12 and 9-13). Connecting the two sacral cornua and deep to the skin and subcutaneous tissue is a hyperechoic band, the sacrococcygeal ligament (Figs. 9-12 and 9-13). Anterior to the sacrococcygeal ligament is another hyperechoic linear structure, which represents the dorsal surface of the sacrum (Fig. 9-12). The hypoechoic space between the sacrococcygeal ligament and the bony
dorsal surface of the sacrum is the caudal epidural space (Figs. 9-12 and 9-13). The two sacral cornua and the posterior surface of the sacrum produce a sonographic pattern that we refer to as the “frog eye sign” because of its resemblance to the eyes of a frog (Figs. 9-12 and 9-13). If one moves the transducer slightly cephalad to the midsection of the sacrum, the dorsal surface of the sacrum with the median sacral crest is visualized (Fig. 9-14). On a sagittal sonogram of the sacrum at the level of the sacral cornua, the sacrococcygeal ligament, the base of sacrum, and the sacral hiatus are also clearly visualized (Figs. 9-15 and 9-16). However, due to the acoustic shadow of the posterior surface of the sacrum, only the lower part of the caudal epidural space is seen (Fig. 9-16).

**FIGURE 9-14** Transverse sonogram of the midsection of the sacrum showing the median sacral crest and the large acoustic shadow of the sacrum.
FIGURE 9-15 (A) Sagittal sonogram of the sacrum at the level of the sacral hiatus that was acquired with the patient in the (B) lateral position.

FIGURE 9-16 (A) Sagittal sonogram of the sacrum at the level of the sacral hiatus. Note the hyperechoic sacrococcygeal ligament that extends from the sacrum to the coccyx and the acoustic shadow of the sacrum that completely obscures the sacral canal. Inset images in the
figure: (B) shows the sacral hiatus from the water-based spine phantom, (C) shows a 3-D reconstructed image of the sacrum at the level of the sacral hiatus from a 3-D CT data set from the author’s archive, and (D) shows a sagittal CT slice of the sacrum at the level of the sacral cornua.

**FIGURE 9-13** (A) Transverse sonogram of the sacrum at the level of the sacral hiatus. Note the two sacral cornua and the hyperechoic sacrococcygeal ligament that extends between the two sacral cornua. The hypoechoic space between the sacrococcygeal ligament and the posterior surface of the sacrum is the sacral hiatus. Inset images in the figure: (B) shows the sacral cornua from the water-based spine phantom, (C) shows a 3-D reconstructed image of the sacrum at the level of the sacral hiatus from a 3-D CT data set from the author’s archive, and (D) shows a transverse CT slice of the sacrum at the level of the sacral cornua.

**Clinical Pearls**

1. There is marked variability in the anatomy of the sacral hiatus.
2. Age-related changes in the sacral hiatus (ie, thickening and calcification of the sacrococcygeal ligament and cornua) can lead to significant narrowing of the hiatus.
3. Avoid advancing the epidural needle too deep into the caudal epidural space during an ultrasound-guided caudal epidural injection because the acoustic shadow of the sacrum obscures ultrasound visualization of the needle tip and injectate. Therefore, unintentional intravascular injection may be missed.
4. Color Doppler ultrasound should be used to confirm correct position of the needle tip and injection into the caudal epidural space.\(^8\)
Basic Anatomy of the Lumbosacral Interlaminar Space

The lumbosacral (L5–S1) interlaminar space, also referred to as the L5 to S1 gap, is the intervertebral space between the lamina of L5 and S1 vertebrae (Fig. 9-17). It is one of the routes (paramedian approach) for needle insertion during central neuraxial blocks (CNBs, spinal and epidural injection), and spinal injections via the L5 to S1 interlaminar space originally described by Taylor in 1940. However, a review of the literature indicates that CNBs are most frequently performed via the L3 to L4 or L4 to L5 intervertebral space and rarely via the L5 to S1 interlaminar space. The exact reason for this practice is not known, although the interlaminar space at the L5 to S1 is wider than that at the other lumbar intervertebral levels. This may be due to a poor understanding of the anatomy of the L5 to S1 interlaminar space or a lack of data comparing CNBs via the L3 to L4 or L4 to L5 and L5 to S1 intervertebral spaces. However, with recent improvements in our understanding of the sonoanatomy of the spine, there are several reports on the use of ultrasound for CNB via the L5 to S1 interlaminar space in patients with difficult spine (eg, scoliosis, instrumented or operated backs). Ultrasound has also been successfully used to accurately locate the lumbar intervertebral (L3–L4 or L4–L5) space during CNB. This method relies on identifying the L5 to S1 interlaminar space or the L5 to S1 gap in a paramedian sagittal scan and then sliding the transducer cephalad to locate the lamina of the L3, L4, and L5 vertebrae and thereby the L4 to L5 and L3 to L4 intervertebral spaces.

There are certain peculiarities in the anatomy of the L5 to S1 interlaminar space that deserve attention as a route for CNB. As described earlier, the L5 to S1 interlaminar space is wider than the interlaminar spaces at the L4 to L5 and L3 to L4 intervertebral levels. Also, because the dorsal surface of the sacrum is directed backwards and slightly upwards in vivo
(Figs. 9-7, 9-18, and 9-19), the L5 to S1 interlaminar space may be closer to the skin than the L4 to L5 intervertebral space. At the L5 to S1 intervertebral level, the ligamentum flavum is also relatively thinner, there is a lack of posterior epidural fat, and there is a greater amount of epidural fat in the midline superficial (external) to the epidural space, when compared to that at the other lumbar intervertebral spaces.

**FIGURE 9-18** Cadaver anatomic section showing the lumbosacral interlaminar space (L5–S1 gap) in the (A) transverse, (B) median (sagittal), and (C) paramedian sagittal axis. IVD, intervertebral disc; ILS, interlaminar space; ITS, intrathecal space; CE, cauda equina.
**FIGURE 9-19** Sagittal cadaver anatomic section of the lumbosacral spine, through the laminae of L4 and L5 vertebrae and the L5 to S1 interlaminar space that was rendered from the Visible Human Server male data set. The lamina and dorsal surface of the sacrum are highlighted in green. Also note how the dorsal surface of the sacrum is directed backwards and slightly upwards. ESM, erector spinae muscle; IVD, intervertebral disc; VB, vertebral body.

**Gross Anatomy of the Lumbosacral Interlaminar Space**

Figs. 9-18 and 9-19

**Computed Tomography Anatomy of the Lumbosacral Interlaminar Space**

Figs. 9-20 to 9-22
FIGURE 9-20 ♦ Transverse CT image of the lumbosacral intervertebral space (junction). VB, vertebral body; ESM, erector spinae muscle.

FIGURE 9-21 ♦ Median sagittal CT image of the lumbosacral intervertebral space. ESM, erector spinae muscle.
**FIGURE 9-22** Paramedian sagittal CT image of the lumbosacral interlaminar space (L5–S1 gap). VB, vertebral body.

**Magnetic Resonance Imaging Anatomy of the Lumbosacral Interlaminar Space**

Figs. 9-23 to 9-25
**FIGURE 9-23** Transverse MRI image of the lumbosacral intervertebral space. VB, vertebral body.

**FIGURE 9-24** Median sagittal MRI image of the lumbosacral spine. Note the tapered thecal sac and its termination at the level of S1 in this subject. Also note the cauda equina nerves within the thecal sac. ITS, intrathecal sac. SP, spinous process.
Ultrasound Imaging of the Lumbosacral Interlaminar Space

1. **Position:**
   a. **Patient:** The L5 to S1 interlaminar space is imaged with the patient in the lateral decubitus position (Fig. 9-26), but it can also be imaged with the patient in the prone position.
b. **Operator and ultrasound machine:** The operator stands behind the patient, and the ultrasound machine is placed directly in front of the patient.

2. **Transducer selection:** Because the L5 to S1 interlaminar space is relatively superficial, it can be imaged using a high-frequency linear transducer (12–5 MHz). However, because the L5 to S1 interlaminar space is imaged as part of a “scan routine” during spinal sonography for CNB, a low-frequency (5–2 MHz) curvilinear transducer is most frequently used.

3. **Scanning technique:** For a transverse scan the ultrasound transducer is placed over the midsection of the sacrum (Fig. 9-26). Once the sacrum with the median sacral crest (Fig. 9-14) is visualized, the transducer is slowly moved in a cephalad direction until the acoustic shadow of the dorsal surface of the sacrum disappears and the spinal canal with the thecal sac, posterior surface of the L5 vertebral body (anterior complex), and the articular process of L5 (laterally) at the L5 to S1 intervertebral space are clearly visualized (Figs. 9-26 and 9-27).

For a sagittal scan the ultrasound transducer is placed over the sacrum in the sagittal orientation (Fig. 9-28) and then slowly moved in a cranial direction until the L5 to S1 interlaminar space is visualized (Figs. 9-28 and 9-29). During image optimization it may be necessary to tilt the transducer slightly medially to produce a paramedian sagittal oblique scan (Fig. 9-28).
FIGURE 9-28  (A) Paramedian sagittal oblique ultrasound scan of the lumbosacral interlaminar space (L5–S1 gap) (B) with the patient in the lateral position. Note the slight oblique tilt in the ultrasound transducer in the inset image.

FIGURE 9-29  Correlative image of the lumbosacral interlaminar space (L5–S1 gap) anatomy. (A) sagittal sonogram from the water-based spine phantom, (B) sagittal sonogram in vivo, and (C) cadaver anatomical section. ESM, erector spinae muscle; PD, posterior dura; CE, cauda equina; ITS, intrathecal space.
4. **Sonoanatomy**: On a transverse sonogram of the L5 to S1 intervertebral space the thecal sac is seen as a round-to-oval anechoic structure within the spinal canal (Figs. 9-26 and 9-27). The anterior complex of the posterior surface of the L5 vertebral body produces a hyperechoic shadow anterior to the thecal sac (Figs. 9-26 and 9-27). The ligamentum flavum with the posterior epidural space may also be seen in some individuals (Fig. 9-27). The cauda equina nerves appear as small hyperechoic shadows within the thecal sac (Fig. 9-27). The articular processes are seen laterally (Figs. 9-27 and 9-28). If one now slowly slides the transducer in a cephalad direction, one can easily recognize the transition of the anatomy from the L5 to S1 intervertebral space to the spinous process of L5, the L4 to L5 intervertebral space, L4 spinous process, and the L3 to L4 intervertebral space, respectively (Figs. 9-30 to 9-32). The transverse scan sequence described earlier is rarely used to identify a given lumbar intervertebral space, but it may be used.

![Figure 9-30](image-url) A sequence of transverse sonogram (same subject) from (A) midsection of sacrum, (B) lumbosacral (L5–S1) intervertebral space, (C) L5 spinous process, (D) L4 to L5 intervertebral space, (E) L4 spinous process, and (F) L3 to L4 intervertebral space. MSC, median sacral crest; SIJ, sacroiliac joint; TP, transverse process; AP, articular process; ITS, intrathecal sac; SP, spinous process; FJ, facet joint; AC, anterior complex; ES, erector spinae muscle.
FIGURE 9-31  A sequence of transverse CT images of the lumbosacral spine (same subject) from (A) midsection of sacrum, (B) lumbosacral (L5–S1) intervertebral space, (C) L5 spinous process, (D) L4 to L5 intervertebral space, (E) L4 spinous process, and (F) L3 to L4 intervertebral space. ESM, erector spinae muscle; MSC, median sacral crest; SIJ, sacroiliac joint; AP, articular process; SP, spinous process; FJ, facet joint.

FIGURE 9-32  A sequence of transverse MRI images of the lumbosacral spine (same subject) from (A) midsection of sacrum, (B) lumbosacral (L5–S1) intervertebral space, (C) L5 spinous process, (D) L4 to L5 intervertebral space, (E) L4 spinous process, and (F) L3 to L4 intervertebral space. ESM, erector spinae muscle; MSC, median sacral crest; SIJ, sacroiliac joint; AP, articular process; SP, spinous process; FJ, facet joint; LF, ligamentum flavum; TP, transverse process.

On a paramedian sagittal sonogram (Figs. 9-33 and 9-34) the dorsal surface of the sacrum appears as a linear hyperechoic structure with a large acoustic shadow anteriorly (Fig. 9-
The osseous structure visualized immediately cranial to the sacrum is the lamina (horse-head appearance) of the L5 vertebra, and the intervening gap is the L5 to S1 interlaminar space (Figs. 9-33 and 9-34). One must not confuse this with a median sagittal scan through the L5 to S1 intervertebral space when the spinous processes of the L5 and S1 are visualized (Fig. 9-35). At the L5 to S1 interlaminar space and within the acoustic window, the following structures are visualized in a posterior-to-anterior direction: erector spinae muscle, ligamentum flavum, posterior epidural space, posterior dura, thecal sac, and the anterior complex, respectively (Figs. 9-33 and 9-34). Occasionally the tapered distal end of the thecal sac can be seen. The cauda equina nerves may also be seen as hyperechoic streaks within the anechoic cerebrospinal fluid–filled thecal sac (Fig. 9-33).

**FIGURE 9-33** Paramedian sagittal oblique sonogram of the lumbosacral (L5–S1) interlaminar space. Note the wide interlaminar space, and correspondingly, the wide acoustic window for ultrasound imaging at this level. The posterior surface of the sacrum is identified as a flat hyperechoic structure with a large acoustic shadow anterior to it. The dip or gap between the sacrum and the lamina of L5 is the L5 to S1 intervertebral space or the L5 to S1 gap. ESM, erector spinae muscle.
FIGURE 9-34 Correlative images (A) paramedian sagittal oblique sonogram and (B) sagittal MRI of the lumbosacral interlaminar space (L5–S1 gap).

FIGURE 9-35 Median sagittal sonogram of the lumbosacral interlaminar (L5–S1 gap) space. ESM, erector spinae muscle.

Clinical Pearls

1. Identification of a given lumbar intervertebral space using anatomical landmark (intercristal or Tuffier’s line) is imprecise\textsuperscript{15} and often results in identification of an intervertebral space one or two spinal levels higher.\textsuperscript{16,17}

2. Cumulative evidence suggests that ultrasound is more accurate than anatomical landmarks
in locating a given lumbar intervertebral space.\textsuperscript{13}

3. To identify a given lumbar intervertebral space using ultrasound, one has to rely on locating the L5 to S1 interlaminar space on a paramedian sagittal scan (described earlier). Therefore, inaccuracies can result in individuals with lumbosacral transitional vertebra, that is, lumbarized S1 (Figs. 9-36 and 9-37) or sacralized L5 (Figs. 9-38 and 9-39) that is present in 4\% to 21\% of individuals.\textsuperscript{18}

\textbf{FIGURE 9-36} Lumbosacral transitional vertebra I: Lumbarization of the S1 vertebra is seen on the plain radiographs (anteroposterior and lateral views).

\textbf{FIGURE 9-37} Lumbosacral transitional vertebra II: Lumbarization of the S1 vertebra is seen on the CT scan images (sagittal and 3-D reconstructed views).
4. The anatomy of the L5 to S1 intervertebral space is rarely altered during spinal instrumentation or scoliosis (particularly idiopathic scoliosis) surgery. Therefore, it should be considered as a route for CNB in such patients.

5. Dry taps are common during spinal access through the L5 to S1 interlaminar space. This is particularly true when the spinal puncture is performed with the patient in the lateral decubitus position and the spinal needle is inserted from the nondependent side (personal experience).
References


CHAPTER 10

Sonoanatomy Relevant for Thoracic Interfascial Nerve Blocks: Pectoral Nerve Block and Serratus Plane Block

Introduction

Blanco and colleagues\(^1\)–\(^3\) have recently described novel ultrasound-guided thoracic interfascial nerve blocks, the pectoral nerve block (PECS)\(^1\),\(^2\) and serratus plane block (SPB),\(^3\) for anesthesia and/or analgesia of the anterior/anterolateral chest wall.\(^1\)–\(^4\) The SPB may also anesthetize the axilla via blockade of the intercostobrachial nerve.\(^3\) These blocks were originally developed for breast surgery in an attempt to avoid some of the rare but serious complications of thoracic paravertebral and neuraxial blocks. During a PECS-I block, the local anesthetic (0.4 mL/kg or approximately 20–30 ml)\(^1\) is injected as a single injection into the myofascial plane between the pectoralis major and minor muscle, aiming to block the medial and lateral pectoral nerves.\(^1\) PECS-II block is a modification of the PECS-I block (modified PECS-I block) and involves two injections.\(^2\) The first injection is the same as that for a PECS-I block (but with 10 mL of local anesthetic),\(^2\) but the second injection is performed deep to the pectoralis minor muscle, at the level of the third and fourth rib, into the interfascial plane between the pectoralis minor and serratus anterior muscle (with 20 mL of local anesthetic).\(^2\) The aim of the PECS-II block is to anesthetize the pectoral nerves, intercostobrachial nerve, third to sixth intercostal nerves, and the long thoracic nerve.\(^2\),\(^4\) The PECS-II block is therefore used for more extensive breast surgery, including mastectomy with or without axillary clearance.\(^2\) The SPB\(^3\) is a more recent addition to the family of thoracic interfascial nerve blocks and involves a single injection of 0.4 mL/kg of local anesthetic into the myofascial plane between the latissimus dorsi and the serratus anterior muscle more posteriorly and at the level of the fifth rib.\(^3\) Local anesthetic spreads in the serratus plane, deep to the latissimus dorsi, and along the lateral chest wall to affect the lateral cutaneous branches of the second to ninth intercostal nerves and possibly the long thoracic and thoracodorsal nerves.\(^3\),\(^4\) A clear understanding of the sonoanatomy of the thoracic wall is a prerequisite to effectively using a PECS or SPB. The following section describes the gross anatomy, ultrasound scan technique, and sonoanatomy of the thoracic wall relevant for the thoracic interfascial nerve blocks. Because these blocks are frequently used for breast surgery, a brief description of the innervation of the breast is also included.

Gross Anatomy

1. **Muscles**: Muscles involved with thoracic interfascial nerve blocks are pectoralis major, pectoralis minor, serratus anterior, intercostal muscles, and the latissimus dorsi.
**Pectoralis major**: The pectoralis major muscle is a triangular, fan-shaped muscle that makes up the bulk of the anterior chest wall (Figs. 10-1 and 10-2). It has two parts: the clavicular head and the sternocostal head (Fig. 10-1). The clavicular head originates from the medial half of the clavicle, and the sternocostal head arises from the anterior surface of the lateral margin of the sternum, the first seven costal cartilages, and aponeurosis of the external oblique muscle. Muscle fibers from the two heads converge laterally to form a flat tendon that is inserted into the lateral lip of the bicipital groove (intertubercular sulcus) of the humerus. It also forms the anterior fold of the axilla. The pectoralis major muscle receives its innervation from the lateral and medial pectoral nerves of the brachial plexus. The clavicular head is innervated by the lateral pectoral nerve, and the sternocostal head is innervated by both the lateral and medial pectoral nerve. It is involved with flexion, adduction, and medial rotation of the humerus; depression of the arm and shoulder; and elevation of the ribs.

**FIGURE 10-1** Figure showing the anatomy of the anterior chest wall and arrangement of the lateral and medial mammary branches of the lateral cutaneous and anterior cutaneous branches of the intercostal nerve (ICN), respectively.
**b. Pectoralis minor:** The pectoralis minor muscle is a thin, triangular-shaped muscle located deep to the pectoralis major muscle (Figs. 10-3 to 10-5). It is significantly smaller in size than the pectoralis major muscle and originates from the outer surface of the third to fifth ribs (Fig. 10-4). The muscle fibers converge superolaterally to form a flat tendon that is attached to the coracoid process of the scapula (Fig. 10-4). It also forms part of the anterior wall of the axilla. The pectoralis minor also receives its innervation from the lateral and medial pectoral nerves of the brachial plexus. It is involved with depression of the elevated shoulder, and along with the serratus anterior muscles, pulls the scapula forward.
relation to the pectoralis major (cutout view) and minor muscles, thoracoacromial artery and its branches, the chest wall, and breast in a female. Note the medial mammary branches of the anterior cutaneous branch of the intercostal nerve (ICN) on the anteromedial aspect of the breast.

**FIGURE 10-4** Figure showing the pectoral nerves and their relation to the pectoral muscles (cutout view of the pectoralis major muscle), thoracoacromial artery, and its pectoral branch.
c. **Serratus anterior**: The serratus anterior muscle covers most of the lateral thoracic wall (Fig. 10-2) and originates as 9 to 10 muscular slips from the external surface of the first to eighth or ninth ribs (Fig. 10-2). Because two slips originate from the second rib, the number of slips is usually greater than the number of ribs from which they arise. The muscle fibers converge posteriorly to be inserted into the medial border of the scapula. It contributes to forming the medial wall of the axilla. It is also called the “boxer’s muscle” because it causes protraction of the scapula around the rib cage—a movement that occurs when throwing a punch. It is also involved with upward rotation of the scapula that occurs while lifting a load overhead. The serratus anterior muscle is innervated by the long thoracic nerve, which travels caudally on the outer surface of the muscle. Injury to the long thoracic nerve can lead to a “winged scapula.”

d. **Latissimus dorsi**: The latissimus dorsi muscle is a large, flat muscle located on the dorsal of the trunk. It originates from the spinous processes of the last six thoracic vertebra (T7–T12), the thoracolumbar fascia, and the posterior third of the external lip of the iliac crest. The muscle fibers converge cranially to form a flattened tendon that is inserted into the floor of the bicipital (intertubercular) groove anterior to the attachment of the teres major muscle. It is involved with adduction, extension, and internal rotation of the arm at the shoulder and innervated by the thoracodorsal nerve. The thoracodorsal artery descends inferiorly with the thoracodorsal nerve and supplies the latissimus dorsi muscle.

e. **Teres major**: The teres major muscle is a rounded muscle that is attached between the scapula and humerus. It originates from the posterior surface of the inferior angle and lower part of the lateral border of the scapula. The fibers converge laterally to a flat
tendon that is inserted into the medial lip of the bicipital groove. The teres major is located superior to the latissimus dorsi, and the muscle fibers run parallel to each other to its insertion in the humerus. It is innervated by the lower subscapular and thoracodorsal nerves, which are branches of the posterior cord of the brachial plexus, and receives spinal contributions from the C5 to C8 spinal nerves. It is involved with extension and medial rotation of the humerus.

2. **Nerves:** The nerves involved with thoracic interfascial nerve blocks are intercostal nerves, pectoral nerves, long thoracic nerve, and thoracodorsal nerve.

   a. **Intercostal nerve:** The intercostal nerves are the anterior primary rami of the spinal nerves T1 to T11. The anterior primary rami of the 12th spinal nerve form the subcostal nerve. The first and second intercostal nerve, in addition to supplying the intercostal spaces, provide innervation to the upper limb. The lower five intercostal nerves (T7–T11) also supply the abdominal wall and are therefore called the thoracoabdominal nerves. The intercostal nerves. T3 to T6 are typical intercostal nerves because they only supply the thoracic wall. The anterior division of the first thoracic spinal nerve divides into two branches: a larger branch that exits the thorax close to the neck of the first rib, and a smaller branch, the first intercostal nerve, that runs through the intercostal space and ends close to the sternum as the anterior cutaneous branch of T1. The first intercostal nerve also receives a small communication from the second intercostal nerve posteriorly along the neck of the rib. This is the “nerve of Kuntz,” which is present in 40% to 80% of individuals.

   Each typical intercostal nerve (Fig. 10-6) passes below the neck of the rib (with the same number) to enter the costal groove. At the posterior part of the costal groove, the intercostal nerve lies between the parietal pleura (with the endothoracic fascia) and the internal intercostal membrane (Fig. 10-6). Otherwise, throughout its course through the intercostal space, the intercostal nerve lies between the innermost intercostal and the internal intercostal muscle (Figs. 10-6 and 10-7). The lateral cutaneous branch pierces the intercostal and serratus anterior muscle complex at the level of the midaxillary line and gives off its anterior and posterior branches (Figs. 10-6, 10-8, and 10-9). The anterior branch (T2–T6) courses forward and supplies the skin on the lateral and anterior aspect of the chest wall (Figs. 10-1, 10-6, and 10-9). In females they form the lateral mammary branches of the intercostal nerve (same number) and supply the breast (Figs. 10-6 and 10-10). The posterior branch courses backwards and supplies the skin over the scapula and the latissimus dorsi muscle. The anterior cutaneous branch of the intercostal nerve (ie, the main intercostal nerve) courses forward through the intercostal space and emerges close to the sternum by crossing anterior to the internal thoracic (mammary) artery (Fig. 10-6). It then pierces the internal intercostal muscle, the external intercostal membrane, and the pectoralis major muscle to terminate as the anterior cutaneous nerve of the thorax and innervate the overlying skin after dividing into its medial and lateral branches (Fig. 10-6). The lateral branch supplies the medial and anterior aspect of the chest wall and in females the medial and anterior aspect of the breast and thus is referred to as the medial mammary nerves (T2–T6) (Figs. 10-3, 10-6, and 10-10). The intercostobrachial nerve, which corresponds to the lateral cutaneous branch of the second intercostal nerve (T2), emerges from the intercostal space and runs oblique towards the arm to supply the axilla and upper part of the medial aspect of the arm (Figs. 10-3, 10-8, and 10-10). The intercostobrachial nerve may also receive contributions from the first, third, and fourth intercostal nerves.5
FIGURE 10-6  Transverse section of the thorax showing a typical intercostal nerve and its relation to the intercostal and pectoral muscles. Note the formation of the medial and lateral mammary nerves from the intercostal nerve (ICN).

FIGURE 10-7  Figure showing the anatomy of the intercostal space.
FIGURE 10-8  Figure showing the emergence of the lateral cutaneous branch of the intercostal nerve (lateral cutaneous nerve of the thorax) and its branching along the lateral chest wall. Note the formation of the intercostobrachial nerve from the second intercostal nerve.

FIGURE 10-9  Figure showing the innervation of the trunk and abdominal wall. Note the anatomical arrangement of the typical intercostal nerves (T3–T6) and the areas innervated by their lateral and anterior cutaneous branches. In females, the anterior branch of the lateral
cutaneous branch of the intercostal nerve (T2–T7) form the lateral mammary nerve, and the medial branch of the anterior cutaneous branch of the intercostal nerve (T1–T6) form the medial mammary nerve.

**FIGURE 10-10** Sensory innervation of the female breast – lateral (T2–T7) and medial (T1–T6) mammary nerves and supraclavicular nerve (medial and intermediate). The axilla is innervated by the intercostobrachial nerve. Also note the course of the long thoracic and thoracodorsal nerve along the lateral chest wall. ICN, intercostal nerve.

b. **Pectoral nerves:** The pectoral nerves are frequently described as “pure motor nerves,” but there is growing evidence that they are also involved with afferent nociception and proprioception, similar to that with other pure motor nerves. Afferent nociception may be transferred by the pectoral nerves from the acromioclavicular joint, coracoclavicular ligaments, subacromial bursa, articular capsule of the shoulder joint, periosteum of the clavicle, and pectoral muscles, and via cutaneous branches they may innervate the anterior chest wall and anterior margin of the deltoid muscle.

The pectoral nerves are also traditionally described as two nerves, the medial and lateral pectoral nerves, with the lateral pectoral nerve (LPN) being larger than the medial pectoral nerve (MPN). The ansa pectoralis is a loop of communication between the LPN and MPN (Figs. 10-3 and 10-4). Published data suggest that the LPN most frequently arises from the anterior divisions of the upper and middle trunk (33.8%), but it may also arise from the lateral cord (23.4%), of the brachial plexus. The MPN also has a variable origin and may arise from the medial cord (49.3%) or anterior division of the lower trunk (43.8%) or lower trunk (4.7%). Spinal contribution to the LPN and MPN also varies. Two types of spinal origin of the LPN (C5–C7 in 50% and C6 and C7 in 50%) and three types of spinal origin of the MPN (C8 and T1 in 73.3%, C8 in 23.4%, and T1 in 3.3%) have been described. After its origin the LPN crosses anterior to the axillary vessels, pierces the clavipectoral fascia, and supplies the pectoralis major muscle (Fig. 10-5). The LPN also shares a constant course with the thoracoacromial vessels and lies on the deep surface of the pectoralis major, beneath the muscle fascia, with the pectoral branch of the thoracoacromial artery (TAA) (Figs. 10-3, 10-4, and 10-11). After its origin, the MPN courses downwards lying anterior to the axillary artery and deep to the pectoralis.
minor muscle (Figs. 10-3, 10-4, and 10-11). It then pierces the pectoralis minor muscle from beneath at about the midclavicular line and over the third intercostal space. A few branches of the MPN may also loop around the inferior border of the pectoralis minor muscle to enter the pectoralis major.

FIGURE 10-11 Figure showing the anatomical structures that are relevant for thoracic interfascial nerve blocks at the medial infraclavicular fossa (ie, between the inferior border of the clavicle and the medial border of the pectoralis minor muscle). Note how the cephalic vein arches over the cords of the brachial plexus and axillary artery from a lateral-to-medial direction to join the axillary vein. Also note the relations of the superior, medial, and inferior branches of the pectoral nerve to the axillary artery, the thoracoacromial artery, and pectoralis minor muscle.

The pectoral nerves may also be present as three constant branches (Figs. 10-3, 10-4, and 10-11), that is, a superior branch that supplies the clavicular fibers of the pectoralis major, the middle branch that courses on the undersurface of the pectoralis major muscle (beneath its fascia) with the pectoral branch of the TAA to innervate the sternal part of the pectoralis major muscle, and the inferior branch that passes under the pectoralis minor muscle to innervate it and the costal part of the pectoralis major muscle. Given the variable spinal origin and formation of the pectoral nerves, a “subpectoral plexus” of nerves with the C5–T1 nerve roots, the two pectoral nerves, and the three terminal branches has been described. With this arrangement the superior and middle branches are divisions of the LPN, and the inferior branch is formed by fusion of the MPN and ansa pectoralis from the C7 (Figs. 10-11 and 10-12).
FIGURE 10-12  Schematic diagram showing the formation of the “subpectoral plexus”\(^\text{10}\) of nerves with both the medial and lateral pectoral nerve and the three terminal branches (ie, the superior, middle, and inferior branches). The superior and middle branches are derived from the lateral pectoral nerve, and the inferior branch is derived from the ansa pectoralis (C7 spinal nerve root) and medial pectoral nerve.

c. **Long thoracic nerve**: The long thoracic nerve, also known as the Bell’s nerve, originates from the ventral rami of the C5, C6, and C7 and descends to the lateral thoracic wall (Fig. 10-9) where it innervates the serratus anterior muscle.

d. **Thoracodorsal nerve**: The thoracodorsal nerve originates from the posterior cord of the brachial plexus with spinal contributions from the C6 to C8. As it descends along the posterior wall of the axilla, it is accompanied by the thoracodorsal artery and innervates the latissimus dorsi muscle.

3. **Blood vessels**: The following blood vessels are of interest while performing thoracic interfascial nerve blocks: axillary, thoracoacromial, and thoracodorsal artery.

a. **Axillary artery**: The axillary artery is a continuation of the subclavian artery into the axilla. It begins at the lateral border of the first rib and ends at the lower border of the teres major muscle after which it continues distally as the brachial artery. It has three parts: the first part lies between the lateral border of the first rib and the medial border of the pectoralis minor muscle and gives off the superior thoracic artery; the second part lies deep to the pectoralis minor muscle and gives off the lateral thoracic and TAA; the third part lies between the lateral border of the pectoralis minor muscle and the lower border of the teres major muscle and gives off three branches: the subscapular artery, the anterior circumflex humeral artery, and the posterior circumflex humeral artery.

b. **Thoracoacromial artery**: The TAA, after its origin (Figs. 10-3 and 10-4), runs a short course along the upper margin of the pectoralis minor muscle, penetrates the clavipectoral fascia (Fig. 10-5), and divides into its terminal branches: the clavicular,
acromial, deltoid, and pectoral branches. The TAA is important for a PECS block because, as described earlier, the pectoral nerves and the ansa pectoralis have a constant relationship with the artery (Fig. 10-11). The LPN also runs parallel to the pectoral branch of the TAA in the myofascial plane between the pectoralis major and minor muscles (Figs. 10-4 and 10-11), lying deep to the muscle fascia. The ansa pectoralis nerve is also formed immediately distal to the origin of the TAA (Fig. 10-4).

c. **Thoracodorsal artery:** The thoracodorsal artery (Fig. 10-3) is a branch of the subscapular artery and travels inferiorly along the lateral chest wall (Fig. 10-3), lying deep to the latissimus dorsi muscle initially and then on the external surface of the serratus anterior muscle. It is accompanied by the thoracodorsal nerve (Fig. 10-3) and supplies the latissimus dorsi.

4. **Fascia**

a. **Clavipectoral fascia:** This is a fascial layer that is interposed between the clavicle and upper border of the pectoralis minor muscle (Fig. 10-5). The portion of the clavipectoral fascia that is attached between the first costosternal articulation and the coracoid process is usually denser than the rest and is referred to as the “costocoracoid ligament.” Inferiorly it is thin, and at the upper border of the pectoralis minor muscle it splits to invest the muscle (Fig. 10-5). Below the inferior border of the pectoralis minor muscle the clavipectoral fascia continues downwards as a single layer, the suspensory ligament of axilla, or Gerdy’s ligament, and attaches to the axillary fascia (Fig. 10-5). The clavipectoral fascia is pierced by the cephalic vein, lateral pectoral nerve, TAA, and lymphatics (Fig. 10-5).

### Innervation of the Breast

The sensory and glandular innervation of the female breast comes from multiple sources. Medially it is innervated by the anterior cutaneous branches (medial mammary nerves) of the first to sixth intercostal nerves (Figs. 10-6 and 10-13) and laterally by the lateral cutaneous branches (lateral mammary nerves) of the second to seventh intercostal nerves (Fig. 10-10). The nipple–areola complex is supplied mainly by the anterior and lateral cutaneous branches of the fourth intercostal nerve (Fig. 10-13), with additional contributions from the cutaneous branches of the third and fifth intercostal nerves. The skin of the superior part of the breast (infraclavicular region) receives innervation from the superficial cervical plexus via the medial and intermediate supraclavicular nerves (C3 and C4, Figs. 10-10 and 10-14). The lateral supraclavicular nerve mainly provides sensory supply to the upper and posterior aspect of the shoulder, but may also contribute to sensory innervation of the breast (Fig. 10-14). Sympathetic nerves reach the breast via the somatic nerves (described earlier) and blood vessels. There is no parasympathetic nerve supply to the breast. When breast surgery involves the axilla (eg, axillary dissection) and pectoral muscles (eg, modified radical mastectomy), the intercostobrachial and pectoral nerves (LPN and MPN) may also be involved in afferent nociception (discussed earlier).
FIGURE 10-13 Figure showing the arrangement of the lateral and medial mammary nerves of the female breast. Note the breast is supplied medially by the medial mammary nerves (T1–T6) and laterally by the lateral mammary nerve (T2–T7).

FIGURE 10-14 Figure showing the contribution of the supraclavicular nerves to the sensory innervation of the breast. ICN, intercostal nerve.

**Ultrasound Imaging for Thoracic Interfascial Blocks**

**Ultrasound Scan Technique**

1. **Position:**
   a. **Patient:** Supine with the arm abducted and the head turned away slightly to the contralateral side. Blanco describes using the supine position for both the PECS\(^1,2\) and SPB,\(^3,4\) but we prefer the lateral position for the SPB because it allows easy placement of the ultrasound transducer along the lateral chest wall for the coronal scan (described later) and also allows easy needle manipulation.
b. **Operator and ultrasound machine:** With the patient in the supine position, the operator stands at the head end of the patient, and the ultrasound machine is positioned ipsilateral to the side to be examined and directly in front of the operator. With the patient in the lateral position and with the side to be scanned uppermost, the operator stands behind the patient, and the ultrasound machine is positioned on the contralateral side and directly in front of the operator.

2. **Transducer selection:** High-frequency (13–15 MHz) linear array transducer.

3. **Scan technique:** The ultrasound scan can be performed in the sagittal, transverse, and coronal axis. The sagittal scan is performed in five sequential steps (Steps I–V) over five contiguous sites starting immediately below the midsection of the clavicle and ending at the lateral chest wall. This is done to better understand the anatomy of the thoracic wall (Fig. 10-15) and the myofascial planes (Fig. 10-16) for local anesthetic injection during a thoracic interfascial nerve block.

![FIGURE 10-15](image) A sagittal oblique panoramic ultrasound image of the chest wall extending from the midsection of the clavicle to the posterior axillary line showing the musculature and fascial planes relevant for thoracic interfascial nerve blocks. R, rib.
FIGURE 10-16 Sagittal oblique panoramic ultrasound image of the chest wall highlighting the PECS-I (in blue) and serratus plane (in green) that are targets for local anesthetic injection during thoracic interfascial nerve blocks. R, rib.

a. **Sagittal scan sequence:**

   **Step 1:** The ultrasound transducer is positioned with its proximal end resting on the midsection of the clavicle and with its orientation marker directed cephalad (Fig. 10-17). The distal end of the transducer is pivoted slightly laterally (directed slightly outwards) towards the anterior axillary fold to produce a sagittal oblique scan of the thoracic wall. The clavicle is visualized as a hyperechoic structure with an underlying acoustic shadow. The second rib is seen lying posterior and distal to the acoustic shadow of the clavicle (Fig. 10-18), and the third rib is visualized immediately caudal to it (Figs. 10-19 to 10-21).
FIGURE 10-17 Figure showing the position of the patient and ultrasound transducer during Step I of the sagittal scan sequence. Inset sagittal sonogram shows the plane of ultrasound imaging (blue color) over the second intercostal space. R, rib.

FIGURE 10-18 A. Sagittal oblique sonogram of the medial infraclavicular fossa (MICF), near the midsection of the clavicle, acquired during Step I of the sagittal scan sequence. Note the second rib lies immediately posteroinferior to the clavicle, and the medial border of the pectoralis minor muscle extends to the upper border of the third rib. B. Position of patient and ultrasound transducer during Step I of the sagittal scan sequence. R, rib.
FIGURE 10-19  A. Sagittal oblique sonogram of the anterior chest wall with the ultrasound transducer positioned slightly lateral to that in Fig. 10-18. The axillary artery (AA) is visualized deep to the subclavius muscle and cranial to the axillary vein (AV). Also note how the cephalic vein (CV) joins the axillary vein from above in the medial infraclavicular fossa (MICF). B. Position of patient and ultrasound transducer during the sagittal oblique scan. R, rib.
FIGURE 10-20  A. Sagittal oblique sonogram of the anterior chest wall acquired during Step I of the sagittal scan sequence with the ultrasound transducer positioned over the axillary artery (midclavicular point). Note the cords of the brachial plexus are clustered together cranial to the axillary artery and within the costoclavicular space (CCS), which is between the clavicular head of the pectoralis major and subclavius muscle anteriorly and the upper slips of the serratus anterior muscle overlying the second rib posteriorly. The axillary vein (AV) lies caudal to the axillary artery in this sonogram. Also note parts of the thoracoacromial artery (TAA) can be seen near the upper border of the pectoralis minor muscle. B. Position of the patient and ultrasound transducer during the scan. R, rib; PC, posterior cord; MC, medial cord; LA, lateral cord.
FIGURE 10-21  Sagittal oblique sonogram of the anterior chest wall acquired during Step I of the sagittal scan sequence with the ultrasound transducer lying parallel to the axillary artery. Note the origin of the thoracoacromial artery from the anterior wall of the first part of the axillary artery in this subject. R, rib.

FIGURE 10-22  Figure showing the position of the patient and ultrasound transducer during Step II of the sagittal scan sequence. The inset sagittal sonogram shows the plane of ultrasound imaging (green) over the third intercostal space. R, rib.
FIGURE 10-23  Sagittal oblique sonogram of the anterior chest wall acquired during Step II of the sagittal scan sequence. Note the PECS-I plane lies between the posterior surface of the pectoralis major muscle and the anterior surface of the pectoralis minor muscles (interpectoral plane), and the serratus plane lies between the posterior surface of the pectoralis minor muscle and the outer surface of the serratus anterior muscle. During a PECS-I and PECS-II block, the local anesthetic is injected into their respective planes at this level. B. Position of the patient and ultrasound transducer during the sagittal oblique scan. R, rib.

FIGURE 10-24  A zoomed sagittal oblique sonogram of the anterior chest wall acquired
during Step II of the sagittal scan sequence. The serratus plane is highlighted in green color. During a PECS-II block local anesthetic is injected into both the PECS-I and serratus plane at this level. R, rib.

**FIGURE 10-25** Figure showing the position of the patient and ultrasound transducer during Step III of the sagittal scan sequence. The inset sagittal sonogram shows the plane of ultrasound imaging (purple color) over the fourth intercostal space. R, rib.
**FIGURE 10-26** A. Sagittal oblique sonogram of the anterior chest wall acquired during Step III of the sagittal scan sequence. Note the inferior border of the pectoralis minor lies over the fifth rib. B. Position of patient and ultrasound transducer during the sagittal oblique scan. R, rib.

**FIGURE 10-27** Sagittal oblique sonogram of the anterior chest wall acquired with the transducer positioned slightly caudal to that in **Figure 10-26** (same subject). Note the sixth rib is now visualized and the lateral border of the pectoralis minor muscle ends at the level of the fifth rib. R, rib.

**FIGURE 10-28** Figure showing the position of the patient and ultrasound transducer during Step IV of the sagittal scan sequence. The inset sagittal sonogram shows the plane of ultrasound imaging (yellow color) over the fifth intercostal space. R, rib.
FIGURE 10-29  A. Sagittal oblique sonogram of the anterolateral chest wall acquired during Step IV of the sagittal scan sequence. Note the inferior border of the pectoralis major muscle ends at the upper border of the sixth rib, and only the serratus anterior muscle overlies the ribs below that. The lateral cutaneous branch of the intercostal nerve emerges from the intercostal space by passing through the intercostal and serratus anterior muscle, along the midclavicular line, and lies subcutaneously at this level. B. Position of the patient and ultrasound transducer during the sagittal oblique scan. R, rib.
FIGURE 10-30 ■ Sagittal oblique sonogram of the lateral chest wall acquired during Step IV of the sagittal scan sequence. Note the lower slips of the serratus anterior muscle are much more bulky than the upper slips. R, rib.

FIGURE 10-31 ■ Figure showing the position of the patient and ultrasound transducer during Step V of the sagittal scan sequence near the posterior axillary line. The inset sagittal sonogram shows the plane of ultrasound imaging (dark green) over the sixth intercostal space. R, rib.

FIGURE 10-32 ■ Sagittal oblique sonogram of the lateral chest wall acquired during Step V of the sagittal scan sequence. Note the thick serratus anterior muscle overlying the sixth and seventh ribs and the inferolateral aspect of the latissimus dorsi muscle lying superficial to the serratus anterior muscle caudally. The myofascial plane between the latissimus dorsi and
serratus anterior muscle is the serratus anterior plane posteriorly.

FIGURE 10-33  A. Doppler ultrasound demonstrating the thoracodorsal artery in the myofascial plane between the latissimus dorsi and the serratus anterior muscle close to the posterior axillary line. The thoracodorsal nerve accompanies the thoracodorsal artery at this level, but is more difficult to delineate with current ultrasound technology. B. Position of the patient and ultrasound transducer during the sagittal scan. R, rib.

Steps II to V: From the earlier position the ultrasound transducer is moved laterally in small steps until the anatomy of the thoracic wall at the level of the third to fourth (Figs. 10-22 to 10-24), fourth to fifth (Figs. 10-25 to 10-27), fifth to sixth (Figs. 10-28 to 10-30), and seventh to eighth (Figs. 10-31 to 10-33) ribs is visualized.

b. Coronal scan sequence: The coronal scan is performed at the lateral chest wall and for an SPB. The ultrasound transducer is placed in the coronal orientation over the lateral chest wall (Fig. 10-34) and close to the posterior–axillary line. The aim at this stage is to identify the underlying ribs and the overlying serratus anterior muscle (Fig. 10-35). The transducer is then gently moved posteriorly until the inferolateral margin of the latissimus dorsi muscle is seen overlying the serratus anterior muscle (Fig. 10-36). The thoracodorsal artery is consistently seen in the myofascial plane between the latissimus dorsi and serratus anterior muscle at this level (Fig. 10-37). The ultrasound image is optimized, after which the transducer is gently moved cranially along the same coronal plane until the inferolateral margin of the teres major muscle and the serratus plane (Fig. 10-38), between the latissimus dorsi and serratus anterior muscle, are clearly visualized. This is the target ultrasound window for a SPB.4
FIGURE 10-34 Figure showing the position of the patient and ultrasound transducer during a coronal scan of the lateral chest wall for a serratus plane block. Note the orientation marker of the ultrasound transducer is directed cranially.

FIGURE 10-35 Coronal sonogram of the lateral chest wall showing the serratus anterior muscle overlying the ribs. Note the serratus anterior muscle is relatively thick at this location.
FIGURE 10-36  A. Coronal sonogram of the lateral chest wall with the transducer positioned slightly posterior to that in Fig. 10-35. The inferolateral border of the latissimus dorsi muscle is now seen lying superficial to the serratus anterior muscle at the cranial end of the sonogram. The thoracodorsal artery is also seen lying superficial to the serratus anterior muscle in this sonogram. B. Position of the patient and ultrasound transducer during the coronal scan.

FIGURE 10-37  Color Doppler sonogram showing the thoracodorsal artery in the myofascial plane between the latissimus dorsi and serratus anterior muscle along the lateral
chest wall near the posterior axillary line.

![Coronal sonogram of the lateral chest wall near the posterior axillary line showing the serratus plane between the latissimus dorsi and the serratus anterior muscle. Note the position of the teres major muscle at the cranial end of the sonogram. The myofascial plane between the latissimus dorsi and serratus anterior muscle at this level is our target for local anesthetic injection during a serratus plane block.](image)

**FIGURE 10-38** Coronal sonogram of the lateral chest wall near the posterior axillary line showing the serratus plane between the latissimus dorsi and the serratus anterior muscle. Note the position of the teres major muscle at the cranial end of the sonogram. The myofascial plane between the latissimus dorsi and serratus anterior muscle at this level is our target for local anesthetic injection during a serratus plane block.

c. **Transverse scan sequence:** In Blanco’s original descriptions of the thoracic interfascial nerve blocks, only the sagittal ultrasound scan technique is described.\(^1,3,4\) We have found the transverse ultrasound scan window to be useful for both the PECS-I and PECS-II blocks. For a transverse scan the patient is positioned supine with the head turned to the contralateral side. The ipsilateral arm is also abducted (Fig. 10-39) and flexed at the elbow, and the hand is tucked behind the head. A linear ultrasound transducer (13–15 MHz) is positioned in the transverse orientation slightly above and medial to the coracoid process with its orientation marker directed laterally (outwards). The medial end of the transducer is also pivoted slightly downwards (inferiorly) such that it is directed towards the midsection of the sternum (Fig. 10-39). The ultrasound image acquired is a transverse oblique view of the underlying thoracic wall anatomy (Figs. 10-40 to 10-45).
FIGURE 10-39  ■ Figure showing the position of the patient and ultrasound transducer during a transverse oblique scan of the anterior chest wall for a PECS block. Note the medial end of the ultrasound transducer has been pivoted slightly caudally for the scan.

FIGURE 10-40  ■ A. Transverse oblique sonogram of the anterior chest wall showing the myofascial plane between the pectoralis major and minor muscles (PECS-I plane). The pectoral branch of the thoracoacromial artery is seen as a hypoechoic and pulsatile structure within the PECS-I plane. B. Position of the patient and ultrasound transducer during the transverse oblique scan.
FIGURE 10-41  A. Power Doppler sonogram showing the pectoral branch of the thoracoacromial artery in the myofascial plane between the pectoralis major and minor muscles (PECS-I plane). B. Position of the patient and ultrasound transducer during the scan.

FIGURE 10-42  Transverse oblique sonogram of the anterior chest wall showing the PECS-I plane and the origin of the thoracoacromial artery (TAA) from the anterior wall of the axillary artery (second part). The cords of the brachial plexus are seen as a cluster of nerves lying lateral to the axillary artery in this sonogram.
FIGURE 10-43  Transverse oblique sonogram of the anterior chest wall showing the thoracoacromial artery lying deep to the pectoralis minor muscle, and its pectoral branches in the PECS-I plane.

FIGURE 10-44  Transverse oblique sonogram of the anterior chest wall, above the superior border of the pectoralis minor muscle, showing the bifurcation of the thoracoacromial artery. Note the pectoralis minor muscle is not visualized in this ultrasound window and the neurovascular structures lie directly on the serratus anterior muscle at this site.
4. **Sonoanatomy of the thoracic wall:**
   a. **Sagittal sonoanatomy:** The sagittal sonoanatomy of the thoracic wall changes as one moves the ultrasound transducer from a medial-to-lateral direction near the midsection of the clavicle (Figs. 10-18 to 10-21) or inferolaterally from the midsection of the clavicle to the lateral chest wall (Figs. 10-22 to 10-33).
   
   i. **Sonoanatomy with Step I of the sagittal scan sequence:** With the upper end of the ultrasound transducer positioned medial to the mid-point of the clavicle during the sagittal scan one is able to visualize the anechoic and compressible axillary vein lying immediately below the clavicle and between the pectoralis major and subclavius muscle anteriorly and the upper slips of the serratus anterior muscle, overlying the second rib, posteriorly (Fig. 10-18). This represents the costoclavicular space, through which the neurovascular structures pass from the neck to the arm and vice versa. Distally the clavicular head of the pectoralis major muscle and upper border of the pectoralis minor muscle are seen lying anterior to the serratus anterior muscle and the second intercostal space with the second and third ribs, intervening intercostal muscles, the hyperechoic pleura, and lung (Fig. 10-18). The space between the undersurface of the clavicle and subclavius muscle cranially, the pectoral muscles anteriorly, and the second and third ribs with the serratus anterior muscle posteriorly is the medial infraclavicular fossa (MICF, Fig. 10-18). The clavipectoral fascia is seen as a hyperechoic linear structure interposed between the subclavius muscle and the upper border of the pectoralis minor muscle (Figs. 10-5 and 10-18). Slightly lateral to the earlier
position (i.e., at the midclavicular point), the axillary artery is visualized as an anechoic and pulsatile structure within the costoclavicular space (Fig. 10-19). The cephalic vein joins the axillary vein from above within the MICF (Fig. 10-19). Lateral to the midpoint of the clavicle the cords of the brachial plexus are seen as multiple round-to-oval structures, each with a hyperechoic rim, within the costoclavicular space and lying superior to the pulsatile axillary artery (Fig. 10-20). The axillary vein is located caudal to the axillary artery (Fig. 10-20). Branches of the TAA are also seen close to the upper border of the pectoralis minor muscle (Fig. 10-20). The TAA in most cases originates from the axillary artery deep to the pectoralis minor muscles, but it may also originate above the medial border of the pectoralis minor muscle (Fig. 10-21). Deep to the serratus anterior muscle, outlines of the anterior intercostal space with the hyperechoic parietal pleura are clearly delineated (Fig. 10-20). The arrangement of the brachial plexus in the sagittal sonogram is also consistent with the lateral cord lying anterior to the medial cord and the posterior cord lying superior to the lateral and medial cord (Fig. 10-20).

**ii. Sonoanatomy with Step II of the sagittal scan sequence:** During Step II of the sagittal scan sequence, the ultrasound transducer is placed over the third intercostal space (Fig. 10-22). The third and fourth ribs with the intercostal muscles, pleura, and lung are clearly delineated (Fig. 10-23). The pectoralis major and minor muscles overlie the serratus anterior muscle, and the latter is closely attached to the adjoining ribs (Fig. 10-23). The myofascial plane between the pectoralis major and minor muscles at the level of the fourth rib may be referred to as the PECS-I plane (Fig. 10-24) because it is the target site for local anesthetic injection during a PECS-I block.

**iii. Sonoanatomy with Step III of the sagittal scan sequence:** During Step III of the sagittal scan sequence, the ultrasound transducer is placed over the fourth intercostal space (Fig. 10-25) and the fourth and fifth ribs are clearly visualized (Fig. 10-26). As seen during Step II (described earlier), the pectoralis major and minor muscles overlie the serratus anterior muscle (Figs. 10-26 and 10-27). The myofascial plane between the pectoralis minor and the serratus anterior muscle is the target site for local anesthetic injection during a PECS-II injection. The inferior border of the pectoralis minor muscle can also be defined at the level of the fifth rib (Fig. 10-27). Distal to that and at the level of the sixth rib there is a hyperechoic layer of connective tissue which probably represents the Gerdy’s ligament (suspensory ligament of the axilla) fusing with the axillary fascia (Fig. 10-5).

**iv. Sonoanatomy with Step IV of the sagittal scan sequence:** During Step IV of the sagittal scan sequence, the ultrasound transducer overlies the fifth intercostal space along the lateral chest wall (Fig. 10-28) and at the level of the anterior axillary line. With the lower border of the pectoralis minor muscle having attached to the fifth rib, only the pectoralis major and serratus anterior muscles are seen overlying the fifth rib (Fig. 10-29), and only the serratus anterior muscle overlies the sixth rib (Fig. 10-29). The lateral branches of the intercostal nerves pierce the intercostal and serratus anterior muscle complex and emerge to lie subcutaneously at this location and along the midaxillary line (Fig. 10-6). Slightly more inferolaterally, the serratus anterior muscle becomes thicker and is the only muscle overlying the lateral chest wall (Fig. 10-30).

**v. Sonoanatomy with Step V of the sagittal scan sequence:** During Step V of the sagittal scan sequence, the transducer overlies the sixth intercostal space close to
the posterior axillary line (Fig. 10-31). The inferolateral aspect of the latissimus dorsi muscle overlies the thick serratus anterior muscle (Fig. 10-32), and the thoracodorsal artery lies in the myofascial plane between the latissimus dorsi and serratus anterior muscle (Fig. 10-33). The thoracodorsal nerve, which innervates the latissimus dorsi muscle, accompanies the thoracodorsal artery (Fig. 10-3).

b. Sonoanatomy of the thoracic wall: Coronal sonoanatomy: During the coronal scan (Fig. 10-34) the ultrasound transducer is placed along the lateral chest wall and near the posterior–axillary line. The serratus anterior muscle is seen overlying the ribs (Fig. 10-35). As one gently moves the transducer posteriorly, the inferolateral border of the latissimus dorsi muscle is seen lying superficial to the serratus anterior muscle at the cranial end of the sonogram (Fig. 10-36). The thoracodorsal artery is consistently visualized in the serratus plane between the latissimus dorsi and serratus anterior muscle (Figs. 10-36 and 10-37). The myofascial plane between the latissimus dorsi and the serratus anterior muscle at the level of the fifth rib (Fig. 10-38) is the target site for local anesthetic injection during a SPB.3

c. Sonoanatomy of the thoracic wall: Transverse sonoanatomy: On the transverse sonogram the pectoralis major and minor muscles lie anterior to the axillary vein, serratus anterior muscle, and the pleura (Fig. 10-40) or the third to fourth ribs (Fig. 10-40) medially. The pectoral branch of the TAA lies in the myofascial plane between the pectoral major and minor muscles (Figs. 10-40 and 10-41). With the transducer positioned slightly lateral to the earlier position, the axillary artery is also visualized deep to the pectoral muscles and lateral to the axillary vein (Fig. 10-42). The cords of the brachial plexus are clustered together lateral to the axillary artery (Fig. 10-42). The origin of the TAA from the axillary artery (Figs. 10-42 and 10-43) and its bifurcation (Figs. 10-44 and 10-45) can also be visualized near the upper border of the pectoralis minor muscle. The TAA is an important anatomical landmark because the LPN, MPN, and ansa pectoralis are all closely related to the artery (Fig. 10-11).8,9

Clinical Pearls

1. Locating the second rib under the clavicle on the sagittal scan (Figs. 10-15 and 10-18) is a useful sonographic landmark for counting the ribs along the anterior and anterolateral chest wall.

2. Due to the complex spinal origin and anatomical arrangement of the pectoral nerves (noted earlier), a single injection of local anesthetic into the myofascial plane between the pectoralis major and minor muscles (PECS-I plane) is unlikely to consistently block all the pectoral nerves or the “subpectoral plexus” of nerves. Cadaver data suggest that a 10-mL injection at three sites: (a) deep and lateral aspect of the pectoralis minor muscle (3.3 mL), (b) in between the pectoralis major and minor muscle (3.3 mL), and (c) superficial to the posterior fascia of the pectoralis major muscle (3.4 mL), is adequate in affecting all the pectoral nerves.17 However, this observation has not been clinically validated, and there are no data evaluating pectoral nerve block dynamics after a PECS-I and or PECS-II block. Future research in this area is warranted.

3. Age-related changes in musculoskeletal structures18 can make it difficult to accurately define the PECS-I plane in the elderly. Doppler (Color or Power) ultrasound helps locate the pectoral branch of the TAA (Fig. 10-41) and facilitates accurate injection of local anesthetic into the PECS-I plane during a PECS-I block.

4. Doppler ultrasound can also be used to locate the thoracodorsal artery in the serratus plane.
during a SPB.

5. A SPB affects the lateral cutaneous branches of the ipsilateral T2 to T9 intercostal nerves and possibly also the long thoracic and thoracodorsal nerves.\textsuperscript{3,4} However, it does not affect the anterior cutaneous branch of the main intercostal nerve, and therefore the anteromedial aspect of the thorax, or the breast in females, is spared by an SPB.

6. The long thoracic and thoracodorsal nerve may be anesthetized by an SPB, but their role in afferent nociception after major breast or thoracic surgery is still not known.

References


CHAPTER 11

Sonoanatomy Relevant for Ultrasound-Guided Thoracic Paravertebral Block

**Introduction**

Thoracic paravertebral block (TPVB) is the technique of injecting local anesthetic alongside the thoracic vertebral body close to where the spinal nerves emerge from the intervertebral foramen. This produces unilateral (ipsilateral), segmental, somatic, and sympathetic nerve blockade in multiple contiguous thoracic dermatomes,\(^1,2\) which is effective for managing acute and chronic pain of unilateral origin from the thorax and abdomen.\(^2\) TPVB can also be used for surgical anesthesia in patients undergoing inguinal herniorrhaphy\(^3\) and breast surgery\(^4-6\) with improved postoperative outcomes.\(^2,5\) TPVB is traditionally performed using surface anatomical landmarks.\(^2\) Recently there has been an increase in interest in the use of ultrasound for peripheral nerve blocks,\(^7-9\) including TPVB.\(^10-18\) However, published data on ultrasound-guided (USG) TPVB are limited.\(^10-20\) This chapter describes the sonoanatomy relevant for USG TPVB.

**Gross Anatomy**

The thoracic paravertebral space (TPVS) is a wedge-shaped space\(^2,21\) that lies on either side of the vertebral column (Fig. 11-1). It is wider on the left than on the right.\(^22\) The parietal pleura forms the anterolateral boundary. The base is formed by the vertebral body, intervertebral disc, and the intervertebral foramen with its contents (Fig. 11-1).\(^21,23\) The superior costotransverse ligament (SCTL), which extends from the lower border of the transverse process above to the upper border of the transverse process below (Figs. 11-2 and 11-4), forms the posterior wall of the TPVS. Also interposed between two transverse processes is the intertransverse ligament (Figs. 11-2 and 11-4). The SCTL is continuous laterally with the internal intercostal membrane, which is the medial extension of the internal intercostal muscle, medial to the angle of the rib (Fig. 11-4). The apex of the TPVS is continuous with the posterior intercostal space lateral to the tips of the transverse processes (Fig. 11-4).\(^21,23\)
FIGURE 11-1 Transverse anatomy of the thoracic paravertebral region.

FIGURE 11-2 Sagittal anatomy of the thoracic paravertebral region.
FIGURE 11-3 Paravertebral ligaments relevant for thoracic paravertebral block.

FIGURE 11-4 Anatomy of the thoracic paravertebral region showing the various paravertebral ligaments and their anatomical relationship to the thoracic paravertebral space.

Interposed between the parietal pleura anteriorly and the superior costotransverse ligament posteriorly is a fibroelastic structure, the “endothoracic fascia” (Figs. 11-1 and 11-2), which is the deep fascia of the thorax and lines the internal aspect of the thoracic cage.
(Figs. 11-5 and 11-6). The presence of the endothoracic fascia in the TPVS was until recently ignored in the paravertebral literature. We have drawn attention to the presence of the endothoracic fascia in the TPVS and proposed that it may play a role in explaining the variable expressions of a TPVB. In the paravertebral location, the endothoracic fascia is loosely applied to the ribs (Fig. 11-2) and fuses medially with the periosteum at the midpoint of the vertebral body (Fig. 11-1). There is an intervening layer of loose areolar connective tissue, “the subserous fascia,” between the parietal pleura and the endothoracic fascia (Figs. 11-1 and 11-2). The endothoracic fascia therefore divides the TPVS into two potential fascial compartments, the anterior “extrapleural paravertebral compartment,” and the posterior “subendothoracic paravertebral compartment” (Figs. 11-1 and 11-2). The TPVS contains fatty tissue within which lie the intercostal (spinal) nerve, the dorsal ramus, intercostal vessels, rami communicantes, and anteriorly the sympathetic chain (Figs. 11-1 and 11-5). The spinal nerves in the TPVS are segmented into small bundles lying freely among the fat and devoid of a fascial sheath, which make them susceptible to local anesthetic block. The intercostal nerve and vessels are located behind the endothoracic fascia and the sympathetic trunk is located anterior to it in the TPVS (Figs. 11-1 and 11-5).
paravertebral space. Note the fascial compartments and the location of the neurovascular structures in relation to the endo thoracic fascia.

**FIGURE 11-6** Paravertebral sagittal section of the thorax showing how the endo thoracic fascia lines the internal aspect of the thoracic cage.

**Communications of the Thoracic Paravertebral Space**

The TPVS is continuous with the epidural space medially via the intervertebral foramen,23,34–36 the intercostal space laterally,26,28,31,34,35,37,38 and the contralateral TPVS via the epidural23 and prevertebral space.2,26,27,29 The cranial extension of the TPVS is still not defined, but we have observed direct paravertebral spread of radio-opaque contrast medium from the thoracic to the cervical region (unpublished data) indicating that there is a direct anatomical continuity between the thoracic and cervical paravertebral regions. Ipsilateral Horner syndrome after thoracic paravertebral injections has also been reported.29,36,39,40 The anatomical pathway for cranial spread of an injectate from the thoracic to the cervical paravertebral space is still not clear.

The caudal boundary of the TPVS is formed by the origin of the psoas major muscle,41 and inferior (lumbar) spread through the TPVS is thought to be unlikely.41 Ipsilateral lumbar spinal nerves are also occasionally involved after a lower thoracic paravertebral injection1,42 Saito and colleagues have demonstrated ipsilateral thoracolumbar spread of colored dye in cadavers.43 We have also reported ipsilateral thoracolumbar anesthesia and radiological spread of contrast below the diaphragm.44 These observations challenge the concept of lumbar nerve root sparing following TPVB.41 The exact mechanism for the ipsilateral thoracolumbar spread of local anesthetic or contrast medium is not clear, but we have proposed that it occurs via the subendothoracic fascial compartment44 to the retroperitoneal space anterior to the psoas major and quadratus lumborum muscle where the ilioinguinal and iliohypogastric nerves are located (Fig. 4-50).44
Computed Tomography Anatomy of the Thoracic Paravertebral Region

Figs. 11-7 to 11-10.

**FIGURE 11-7** Transverse CT of the thoracic spine showing the anatomical relationship of the transverse process, rib, and the costotransverse junction to the thoracic paravertebral space. VB, vertebral body.

**FIGURE 11-8** Transverse CT of the thoracic spine showing the anatomical relationship of the vertebral body (VB) and transverse process to the thoracic paravertebral space (TPVS). IVF, intervertebral foramen.
FIGURE 11-9 Transverse CT of the thoracic spine showing the anatomical relationship of the inferior articular process of the vertebra to the intervertebral foramen (IVF) and the thoracic paravertebral space (TPVS). VB, vertebral body; SCTL, superior costotransverse ligament.
FIGURE 11-10  ■ Sagittal CT of the thorax through the thoracic paravertebral space (TPVS). Note the anatomical relationship of the neck of the rib to the transverse process (TP) and the costotransverse junction (CTJ). SCTL, superior costotransverse ligament.

**Magnetic Resonance Imaging Anatomy of the Thoracic Paravertebral Region**

Figs. 11-11 to 11-14.
FIGURE 11-11 Transverse T2-weighted MRI of the thoracic spine showing the anatomical relationship of the transverse process, rib, and the costotransverse junction to the thoracic paravertebral space. VB, vertebral body; TP, transverse process; PSM, paraspinal muscle.

FIGURE 11-12 Transverse T2-weighted MRI of the thoracic spine showing the anatomical relationship of the vertebral body (VB) and transverse process (TP) to the thoracic paravertebral space (TPVS). PSM, paraspinal muscle; SCTL, superior costotransverse ligament.
FIGURE 11-13 Transverse T2-weighted MRI of the thoracic spine showing the anatomical relationship of the inferior articular process of the vertebra to the intervertebral foramen (IVF) and the thoracic paravertebral space (TPVS). Note the spinal nerve root as it exits the IVF. SP, spinous process; VB, vertebral body; PSM, paraspinal muscles; SCTL, superior costotransverse ligament.
FIGURE 11-14  Sagittal T2-weighted MRI of the thorax through the thoracic paravertebral space (TPVS). Note the intercostal neurovascular bundle in the TPVS. TP, transverse process; PSM, paraspinal muscle; SCTL, superior costotransverse ligament.

**Sonoanatomy of the Thoracic Paravertebral Region**

**Ultrasound Scan Technique**

1. **Position:**
   a. **Patient:** An ultrasound scan of the thoracic paravertebral region can be performed in the transverse (axial scan) or longitudinal (sagittal scan) axis with the patient in the sitting (Fig. 11-15), lateral decubitus (Fig. 11-16), or prone position. The prone position is useful in patients presenting for a chronic pain procedure when fluoroscopy can also be used in conjunction with ultrasound imaging. Currently there are no data demonstrating an optimal axis or position for the ultrasound scan or the paravertebral injection. It is often a matter of individual preference and experience.
FIGURE 11-15 Transverse ultrasound scan of the thoracic paravertebral region with the patient in the sitting position. Note the position of the ultrasound transducer (linear) relative to the spine.

FIGURE 11-16 Transverse ultrasound scan of the thoracic paravertebral region with the patient in the right lateral position. Note the position of the ultrasound (curved array) transducer relative to the spine.

b. **Operator and ultrasound machine:** The operator sits or stands behind the patient, and the ultrasound machine is placed directly in front on the contralateral side (Fig. 11-17) for an USG TPVB.
2. **Transducer selection:** The transducer used for the ultrasound scan depends on the body habitus of the patient. High-frequency ultrasound provides better resolution than low-frequency ultrasound, but its penetration is poor. Moreover if one has to scan at a depth using high-frequency ultrasound, then the field of vision is also significantly narrow. Under such circumstances it may be preferable to use a low-frequency curved array transducer (5–2 MHz) with a divergent beam and a wider field of vision. Published data suggest that a high-frequency linear transducer (13–6 MHz) is frequently used for scanning the thoracic paravertebral region.\(^{10,11,14,18}\) This may be because the transverse process, costotransverse ligament, and the pleura in the midthoracic region are located at a relatively shallow depth and lend themselves to ideal conditions for imaging with a high-frequency linear array transducer. However, ultrasound imaging of the TPVS is not similar at all thoracic levels, and high-frequency transducers are generally not suitable in the upper thoracic region. Recently we have used a low-frequency curved array transducer (5–2 MHz) to perform a transverse scan of the thoracic paravertebral region (at all levels) with great success (Fig. 11-17, see details later).

3. **Sonoanatomy:**
   a. **Transverse sonoanatomy of the thoracic paravertebral region:**
      A transverse scan of the thoracic paravertebral region can be performed using a linear (high-frequency) or curved (low-frequency) array transducer. In slim individuals a high-frequency linear array transducer will suffice, but in those with a larger body habitus, a curved array transducer is preferable. The high-frequency linear array transducer is positioned lateral to the thoracic spinous process at the target level (Figs. 11-15 and 11-18). On a transverse sonogram the paraspinal muscles are clearly delineated and lie superficial to the transverse process (Figs. 11-19 to 11-21). The transverse process is seen as a hyperechoic structure, anterior to which there is a dark acoustic shadow that completely obscures the TPVS (Figs. 11-19 and 11-20). Lateral
to the transverse process, the hyperechoic pleura that moves with respiration and exhibits the typical “lung sliding sign,”\(^4\) which is the sonographic appearance of the pleural surfaces moving relative to each other within the thorax. Comet tail artifacts, which are reverberation artifacts, may also be seen deep to the pleura and within the lung tissue, and are often synchronous with respiration.\(^4\) A hypoechoic space is also seen between the parietal pleura and the internal intercostal membrane (Figs. 11-19 to 11-21), which is the medial extension of the internal intercostal muscle and is continuous medially with the superior costotransverse ligament (SCTL, Fig. 11-4). This hypoechoic space represents the medial limit of the posterior intercostal space or the apex of the TPVS, and the two communicate with each other (Figs. 11-19 to 11-21). Therefore, local anesthetic injected medially into the TPVS can often be seen to spread laterally to distend this space; vice versa, local anesthetic injected laterally into the posterior intercostal space can also spread medially to the paravertebral space and is the basis of the intercostal approach for USG TPVB\(^10,18\) where the needle is inserted in the plane of the ultrasound beam from a lateral-to-medial direction. From the scan position described earlier (ie, over the transverse process), if one now slides the transducer slightly cranially or caudally, it is possible to perform a transverse scan of the paravertebral region with the ultrasound beam being insonated between the two transverse processes (intertransverse space) and over the inferior articular process medially (Fig. 11-22). The ultrasound signal is now not impeded by the transverse process or the costotransverse junction, and parts of the parietal pleura and the “true” TPVS can be faintly visualized (Fig. 11-23). However, one must note that the inferior vertebral notch and the intervertebral foramen are located immediately anterior to the inferior articular process (Figs. 11-22 and 11-23). The SCTL, which forms the posterior border of the TPVS, is also visible and it blends laterally with the internal intercostal membrane, which forms the posterior border of the posterior intercostal space (Fig. 11-23). The communication between the TPVS and the posterior intercostal space is also clearly visualized (Figs. 11-19 and 11-23).
**FIGURE 11-18** Figure illustrating the orientation of the ultrasound transducer and how the ultrasound beam is insonated during a transverse scan of the thoracic paravertebral region with a linear transducer. The TP (transverse process) usually casts an acoustic shadow (represented in black), which obscures the ultrasound visibility of the thoracic paravertebral space.

![Ultrasound image showing the orientation of the ultrasound transducer and the thoracic paravertebral region.](image)

**FIGURE 11-19** Transverse sonogram of the right thoracic paravertebral region using a high-frequency linear transducer with the ultrasound beam being insonated over the transverse process. Note how the acoustic shadow of the transverse process (TP) obscures the thoracic paravertebral space (TPVS). The hypoechoic space posterior to the parietal pleura and anterolateral to the TP is the apex of the TPVS, or the medial limit of the posterior intercostal space.

![Ultrasound image showing the transverse sonogram of the thoracic paravertebral region.](image)
**FIGURE 11-20** Transverse sonogram of the left thoracic paravertebral region using a high-frequency linear transducer with the ultrasound beam being insonated over the transverse process. Note how the acoustic shadow of the transverse process (TP) obscures the TPVS. The hypoechoic space between the parietal pleura and the internal intercostal membrane laterally represents the apex of the TPVS, or the medial limit of the posterior intercostal space.

**FIGURE 11-21** A multiplanar 3-D view of the thoracic paravertebral region with the reference marker placed immediately lateral to the transverse process and over the superior costotransverse ligament (SCTL). Note how the three slice planes (red – transverse, green – sagittal, and blue – coronal) are obtained. PSM, paraspinal muscles; TPVS, thoracic paravertebral space; TP, transverse process.
FIGURE 11-22 Figure illustrating the osseous structures that are insonated during a transverse ultrasound scan of the thoracic paravertebral region through the thoracic intertransverse space and at the level of the inferior articular process. Note the relationship of the inferior articular process to the inferior vertebral notch and the intervertebral foramen. VB, vertebral body.

FIGURE 11-23 Transverse sonogram of the left thoracic paravertebral region using a high-frequency linear transducer. The ultrasound beam is being insonated through the intertransverse space and at the level of the articular (inferior) process. Note the acoustic shadow of the transverse process is no longer visible and parts of the thoracic paravertebral space (TPVS) and the anteromedial reflection of the pleura are now partly visible. The superior costotransverse ligament (SCTL), which forms the posterior border of the TPVS, is
also visible posteriorly, and it blends laterally with the internal intercostal membrane, which forms the posterior border of the posterior intercostal space. The communication between the TPVS and the posterior intercostal space is also clearly delineated. PSM, paraspinal muscle.

**FIGURE 11-24** The thoracic spine in the midthoracic region and the various transducer positions for a transverse scan of the thoracic paravertebral region using a low-frequency curved array transducer. Position 1 – midline over the spinous process, position 2 – at the level of the transverse process and rib, position 3 – at the level of the transverse process, and position 4 – at the level of the articular process.
FIGURE 11-25 ■ Cross-sectional cadaver anatomic section of the thoracic spine through the T4 vertebral body, transverse process, and the rib corresponding to the level at which the transverse scan is performed in the midline (position 1 in Fig. 11-24). Note the costotransverse junction (CTJ) on either side.

FIGURE 11-26 ■ Cross-sectional cadaver anatomic section of the thoracic spine through the T3 vertebral body and transverse process corresponding to the level at which the transverse scan is performed at the level of the transverse process (position 3 in Fig. 11-24). CTJ, costotransverse junction; TPVS, thoracic paravertebral space; Eo, esophagus.
FIGURE 11-27 Cross-sectional cadaver anatomic section of the thoracic spine through the T4 vertebral body and inferior articular process of the vertebra corresponding to the level at which the transverse scan is performed at the level of the articular process (position 4 in Fig. 11-24). Note the position of the intervertebral foramen (IVF) relative to the inferior articular process and the spinal nerve root as it exits the IVF. TPVS, thoracic paravertebral space.

A low-frequency (5–2 MHz) curved array transducer (authors’ choice) can also be used to perform a transverse scan of the thoracic paravertebral region and USG TPVB. To the best of our knowledge there are limited published data describing the use of a low-frequency ultrasound transducer for sonography during TPVB, and there are no published data describing the detailed sonoanatomy of the thoracic paravertebral region using a low-frequency curved array transducer. Our preliminary experience is that satisfactory ultrasound images of the paravertebral region are obtained using a low-frequency transducer. Also the wide field of vision produced by the divergent ultrasound beam is an added advantage when compared to the narrow rectangular field of view produced by a linear array transducer during USG TPVB. Furthermore the ability to image at a depth with a low-frequency curved array transducer is an advantage in the upper thoracic region because the thoracic paravertebral space is at a greater depth. Using a curved array transducer the transverse scan can be performed with the ultrasound beam being insonated at four different locations: (1) midline over the spinous process, (2) at the level of the rib and costotransverse articulation/junction, (3) at the level of the transverse process, and (4) at the level of the articular process. Corresponding cadaver anatomical sections are presented in Figs. 11-25 to 11-27 to demonstrate the anatomy visualized during the ultrasound scan.

Each of these four ultrasound scan windows produces a distinct sonogram reflecting the different osseous and musculoskeletal structures that are visualized in the sonograms. On a transverse sonogram in the midline (position 1, Fig. 11-24), the spinous process is visualized as a bright hyperechoic dot with a corresponding acoustic shadow anteriorly (Fig. 11-28). Due to the steep caudal angulation of the thoracic spinous processes in the midthoracic region, the spinous process that is visualized on the sonogram arises from the vertebra above rather than that from which
the transverse process, lamina, and the articular process arise (Fig. 11-29). Because the spinous process and transverse process cast a large acoustic shadow, visualization of the paravertebral anatomy is limited in this ultrasound scan window. Also the acoustic shadow of the spinous process, lamina, transverse process, and ribs produce a sonographic pattern that we refer to as the “flying swan sign” due to its close resemblance to a swan in flight (Fig. 11-30).

**FIGURE 11-28** Median transverse scan of the thoracic spine (midthoracic region) using a low-frequency curved array transducer with the ultrasound beam being insonated over the spinous process (position 1 in Fig. 11-24). Note the hyperechoic spinous process with its acoustic shadow in the midline. The hyperechoic lamina and the posteriorly directed transverse process (TP) are also seen laterally on either side of the midline. The acoustic shadow of the SP, TP, and the lamina produces a sonographic pattern that resembles a “flying swan” (details in text) and completely obscures the spinal canal and the paravertebral space.
FIGURE 11-29 Figure illustrating the structures that are insonated during a median transverse scan of the midthoracic spine. Note the posteriorly directed transverse processes. Also due to the acute caudal angulation of the thoracic spinous processes, the posterior elements of the vertebra (ie, the lamina and transverse process), which are insonated, are from the vertebra one level below.

FIGURE 11-30 Figure demonstrating the outlines of the bony elements that are insonated during a median transverse ultrasound scan of the thoracic spine and how the acoustic shadow produced resembles a swan in flight (“flying swan sign”).
With the ultrasound transducer positioned slightly laterally (position 2, Fig. 11-24), the hyperechoic outlines of the lamina, transverse process, and the rib with their corresponding acoustic shadows are clearly delineated (Fig. 11-31). However, unlike the transverse process of the lumbar vertebra, which are more or less at right angles to the vertebral body, the transverse processes in the thoracic spine are directed posteriorly (Fig. 11-32), and this posterior angulation can be clearly delineated in the transverse sonogram (Fig. 11-31). Once the transverse process, costotransverse articulation, and the rib are identified, one can gently slide or tilt the transducer caudally until the acoustic shadow of the rib is no longer visualized (position 3, Fig. 11-24), and the hyperechoic outline of the lamina and transverse process with their acoustic shadow are seen (Fig. 11-33). Lateral to the transverse process, the hyperechoic pleura and lung are visualized anteriorly, the thick hyperechoic SCTL posteriorly, and the hypoechoic apical part of the TPVS is interposed between the two (Fig. 11-33). If one now gently slides or tilts the ultrasound transducer slightly caudally (position 4, Fig. 11-24), the acoustic shadow of the transverse process disappears, and the hyperechoic articular process (inferior) with its acoustic shadow is seen medially (Fig. 11-34). As in the ultrasound scan at the level of the transverse process (Fig. 11-33), the SCTL, parietal pleura, lung, and the apical part of the paravertebral space are also clearly delineated. However, because the acoustic shadow of the transverse process is no longer present, outlines of the true TPVS can now be visualized (Fig. 11-34). Currently the majority of the published data describing the use of a transverse scan for TPVB have used the ultrasound scan window at the level of the transverse process (position 3, Fig. 11-24),\textsuperscript{17,18,20} and there are limited published data describing the use of the transverse ultrasound scan window at the level of the articular process for TPVB. Because there is less bony obstruction through the intertransverse space and at the level of the articular process (position 4, Fig. 11-24), it is our preferred route for imaging and needle insertion during an USG TPVB. However, ultrasound visibility of the paravertebral anatomy is more challenging in the upper thoracic region (Figs. 11-35 to 11-37). This may be related to the increased depth to the paravertebral space and anisotropy, from the pleura reflecting away from the paravertebral space, in the upper thoracic region (Fig. 11-36). Despite some of these limitations, it is possible to perform a transverse scan of the TPVS at all segments of the thoracic spine for TPVB (Figs. 11-35 to 11-44). We have successfully used this approach for both single-injection and multi-injection TPVB at all levels of the thoracic spine.
FIGURE 11-31  Paramedian transverse scan of the right thoracic paravertebral region using a low-frequency curved array transducer with the ultrasound beam being insonated over the transverse process (TP) and the rib (position 2 in Fig. 11-24). Note the posteriorly directed TP and how the acoustic shadow of the TP and rib completely obscures the underlying paravertebral anatomy.

FIGURE 11-32  Figure showing the difference in the size, shape, and orientation of the transverse process (TP) of a thoracic and lumbar vertebra. Note how the TP of a thoracic vertebra is directed posteriorly. SP, spinous process; AP, articular process; TP, transverse process; SC, spinal canal; VB, vertebral body.
FIGURE 11-33  Paramedian transverse scan of the right thoracic paravertebral region using a low-frequency curved array transducer with the ultrasound beam being insonated over the transverse process (TP, position 3 in Fig. 11-24). Note the hyperechoic TP and its acoustic shadow. The apex of the thoracic paravertebral space (TPVS), parietal pleura, and the superior costotransverse ligament are seen lateral to the TP. SCTL, superior costotransverse ligament.

FIGURE 11-34  Paramedian transverse scan of the right thoracic paravertebral region using a low-frequency curved array transducer with the ultrasound beam being insonated through the intertransverse space, that is, between two adjoining thoracic transverse processes (position 4 in Fig. 11-24). Note the hyperechoic inferior articular process and its acoustic shadow medially, which obscures the underlying intervertebral foramen (IVF). As with the paramedian transverse scan at position 3, the apex of the thoracic paravertebral space
(TPVS), parietal pleura, and the superior costotransverse ligament (SCTL) are visualized laterally, but the area of the acoustic shadow is smaller in this ultrasound scan window (compare with Fig. 11-33). PSM, paraspinal muscle.

**FIGURE 11-35** Paramedian transverse scan of the right upper thoracic paravertebral region (T1 level), using a low-frequency curved array transducer, with the ultrasound beam being insonated at the level of the transverse process (TP) and rib. CTJ, costotransverse junction.

**FIGURE 11-36** Paramedian transverse scan of the right upper thoracic paravertebral region (T1 level) using a low-frequency curved array transducer, with the ultrasound beam being insonated at the level of the articular process. Note the pleura is not clearly delineated in the transverse sonogram, and it is also located at a depth at this level (compare with that in
the midthoracic region, Fig. 11-41). TPVS, thoracic paravertebral space.

**FIGURE 11-37** Paramedian transverse scan of the right upper thoracic paravertebral region (T1 level) using a low-frequency curved array transducer with the ultrasound beam being insonated at the level of the transverse process (TP). Note the slight caudal orientation of the ultrasound transducer. SCTL, superior costotransverse ligament.

**FIGURE 11-38** Paramedian transverse scan of the right upper thoracic paravertebral region (T1 level) using a low-frequency curved array transducer with the ultrasound beam being insonated at the level of the articular process. Once again, note the slight caudal orientation of the ultrasound transducer. SCTL, superior costotransverse ligament; TPVS, thoracic paravertebral space.
**FIGURE 11-39** Paramedian transverse scan of the right midthoracic paravertebral region using a low-frequency curved array transducer, with the ultrasound beam being insonated at the level of the transverse process (TP) and rib. SP, spinous process; CTJ, costotransverse junction.

**FIGURE 11-40** Paramedian transverse scan of the right midthoracic paravertebral region using a low-frequency curved array transducer, with the ultrasound beam being insonated at the level of the transverse process (TP). SCTL, superior costotransverse ligament; TPVS, thoracic paravertebral space.
**FIGURE 11-41** Paramedian transverse scan of the right midthoracic paravertebral region using a low-frequency curved array transducer with the ultrasound beam being insonated at the level of the articular process and rib. IVF, intervertebral foramen; TPVS, thoracic paravertebral space; SCTL, superior costotransverse ligament.

**FIGURE 11-42** Paramedian transverse scan of the right lower thoracic paravertebral region using a low-frequency curved array transducer with the ultrasound beam being insonated at the level of the transverse process (TP) and rib. CTJ, costotransverse junction.
FIGURE 11-43  Paramedian transverse scan of the right lower thoracic paravertebral region using a low-frequency curved array transducer with the ultrasound beam being insonated at the level of the transverse process (TP). TPVS, thoracic paravertebral space.

FIGURE 11-44  Paramedian transverse scan of the right lower thoracic paravertebral region using a low-frequency curved array transducer with the ultrasound beam being insonated at the level of the articular process. IVF, intervertebral foramen; SCTL, superior costotransverse ligament; TPVS, thoracic paravertebral space.

b. Sagittal sonoanatomy of the thoracic paravertebral region:
Published data on sagittal sonography of the thoracic paravertebral region in the clinical setting are limited and have been described with the use of a high-frequency linear array transducer. During a sagittal scan of the thoracic paravertebral region,
the ultrasound transducer is positioned 2 to 3 cm lateral to the midline (paramedian) with its orientation marker directed cranially (Figs. 11-45 to 11-47). On a sagittal sonogram the transverse processes are seen as hyperechoic and rounded structures deep to the paraspinal muscles, and they cast an acoustic shadow anteriorly (Fig. 11-48). In between the acoustic shadows of two adjacent transverse processes, an acoustic window is produced by reflections from the SCTL and intertransverse ligaments, the paravertebral space and its contents, the parietal pleura, and lung tissue (in a posterior-to-anterior direction) (Fig. 11-48).

**FIGURE 11-45** Figure demonstrating the position of the patient (lateral in this image) and how the ultrasound transducer is oriented during a paramedian sagittal scan of the thoracic paravertebral region.

**FIGURE 11-46** Figure showing how the ultrasound beam is insonated during a
paramedian sagittal scan of the thoracic paravertebral region.

**FIGURE 11-47** Figure illustrating the various anatomical structures that are insonated during a paramedian sagittal ultrasound scan of the thoracic paravertebral region.

**FIGURE 11-48** Paramedian sagittal sonogram of the thoracic paravertebral region. Note that although the superior costotransverse ligament, pleura, and the paravertebral space are visible, they are not clearly delineated (compare with Fig. 11-52 from the same patient). TP, transverse process.

Ultrasound visibility of the paravertebral structures is relatively poor in a true sagittal scan (Figs. 11-49 and 11-50), and this is true with both high-frequency (Fig. 11-49) and low-frequency (Fig. 11-50) transducers. This may be due to the loss of spatial resolution at the depth at which the paravertebral structures are located. Also anisotropy from the ultrasound beam not being at right angles to the pleura due to its
anteromedial reflection close to the vertebral bodies (Fig. 11-46) may play a part. Ultrasound visibility of the paravertebral structures can be improved by gently tilting the ultrasound transducer laterally (ie, outward) during the sagittal scan (paramedian sagittal oblique axis, Figs. 11-51 and 11-52). This maneuver improves imaging by reducing the distance from the skin to pleura (reduced attenuation), and the ultrasound beam is also more at right angles to the pleura (reduced anisotropy (Fig. 11-51). It is difficult to define an optimal angle of lateral tilt for the paramedian sagittal oblique scan, but in clinical practice we recommend that one should gently tilt the transducer outward (laterally) until the parietal pleura is clearly visualized (Fig. 11-52). A pitfall of the lateral tilt maneuver is that one may see the same result if the ultrasound transducer is inadvertently manipulated or tilted too far laterally so that it is now insonating the rib and the posterior intercostal space (Figs. 11-53 and 11-54) instead of the transverse process and the apical part of the paravertebral space. The clinical implication is that one may unknowingly perform a posterior intercostal injection instead of a paravertebral injection, and depending on the approach used the potential for pleural puncture may be greater with the intercostal injection. Also segmental spread of anesthesia is limited with an intercostal injection. Therefore, it is important to differentiate the transverse process (Fig. 11-55) from a rib (Fig. 11-56) in the sagittal sonogram of the thoracic paravertebral region (Fig. 11-57).

**FIGURE 11-49** Paramedian sagittal scan of the right midthoracic paravertebral region using a high-frequency linear transducer. Note the paravertebral structures, including the parietal pleura and the paravertebral space, are not clearly delineated in this image. TP, transverse process; SCTL, superior costotransverse ligament; TPVS, thoracic paravertebral space.
FIGURE 11-50 Paramedian sagittal scan of the right midthoracic paravertebral region using a low-frequency curvilinear transducer. Note the paravertebral structures, including the parietal pleura and the paravertebral space, are not clearly delineated in the sagittal sonogram. TP, transverse process; SCTL, superior costotransverse ligament; TPVS, thoracic paravertebral space.

FIGURE 11-51 Figure illustrating how the ultrasound beam is insonated during a paramedian sagittal oblique scan of the thoracic paravertebral region.
FIGURE 11-52  Paramedian sagittal oblique sonogram of the thoracic paravertebral region. Note the pleura, superior costotransverse ligament, and the paravertebral space are now clearly delineated (same patient as in Fig. 11-48). TP, transverse process.

FIGURE 11-53  Paramedian sagittal oblique scan of the right midthoracic paravertebral region, using a high-frequency linear transducer, whereby the ribs instead of the transverse process are being insonated. Note the intercostal muscles (not the superior costotransverse ligament), pleura, and the posterior intercostal space are clearly delineated in this sonogram.
FIGURE 11-54 Paramedian sagittal oblique scan of the right midthoracic paravertebral region using a low-frequency curved array transducer whereby the ribs instead of the transverse processes are being insonated. Note the pleura is clearly delineated in this sonogram.

FIGURE 11-55 A multiplanar 3-D view of the thoracic paravertebral region with the reference marker, or “marker dot,” placed over the transverse process (TP). Note how the three slice planes (red – transverse, green – sagittal, and blue – coronal) have been obtained and how the superior costotransverse ligament (SCTL) is continuous with the internal intercostal membrane (IICM) laterally in the coronal plane. TPVS, thoracic paravertebral space; CTJ, costotransverse junction.
FIGURE 11-56  A multiplanar 3-D view of the thoracic paravertebral region in color (sepia tone) with the reference marker, or “marker dot,” placed over the apex of the thoracic paravertebral space (TPVS). Note the hyperechoic pleura in the coronal plane. SCTL, superior costotransverse ligament; TPVS, thoracic paravertebral space; TP, transverse process.

FIGURE 11-57  A sequence of sagittal sonograms of the thoracic paravertebral region (from the same subject) showing the transition of the anatomy from the level of the lamina to the ribs. Note the difference in the sonographic appearance of the lamina, transverse process (TP), and the ribs. Also note the relative depths at which each structure is located. The articulation of the rib with the transverse process at the CTJ (costotransverse junction) is
clearly delineated in Fig. 11-57D. Also note that the pleura is not clearly visualized at the level of the TP, but it is at the level of the ribs. ES, epidural space; ILS, interlaminar space; LF, ligamentum flavum; SCTL, superior costotransverse ligament; TPVS, thoracic paravertebral space; ICM, intercostal muscles; ICS, intercostal space.

We are not aware of any published data validating the sonoanatomy of the thoracic paravertebral region, but it is our experience that there is good correlation between structures that are visualized in a thoracic paravertebral sonogram and that in corresponding anatomical sections, CT, and MRI images of the thoracic paravertebral region (Figs. 11-58 to Fig. 11-60). However, irrespective of the plane of ultrasound imaging, we still have not been able to delineate the intercostal nerve or its branches with currently available ultrasound technology. The intercostal blood vessels are more readily visualized close to the inferior border of the transverse process using Color or Power Doppler ultrasound (Figs. 11-61 and 11-62).

**FIGURE 11-58** Correlative transverse cadaver anatomic (Fig. 11-58A), CT (Fig. 11-58B), MRI (T2-weighted, Fig. 11-58C), and ultrasound (Fig. 11-58D) images of the thoracic paravertebral region from the level of the thoracic vertebral body, transverse process, and the rib corresponding to the level at which the transverse scan was performed in the midline (position 1, Fig. 11-24). PSM, paraspinal muscle; VB, vertebral body; TP, transverse process.
FIGURE 11-59 Correlative transverse cadaver anatomic (Fig. 11-59A), CT (Fig. 11-59B), MRI (T2-weighted, Fig. 11-59C), and ultrasound (Fig. 11-59D) images of the thoracic paravertebral region from the level of the vertebral body and transverse process corresponding to the level at which the transverse scan was performed (position 3, Fig. 11-24). E0, esophagus; CTJ, costotransverse junction; TPVS, thoracic paravertebral space; VB, vertebral body; PSM, paraspinal muscle; IVF, intervertebral foramen; TP, transverse process; SCTL, superior costotransverse ligament.
FIGURE 11-60 Correlative transverse cadaver anatomic (Fig. 11-60A), CT (Fig. 11-60B), MRI (T2-weighted, Fig. 11-60C), and ultrasound (Fig. 11-60D) images of the thoracic paravertebral region from the level of the vertebral body and inferior articular process corresponding to the level at which the transverse scan was performed (position 4, Fig. 11-24). TPVS, thoracic paravertebral space; IVF, intervertebral foramen; SCTL, superior costotransverse ligament; VB, vertebral body; PSM, paraspinal muscle; SP, spinous process.

FIGURE 11-61 Paramedian sagittal oblique sonogram of the thoracic paravertebral region showing the Color Doppler signal from the intercostal artery at the apex of the paravertebral space. TP, transverse process.
FIGURE 11-62 Paramedian transverse sonogram of the thoracic paravertebral region at the level of the inferior articular process showing the Power Doppler signal from the intercostal artery in the paravertebral space. PSM, paraspinal muscle; SCTL, superior costotransverse ligament; TPVS, thoracic paravertebral space.

Three-Dimensional Sonography of the Thoracic Paravertebral Region

As described earlier, it is possible to obtain high-resolution 2-D ultrasound images of the paravertebral anatomy in the transverse, sagittal, and coronal axes. However, this requires the operator to rotate the ultrasound transducer through 90 degrees. Three-dimensional ultrasound imaging technology is currently available and allows one to simultaneously visualize the anatomy of a volume or area of interest in the transverse, sagittal, and coronal planes without having to move or rotate the transducer. Using traditional 2-D ultrasound it is not possible to obtain ultrasound images of the paravertebral anatomy in the coronal axis. The coronal view presents the anatomy as though one were looking down on to the surface being imaged, analogous to a “bird’s-eye view” and has also been referred to as the “architectural” or “plan view.” The potential utility of the coronal view during USG regional anesthesia is not clear, but has been used to visualize the spread of a local anesthetic on either side of a nerve during peripheral nerve blockade. We have recently demonstrated that it is feasible to perform volumetric 3-D ultrasound imaging of the thoracic paravertebral region and study the acquired data set in various 3-D formats.
FIGURE 11-63 3-D ultrasound scan. (A). The Philips iU22 Ultrasound System, (B) the high-frequency 3-D and 4-D integrated mechanical volume linear array transducer (VL13, 13–5 MHz) used for the scan, and (C) the position of the volunteer and the orientation of the transducer during the data acquisition.

In a multiplanar view of the thoracic paravertebral volume (anatomy) it is possible to simultaneously visualize the transverse (x-axis), sagittal (y-axis), and coronal (z-axis) images of the paravertebral anatomy (Figs. 11-21, 11-55, and 11-56). Moreover, when the “reference marker,” a point where all the three orthogonal planes intersect, is moved in any of the 2-D images of the multiplanar display, it automatically updates its position in the other 2-D images. This allows one to navigate through or electronically dissect through the paravertebral volume, which helps in better understanding the 3-D anatomy of the paravertebral region. Also, by using the reference marker it is possible to visualize a specific point or anatomical structure in all three planes simultaneously. This feature facilitates validation of the sonographic appearance of a given anatomical structure in the paravertebral region (Figs. 11-55 and 11-56) and to exclude artifacts. We have also demonstrated that the anatomical information obtained in a 3-D ultrasound image is more detailed than that seen in a 2-D ultrasound image. Structures such as the costotransverse junction (Fig. 11-55) and all six surfaces (faces) (Fig. 11-64) or a given surface (Fig. 11-65) of the paravertebral volume, which are otherwise not visualized using 2-D ultrasound imaging, are clearly delineated using 3-D ultrasound. One is also able to display and study the acquired data set like a computerized tomogram (Figs. 11-66 and 11-67). Overall, volumetric 3-D ultrasound imaging allows the anesthesiologists to develop a better spatial awareness of the paravertebral anatomy.
FIGURE 11-64  Rendered 3-D volumes of the thoracic paravertebral region showing the cranial, caudal, lateral, medial, and posterior surfaces of the acquired paravertebral volume.

FIGURE 11-65  A rendered 3-D volume of the thoracic paravertebral region. The acquired paravertebral volume has been rendered such that the sagittal anatomy is being visualized from the lateral (intercostal space) side. Note the apical part of the TPVS (thoracic paravertebral space) is clearly delineated between the SCTL (superior costotransverse ligament) and the parietal pleura. TP, transverse process.
FIGURE 11-66 A transverse iSlice display of the thoracic paravertebral region in color (blue tone). In this figure, 16 contiguous transverse ultrasound images of the acquired paravertebral volume that are 1 mm apart are displayed. CTJ, costotransverse junction; SCTL, superior costotransverse ligament; TPVS, thoracic paravertebral space; TP, transverse process.
FIGURE 11-67 A sagittal iSlice display of the thoracic paravertebral region in color (sepia tone). In this figure, 16 contiguous sagittal ultrasound images of the acquired paravertebral volume that are 1 mm apart are displayed. CTJ, costotransverse junction; SCTL, superior costotransverse ligament; TPVS, thoracic paravertebral space; TP, transverse process.

Reference

CHAPTER 12
Sonoanatomy Relevant for Ultrasound-Guided Lumbar Plexus Block

Introduction

Lumbar plexus block (LPB),\textsuperscript{1,2} also referred to as a psoas compartment block (PCB),\textsuperscript{3,4} is frequently used on its own or in combination with a sciatic nerve block for anesthesia and/or analgesia during hip or lower extremity surgery.\textsuperscript{1,3,5,6} During an LPB the local anesthetic is injected into a fascial plane within the posterior aspect of the psoas muscle.\textsuperscript{7} This produces complete blockade of the major components of the ipsilateral lumbar plexus, namely the femoral nerve (FN), lateral femoral cutaneous nerve (LFC), and the obturator nerve (OBN).\textsuperscript{8} The term PCB was originally coined by Chayen and colleagues.\textsuperscript{4} They believed that branches of the lumbar plexus and parts of the sacral plexus were located close to each other in a “compartment,” between the psoas and quadratus lumborum muscle (an “intermuscular compartment”) at the level of the L4 vertebra, which could be identified using a “loss of resistance” technique.\textsuperscript{4} However, recent research has demonstrated that the lumbar plexus is located within the substance of the psoas muscle.\textsuperscript{7} PCB is also referred to as posterior lumbar plexus block,\textsuperscript{1} and several variations of this technique have been described in the literature.\textsuperscript{2,3} LPB is traditionally performed using peripheral nerve stimulation,\textsuperscript{8} but with the recent widespread use of ultrasound guidance for regional anesthesia ultrasound-guided (USG) LPB has also been described.\textsuperscript{9,10} A clear understanding of the sonoanatomy of the lumbar paravertebral region\textsuperscript{9—11} is a prerequisite to safely performing USG LPB.\textsuperscript{9,10}

Gross Anatomy

The lumbar plexus is formed by the union of the anterior primary rami of the L1, L2, and L3 spinal nerves and the greater part of the L4 nerve (Figs. 3-1 and 12-1). The L1 nerve root may also receive contribution from the T12 spinal nerve. In the majority of individuals the lumbar plexus is located in a fascial plane or compartment within the substance of the psoas muscle (Figs. 12-2 to 12-4).\textsuperscript{7,11} We will henceforth refer to this intramuscular fascial compartment as the psoas compartment. Anatomically the psoas compartment is located between the fleshy anterior two-thirds of the psoas muscle and the posterior one-third of the muscle (Figs. 12-3 and 12-4).\textsuperscript{7,11} Therefore, the lumbar plexus is sandwiched between two portions of the psoas muscle and closely related to the lumbar transverse processes (Figs. 12-2 to 12-8). The bulkier anterior (fleshy) part of the psoas muscle originates from the anterolateral surface of the lumbar vertebral bodies and their intervertebral disc, whereas the thinner posterior (accessory) portion of the muscle originates from the anterior aspect of the lumbar transverse
processes (Fig. 12-3).\textsuperscript{7} Also the anterior and posterior parts of the psoas muscle fuse to form the main muscle bulk, but close to the vertebral bodies these two parts are separated by a fascia\textsuperscript{7} or space within which the lumbar nerve roots, branches of the lumbar artery, and the ascending lumbar veins are located (Figs. 12-2 to 12-6).\textsuperscript{7,11} This wedge-shaped space close to the intervertebral foramen is the lumbar paravertebral space (LPVS) (Fig. 12-7).\textsuperscript{11}

\textbf{FIGURE 12-1} Anatomy of the lumbar plexus with its three major components: the lateral femoral cutaneous nerve, obturator nerve, and the femoral nerve. Note the anatomical relation of the lumbar plexus to the transverse processes.
FIGURE 12-2 Figure showing the anatomical relation of the lumbar plexus to the psoas muscle and how the nerves of the lumbar plexus (iliohypogastric, ilioinguinal, lateral femoral cutaneous, femoral, and obturator) emerge from the psoas muscle.

FIGURE 12-3 Location of the lumbar nerve root within the substance of the psoas muscle and their relation to the transverse process.
**FIGURE 12-4** Transverse anatomy of the lumbar paravertebral region at the L4 vertebral level. Note the origin and branching of the lumbar artery. Ao, aorta; IVC, inferior vena cava; RPS, retroperitoneal space; EOM, external oblique muscle; IOM, internal oblique muscle; TAM, transversus abdominis muscle; PM, psoas muscle; QLM, quadratus lumborum muscle; IVF, intervertebral foramen; DBLA, dorsal branch of lumbar artery; LPVS, lumbar paravertebral space; NR, nerve root; PC, psoas compartment; LPlx, lumbar plexus; VB, vertebral body; AP, articular process; ESM, erector spinae muscle.

**FIGURE 12-5** Cadaver dissection image showing the lumbar plexus nerves within the substance of the psoas muscle. The psoas muscle has been split longitudinally to expose the lumbar plexus nerves within the posterior aspect of the muscle.
FIGURE 12-6 Cross-sectional cadaver anatomic section through the L4 vertebral body and transverse process corresponding to the level at which the PMTOS-TP (paramedian transverse oblique scan at the level of the transverse process) was performed. ESM, erector spinae muscle; PM, psoas muscle; QLM, quadratus lumborum muscle; AP, articular process; LF, ligamentum flavum; ES, epidural space; VB, vertebral body; TP, transverse process.

FIGURE 12-7 Cross-sectional cadaver anatomical section from just inferior to the L4 transverse process and through the lower part of the L4 vertebral body corresponding to the level at which the PMTOS-ITS (paramedian transverse oblique scan through the space between two adjacent transverse processes) was performed. Note the intervertebral foramen.
(IVF) and the L4 spinal nerve root as it exits the IVF to enter the lumbar paravertebral space (LPVS). Also note the relation of the L3 nerve of the lumbar plexus to the L4 nerve root close to the L4 IVF. This is because the L3 lumbar nerve root after it exits the IVF takes a steep caudal course through the posterior part of the psoas muscle. PM, psoas muscle; QLM, quadratus lumborum muscle; IVF, intervertebral foramen; AP, articular process; LPVS, lumbar paravertebral space; ESM, erector spinae muscle; VB, vertebral body.

FIGURE 12-8  Sagittal cadaver anatomic section showing the relation of the lumbar plexus to the transverse process (TP) and the psoas muscle (PM). The reference marker of the Java application, seen in this figure as a green cross-hair, is over the L3 nerve of the lumbar plexus (same as in Fig. 12-7). The L3 nerve of the lumbar plexus is seen in a fat-filled “intramuscular compartment,” that is, the psoas compartment between the thick fleshy anterior and a thin posterior part of the psoas muscle between the L3 and L4 TP. ESM, erector spinae muscle.

The lumbar nerve root after it exits the intervertebral foramen enters the fat-filled LPVS (Fig. 12-7). However, the lumbar nerve root, instead of entering the psoas muscle at the same vertebral level, takes a steep caudal course and enters the substance of the psoas muscle at the vertebral level below (Fig. 12-9). This explains why the L3 nerve of the lumbar plexus lies opposite the L4 intervertebral foramen and the L4 nerve root (Fig. 12-7). Also as seen in the sagittal anatomic section (Fig. 12-8), the L3 nerve of the lumbar plexus is located in an intramuscular compartment (ie, the psoas compartment) between the thick fleshy anterior and a thin posterior part of the psoas muscle. Outlines of the psoas compartment with the lumbar plexus can also be delineated in the transverse anatomic section (Fig. 12-7). Once the plexus is formed it displays a triangular shape, narrow in its superior portion and wider in its lower portion (Fig. 12-1). The nerves that originate from the plexus also exhibit a fanned-out
distribution with the LFC being outermost, the OBN innermost, and the femoral nerve in between (Fig. 12-1). Being a fusiform muscle (ie, shaped like a spindle), the width of the psoas muscle is wider at its belly, close to the lower lumbar region, than at its origin and insertion. There are also gender- (male > female)\textsuperscript{-12} and race- (black > white)\textsuperscript{-13} related differences in the width and cross-sectional area of the psoas muscle. The position of the lateral femoral cutaneous nerve and femoral nerve within the psoas compartment is relatively consistent,\textsuperscript{7} but the position of the obturator can be variable and may even lie in a fold of the psoas muscle separate from that enclosing the other two nerves (Fig. 12-10).\textsuperscript{7} The depth from the skin to the lumbar plexus also varies with gender and body mass index (BMI). Such differences in anthropometric parameters may be relevant when performing an LPB.

**FIGURE 12-9** Coronal cadaver anatomic section showing how the lumbar nerve roots after they exit the intervertebral foramen take a steep caudal course and enter the substance of the psoas muscle (PM) more caudally. Also seen is the formation of the lumbar plexus within the substance of the psoas muscle (PM). The reference marker of the Java application, seen in this figure as a green cross-hair, is over the L3 nerve of the lumbar plexus (same as in Figs. 8-7 and 8-8). VB, vertebral body; ITS, intrathecal space; CE, cauda equina; NR, nerve root.
FIGURE 12-10 Figure showing the position of the (1) lateral femoral cutaneous nerve, (2) femoral nerve, and (3) obturator nerve in the psoas compartment. Note that whereas the position of 1 and 2 are fairly consistent, the position of 3 can vary and may even lie in a separate intramuscular fold (C) or compartment separate from the psoas compartment (D).

Computed Tomography Anatomy of the Lumbar Paravertebral Region

Figs. 12-11 and 12-12

FIGURE 12-11 Transverse CT of the abdomen at the level of the body and transverse process of the L4 vertebra corresponding to the level at which the PMTOS-TP (paramedian transverse oblique scan at the level of the transverse process) is performed. Note the position of the inferior vena cava and the aorta relative to the vertebral body. VB, vertebral body.
FIGURE 12-12 Transverse CT of the abdomen at the level of the body and articular process (inferior) of the L4 vertebra corresponding to the level at which the PMTOS-ITS (paramedian transverse oblique scan through the intertransverse space) is performed. VB, vertebral body; LPVS, lumbar paravertebral space.

Magnetic Resonance Imaging Anatomy of the Lumbar Paravertebral Region

Figs. 12-13 to 12-16

FIGURE 12-13 Transverse T1-weighted MRI at the level of the L4 vertebral body and the transverse process corresponding to the level at which the PMTOS-TP (paramedian transverse oblique scan at the level of the transverse process) is performed. The L3 nerve root of the lumbar plexus is seen as the hypointense nerve outlined by a layer of hyperintense fat in the posterior aspect of the psoas muscle close to the angle between the vertebral body and ...
the transverse process. PM, psoas major muscle; QLM, quadratus lumborum muscle; ESM, erector spinae muscle; IVC, inferior vena cava; NR, nerve root; ITS, intrathecal space; VB, vertebral body.

FIGURE 12-14 Transverse T1-weighted MRI image from just below the L4 transverse process and through the lower half of the body of L4 vertebra and the articular process (inferior) corresponding to the level at which the PMTOS-ITS (paramedian transverse oblique scan through the intertransverse space) is performed. Note the hypointense L4 nerve root as it exits the intervertebral foramen (IVF) and enters the hyperintense fat-filled lumbar paravertebral space (LPVS). Also seen in the posterior aspect of the psoas muscle is the L3 nerve of the lumbar plexus, which is surrounded by a layer of hyperintense fat, and in an intramuscular compartment (ie, the “psoas compartment”). PM, psoas major muscle; QLM, quadratus lumborum muscle; ESM, erector spinae muscle; VB, vertebral body; AP, articular process; LPVS, lumbar paravertebral space; ITS, intrathecal space; NR, nerve root; IVF, intervertebral foramen.
FIGURE 12-15 Sagittal T1-weighted MRI image of the lumbar paravertebral region at the L3-L4-L5 vertebral level showing the steep caudal course of the lumbar nerve roots. Note the hypointense lumbar plexus nerves are located in an intramuscular compartment in the posterior part of the psoas muscle (ie, the “psoas compartment”), which is filled with hyperintense fatty tissue. TP, transverse process; PM, psoas major muscle.
FIGURE 12-16 — Coronal T1-weighted MRI image at the L3-L4-L5 vertebral level showing the steep caudal course of the lumbar spinal nerves after they emerge from the intervertebral foramen (IVF). Note the hypointense lumbar nerve roots (NR), after they emerge from the L4 IVF, enter a hyperintense fat-filled space on the medial aspect of the psoas muscle (PM), that is, the lumbar paravertebral space (LPVS), comparable to that seen in Figs. 12-12 and 12-14. VB, vertebral body.

Lumbar Paravertebral Sonography

Ultrasound Scan Technique

1. **Position:**
   a. **Patient:** The authors prefer to position the patient in the lateral position with the side to be blocked uppermost (Fig. 12-17A). The hips and knees of the patient are also flexed to mimic the position normally adapted during an LPB. The ultrasound scan can also be performed with the patient in the prone position, but the disadvantage is impaired visualization of the quadriceps muscle contraction during an LPB if nerve stimulation is used.

   b. **Operator and ultrasound machine:** The operator sits or stands behind the patient, and the ultrasound machine is placed directly in front on the contralateral side.

2. **Transducer selection:** Because the lumbar plexus and psoas muscle are located at a depth in the abdomen and pelvis, it necessitates the use of a low-frequency ultrasound (5–2 MHz) and curved array transducer to image the lumbar paravertebral region. Low-frequency ultrasound provides good penetration but lacks spatial resolution at the depths (5–9 cm) at which the anatomy relevant for LPB is located. The latter often compromises the ability to locate the lumbar plexus within the psoas muscle. However, recent improvements in ultrasound technology, image processing capabilities of ultrasound
machines, the availability of compound imaging and tissue harmonic imaging (THI), and the use of new scan protocols have significantly improved our ability to image the lumbar paravertebral region. Today, we are not only able to accurately delineate the lumbar plexus, but also the adjoining paravertebral anatomy.\textsuperscript{9–11}

\textbf{FIGURE 12-17} Position of the volunteer (Fig. 12-17A) and the plane of ultrasound imaging during a sagittal and transverse scan of the lumbar paravertebral region. A picture of the ultrasound transducer and the plane of the ultrasound beam (green pane) has been superimposed onto the transverse cadaver anatomic sections to illustrate how the ultrasound beam was insonated during the sagittal (Fig. 12-17B), PMTOS-TP (paramedian transverse oblique scan at the level of the transverse process, Fig. 12-17C), and PMTOS-ITS (paramedian transverse oblique scan through the intertransverse space, Fig. 12-17D). A – midline, B – intercristal line, C – sagittal scan line, X – a point 4 cm from the midline along the intercristal line.

3. \textbf{Scan technique:} An ultrasound scan of the lumbar paravertebral region for USG LPB can be performed in the sagittal (Fig. 12-17B)\textsuperscript{9–14} or transverse (Figs. 12-15C and 12-15D)\textsuperscript{10,11,14} axis. The following anatomical landmarks are identified and marked on the skin of the nondependent side of the back using a skin marking pen: posterior superior iliac spine, iliac crest, lumbar spinous processes (midline, line A, Fig. 12-17A) and the intercristal line (line B, Fig. 12-17A). Thereafter a line (line C) parallel to the midline and which intersects the intercristal line (line B) at a point 4 cm lateral to the midline, corresponding to the point of needle insertion during a landmark-based LPB, is also marked (sagittal scan line) (Fig. 12-17A). The target vertebral level for the ultrasound scan (L3-L4-L5) is then identified as previously described.\textsuperscript{15–16} This involves visualizing the lumbosacral junction (L5–S1 gap) on a sagittal sonogram and then counting cranially to locate the lamina and transverse processes of the L3, L4, and L5 vertebrae. For a sagittal scan, the ultrasound transducer is positioned over the sagittal scan line (Fig. 12-18) with its orientation marker directed cranially. For a transverse scan the ultrasound transducer, with its orientation marker directed laterally, is positioned 4 cm
lateral to the midline along the intercristal line and just above the iliac crest (Fig. 12-19). The transducer is also directed slightly medially (Fig. 12-19) so as to produce a transverse oblique view of the lumbar paravertebral region.\textsuperscript{10,11} During the paramedian transverse oblique scan (PMTOS), the ultrasound beam can be insonated either at the level of the transverse process (PMTOS-TP, Fig. 12-17C) or through the intertransverse space (PMTOS-ITS, Fig. 12-17D).\textsuperscript{11} Alternatively a transverse scan can be performed by placing the ultrasound transducer more anteriorly in the flank and above the iliac crest (Figs. 12-15 to 12-20) as described by Sauter and colleagues with the “shamrock technique.”\textsuperscript{17}

**FIGURE 12-18** Position of the patient and the ultrasound transducer during a paramedian sagittal scan of the lumbar paravertebral region. Note the ultrasound transducer with its orientation marker directed cranially has been placed over the sagittal scan line (refer to Fig. 12-17A), which is a line 4 cm lateral and parallel to the midline (paramedian), at the level of the iliac crest.
FIGURE 12-19  Position of the patient and the ultrasound transducer during a paramedian transverse oblique scan of the lumbar paravertebral region. The ultrasound transducer has been placed lateral to the sagittal scan line and over the intercristal line with its orientation marker directed laterally (outward). Also note how the transducer is angled medially for the ultrasound scan.

FIGURE 12-20  The shamrock method of ultrasound imaging of the lumbar paravertebral region for lumbar plexus block. (A) Position of the patient and the ultrasound transducer. (B) The plane of ultrasound imaging during the shamrock method. A picture of the ultrasound transducer and the plane of the ultrasound beam (green pane) have been superimposed onto the transverse cadaver anatomic section of the lumbar region to illustrate how the ultrasound
beam is insonated during the scan.

4. Sonoanatomy:
   a. Sagittal sonoanatomy:
      On a sagittal sonogram the transverse processes of the lumbar vertebrae (L3-L4-L5) are identified by their hyperechoic reflection and their corresponding acoustic shadow anteriorly (Fig. 12-21). This produces a sonographic pattern that we refer to as the lumbar ultrasound trident or the “trident sign” because of its similarity to the trident (Latin for *tridens* or *tridentis*) that is often associated with Poseidon (the god of the sea in Greek mythology) and the Trishula of the Hindu god Shiva. However one must bear in mind that because the L5 transverse process is the shortest of the lumbar transverse processes, it may be more difficult to locate and may require some degree of medial orientation of the transducer until the ultrasound trident is visible. The psoas muscle is seen in the acoustic window of the lumbar ultrasound trident (Fig. 12-21) as multiple longitudinal hyperechoic striations against a hypoechoic background typical of muscle (Fig. 12-22). The lumbar plexus may also be visualized in the posterior aspect of the psoas muscle (Fig. 12-22). It appears hyperechoic (Fig. 12-22), is sonographically distinct from the muscle fibers, and is more posterior in location than the intramuscular tendons of the psoas muscle. The lumbar plexus nerves are also thicker than the muscle fibers (Fig. 12-22) and take an oblique course through the psoas muscle. A laterally positioned ultrasound transducer will produce a suboptimal view without the ultrasound trident, but may visualize the lower pole of the kidney, which lies anterior to the quadratus lumborum muscle (QLM), and can reach the L3 to L4 vertebral level in some individuals.

![Figure 12-22](image)

**FIGURE 12-22** Sagittal sonogram of the lumbar paravertebral region showing the lumbar plexus as a hyperechoic structure in the posterior aspect of the psoas muscle (PM) between the L4 and L5 transverse processes. Also note the hyperechoic intramuscular tendons within the substance of the psoas muscle. ESM, erector spinae muscle; IM, intramuscular.
FIGURE 12-21  Sagittal sonogram of the lumbar paravertebral region showing the acoustic shadows of the lumbar transverse processes (L3, L4, and L5), which produce a sonographic pattern called the “trident sign.” The psoas muscle (PM) is seen in the intervening acoustic window.

b. Transverse sonoanatomy – Paramedian transverse oblique scan:
In a typical PMTOS–TP, the erector spinae muscle, the transverse process, the psoas muscle, quadratus lumborum muscle, and the anterolateral surface of the vertebral body are visualized (Fig. 12-23). The psoas muscle appears hypoechoic, but areas of hyperechogenicity are interspersed within the central part of the muscle (Fig. 12-23 to 12-25). These dots or speckles represent the intramuscular tendon fibers of the psoas muscle, and they are more pronounced below the level of the iliac crest. The IVC (on the right side, Fig. 12-24) and the aorta (on the left side) are also identified anterior to the vertebral body and are useful landmarks to look out for while performing a transverse scan. The lower pole of the kidney, which can extend to the L3 vertebral level, is visualized as an oval structure and moves synchronously with respiration in the retroperitoneal space (Fig. 12-25). The acoustic shadow of the transverse process obscures the posterior aspect of the psoas muscle (Fig. 12-23). Therefore, the lumbar nerve root or lumbar plexus are rarely visualized through the PMTOS-TP scan window. However, the dura, epidural space, and the intrathecal space may be visualized during a PMTOS-TP (Fig. 12-23). We believe this is because the ultrasound signal, which is medially directed, enters the spinal canal through the interlaminar space (Fig. 12-17C). Being able to visualize the neuraxial structures during a lumbar paravertebral scan may be useful in documenting epidural spread after an LPB.
FIGURE 12-23 Paramedian transverse oblique scan of the right lumbar paravertebral region at the level of the transverse process (PMTOS-TP). Note how the acoustic shadow of the transverse process obscures the posterior part of the psoas muscle and the intervertebral foramen and how parts of the spinal canal and neuraxial structures (dura and intrathecal space) are seen through the interlaminar space. VB, vertebral body; IVC, inferior vena cava; PM, psoas muscle; QLM, quadratus lumborum muscle; ESM, erector spinae muscle.

FIGURE 12-24 Paramedian transverse oblique scan of the right lumbar paravertebral region through the space between two adjacent transverse processes (PMTOS-ITS). Note the intervertebral foramen (IVF), articular process (AP), and lumbar nerve root (LNR) after it has emerged from the IVF and the hypoechoic space surrounding the lumbar nerve root adjacent...
to the IVF (ie, the LPVS: lumbar paravertebral space). The lumbar plexus is also seen in a separate hypoechoic intramuscular compartment, which is the psoas compartment, in the posterior part of the psoas muscle (PM). VB, vertebral body; PM, psoas muscle; QLM, quadratus lumborum muscle; ESM, erector spinae muscle; RPS, retroperitoneal space; IVC, inferior vena cava.

**FIGURE 12-25** Paramedian transverse oblique scan of the right lumbar paravertebral region through the space between two adjacent transverse processes (PMTOS-ITS). The lumbar nerve root is seen emerging from the intervertebral foramen, and the lumbar plexus (hyperechoic) is located within a hypoechoic space (psoas compartment) in the posterior aspect of the psoas muscle. Also note the lower pole of the right kidney is seen anterior to the psoas muscle in this sonogram. ESM, erector spinae muscle; AP, articular process; VB, vertebral body; IVF, intervertebral foramen; IVC, inferior vena cava.

In the PMTOS-ITS\(^1\) apart from the erector spinae, psoas, and quadratus lumborum muscles, the intervertebral foramen, articular process, and the lumbar spinal nerve root are clearly delineated (Figs. 12-24 to 12-26).\(^1\) The LPVS is also seen as a hypoechoic space adjacent to the intervertebral foramen (Figs. 12-24 to 12-26), and the lumbar spinal nerve root can be seen exiting the foramen (Figs. 12-24 and 12-25).\(^1\) The latter does not enter the psoas muscle directly opposite the intervertebral foramen from which it emerges (Figs. 12-24 and 12-25), but takes a caudal course as seen in the CT (Fig. 12-12), MRI (Figs. 12-14 to 12-16), and cadaver anatomical section (Fig. 12-9). In some individuals an additional hyperechoic structure surrounded by a hypoechoic space (Figs. 12-24 to 12-26) is seen in the posterior aspect of the psoas muscle.\(^1\) Based on our observation in the anatomical sections (Fig. 12-7) and MRI images (Fig. 12-14) we believe this represents the lumbar plexus within the psoas compartment.\(^1\) Currently there are limited data validating the transverse sonoanatomy of the lumbar paravertebral region, but it is our experience that there is good correlation between structures that are visualized in a lumbar paravertebral sonogram and that in corresponding cadaver anatomical sections, CT, and MRI images of the lumbar
paravertebral region (Figs. 12-27 to 12-30). Because the lumbar plexus and the paravertebral anatomy are clearly delineated through the PMTOS-ITS ultrasound scan window, it is our preferred window for imaging during an ultrasound-guided LPB.

**FIGURE 12-26** Paramedian transverse oblique scan of the right lumbar paravertebral region through the space between two adjacent transverse processes (PMTOS-ITS) showing the lumbar plexus as a discrete hyperechoic structure inside a hypoechoic intramuscular space (psoas compartment) in the posteromedial aspect of the psoas muscle. ESM, erector spine muscle; QLM, quadratus lumborum muscle; PM, psoas muscle; AP, articular process; VB, vertebral body; IVC, inferior vena cava.
FIGURE 12-27 Correlative sagittal (A) cadaver anatomic, (B) CT, (C) MRI (T1-weighted), and (D) ultrasound images of the lumbar paravertebral region from the level of the L3, L4, and L5 lumbar transverse processes. ESM, erector spinae muscle; PM, psoas muscle; NR, nerve root; RPS, retroperitoneal space; TP, transverse process.
Correlative transverse (A) cadaver anatomic, (B) CT, (C) MRI (T1-weighted), and (D) ultrasound images of the lumbar paravertebral region from the level of the L4 vertebral body (VB) and transverse process (TP). ESM, erector spinae muscle; QLM, quadratus lumborum muscle; PM, psoas muscle; AP, articular process; LF, ligamentum flavum; ES, epidural space; IVC, inferior vena cava.
FIGURE 12-29 Correlative transverse (A) cadaver anatomic, (B) CT, (C) MRI (T1-weighted), and (D) ultrasound images of the lumbar paravertebral region from the level of the L4 vertebral body (VB) and articular process (AP). ESM, erector spinae muscle; QLM, quadratus lumborum muscle; PM, psoas muscle; AP, articular process; LPVS, lumbar paravertebral space; VB, vertebral body; IVC, inferior vena cava.
FIGURE 12-30  Correlative coronal (A) cadaver anatomic and (B) MRI (T1-weighted) images of the lumbar paravertebral showing the exit of the lumbar nerve roots (NR) from the intervertebral foramen (IVF) and the formation of the lumbar plexus within the substance of the psoas muscle (PM). ITS, intrathecal space; CE, cauda equina.

c. Transverse sonoanatomy – Shamrock method:

In a transverse sonogram produced by the shamrock method (Fig. 12-20) the psoas, erector spinae, and quadratus lumborum muscles are also clearly visualized (Figs. 12-31 and 12-32). The anatomical arrangement of the three muscles around the transverse process, that is, the psoas muscle lying anterior, the erector spinae muscle lying posterior, and the quadratus lumborum muscle lying at the apex (Fig. 12-31), produces a sonographic pattern that has been likened to a shamrock, with the muscles representing its three leaves.\(^{17}\) The lumbar nerve root is visualized close to the angle between the vertebral body and the transverse process (Figs. 12-32 and 12-33), and the lumbar plexus within the posterior aspect of the psoas muscle, typically about 2 cm anterior to the transverse process (Figs. 12-31 to 12-33).\(^{17}\) From this position if the transducer is gently tilted caudally, the acoustic shadow of the L4 transverse process disappears and the ultrasound beam is now insonated through the intertransverse space and at the level of the articular process of L4 vertebra, similar to that with a PMTOS-AP (Fig. 12-17D).\(^{10,11,17}\) In the resultant sonogram the psoas, erector spinae and quadratus lumborum muscles, the intervertebral foramen, and lumbar plexus are now clearly visualized (Figs. 12-34 and 12-35). In our experience, the lumbar plexus is better visualized with the shamrock method than with a PMTOS. This may be because the ultrasound beam is more at right angles to the lumbar plexus nerves during a shamrock scan.
FIGURE 12-31 Transverse sonogram of the lumbar paravertebral area obtained with the shamrock method at the level of the transverse process of the L4 vertebra. Note the prominent transverse process and the arrangement of the psoas major (PM), quadratus lumborum (QLM), and erector spine (ESM) muscles around the transverse process that has been likened to a shamrock. The accompanying photograph on the right illustrates the position of the patient and the ultrasound transducer during the scan. VB, vertebral body; IVC, inferior vena cava.

FIGURE 12-32 Transverse sonogram of the lumbar paravertebral region with the
ultrasound beam being insonated at the level of the transverse process during the shamrock method. Note the lumbar nerve root is visualized close to the angle between the vertebral body and the transverse process and the lumbar plexus nerve is located within the substance of the psoas muscle. TAM, transversus abdominis muscle; ESM, erector spine muscle; PM, psoas major muscle; QLM, quadratus lumborum muscle; RPS, retroperitoneal space; IVC, inferior vena cava; Ao, abdominal aorta; VB, vertebral body; LPVS, lumbar paravertebral space; ITS, intrathecal space; TP, transverse process.

FIGURE 12-33 Biplanar ultrasound image of the lumbar paravertebral region obtained with the shamrock method and with the ultrasound beam being insonated through the lumbar intertransverse space and at the level of the articular process. Note the transverse axis (A) is the primary data acquisition plane and the corresponding image along the secondary data acquisition plane (x-plane – dotted line with blue arrow head in A) is a coronal view showing the lumbar plexus nerves within the psoas muscle. PM, psoas muscle; VB, vertebral body; ITS, intrathecal space; AP, articular process.
FIGURE 12-34  Transverse sonogram of the lumbar paravertebral region with the ultrasound beam being insonated through the lumbar intertransverse space and at the level of the articular process (AP) during the shamrock method. The lumbar plexus nerves are clearly delineated in the posterior aspect of the psoas major (PM) muscle. The accompanying photograph on the right illustrates the position of the patient and the ultrasound transducer during the scan. VB, vertebral body; IVC, inferior vena cava; ESM, erector spine muscle; PM, psoas major muscle; QLM, quadratus lumborum muscle; IVC, inferior vena cava; VB, vertebral body; IVF, intrathecal foramen.

FIGURE 12-35  Transverse sonogram of the lumbar paravertebral region with the ultrasound beam being insonated through the lumbar intertransverse space and at the level of the articular process of the lumbar vertebra during the shamrock scan. ESM, erector spine muscle; PM, psoas major muscle; QLM, quadratus lumborum muscle; IVC, inferior vena cava; VB, vertebral body; ITS, intrathecal space.
Clinical Pearls

1. The lumbar paravertebral region is highly vascular and contains the ascending lumbar veins and the lumbar arteries (Fig. 12-36), which can be visualized using Color and Power Doppler ultrasound (Figs. 12-37 and 12-38). There is also a rich network of blood vessels (arteries and veins) within the substance of the psoas muscle. The dorsal branch of the lumbar artery is also closely related to the transverse process and the posterior part of the psoas muscle (Fig. 12-38) where the lumbar plexus is located. Therefore, it may be at risk for needle-related injury during an LPB, as it is directly in the path of the advancing needle. Considering the rich vascularity of the lumbar paravertebral region, it is not surprising that inadvertent intravascular injection of local anesthetic, psoas hematoma, lumbar plexopathy, and delayed retroperitoneal hematoma have all been reported after an LPB. It is for the same reason, and because the psoas muscle lies in an incompressible area, that we recommend one must avoid LPB in patients with coagulopathy.

FIGURE 12-36 Three-dimensional reconstruction of a CT angiogram showing the origin of the lumbar artery from the abdominal aorta and how it is closely related to the anterolateral surface of the lumbar vertebral body. The spinal artery, which is a branch of the lumbar artery, is also seen entering the spinal canal through the intervertebral foramen (C).
FIGURE 12-37 Color Doppler ultrasound image of the right lumbar paravertebral region showing the lumbar artery and the ascending lumbar vein close to the anterolateral surface of the lumbar vertebra and medial to the psoas muscle. QLM, quadratus lumborum muscle; ESM, erector spinae muscle; PM, psoas muscle; VB, vertebral body; IVC, inferior vena cava.

FIGURE 12-38 Color Doppler ultrasound images of the lumbar paravertebral region in the transverse (A and B) and sagittal (C and D) scan planes. Note the dorsal branch of the lumbar
artery (DBLA) on the posterior aspect of the psoas muscle in both the transverse and sagittal sonograms. PMTOS-ITS, paramedian transverse oblique scan through the lumbar intertransverse space; SS, sagittal scan; LA, lumbar artery; VB, vertebral body; AP, articular process; PM, psoas muscle; TP, transverse process.

2. The echo-intensity (EI) of skeletal muscles is significantly increased in the elderly, and there is a strong correlation between EI of muscles and age (EI of the biceps increases 1.8% per year and EI of the quadriceps increases 1.9% per year). The increase in EI of skeletal muscles with age is due to age-related changes in the muscle. In the elderly there is a reduction in skeletal muscle mass (sarcopenia), replacement of the contractile elements in the muscle by fat and connective tissue, and an increase in extracellular water content in the muscle. There is also an increase in body fat. Normally subcutaneous fat, water, and skeletal muscle fibers are hypoechoic, but infiltration of skeletal muscles by fat results in increased muscular EI. This may be due to a change in acoustic impedance at the surface of the fat cells and an increase in scattering of the ultrasound energy by the intramuscular fat. Therefore, ultrasound images of the lumbar paravertebral region in the elderly appear whiter and brighter, and there is also loss of contrast between the muscle and the adjoining structures (Fig. 12-39), making it difficult to delineate the lumbar plexus when compared to that in the young. Therefore, lumbar paravertebral sonography and ultrasound-guided LPB in the elderly can be challenging. The same may also be true when LPB is performed in the obese when excessive fat and increased depth to the relevant structure can make ultrasound imaging of the lumbar paravertebral region difficult (Fig. 12-40).

FIGURE 12-39 Paramedian transverse oblique scan of the right lumbar paravertebral region through the space between two adjacent transverse processes (PMTOS-ITS) in an elderly subject (85 yrs.). Note the relatively small psoas muscle (PM) and the loss of contrast between the various paravertebral structures. ESM, erector spinae muscle; QLM, quadratus
lumborum muscle; VB, vertebral body; AP, articular process.

FIGURE 12-40  Sagittal sonogram of the lumbar paravertebral region in a morbidly obese patient (BMI = 50 kg·m$^{-2}$). Note the transverse processes (TP) of the lumbar vertebra are barely recognizable in this ultrasound image. There is also a marked loss of contrast between the various lumbar paravertebral structures. ESM, erector spinae muscle.

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