ULTRASOUND GUIDANCE
for Vascular Access
and Regional Anesthesia

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ULTRASOUND IMAGING
for Vascular Access and Regional Anesthesia

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Although ultrasound has recently emerged within clinical anesthesia practice, the routine use of this technology among anesthesiologists continues to develop in both community and academic settings. The introduction of ultrasound techniques to anesthesia for vascular access and regional anesthesia is currently a focus for anesthesia education, and is paralleled by a drive for technological innovation and development among industry leaders. Efforts to incorporate ultrasound into anesthetic practice are fundamentally rooted in the goals of improving patient safety and interventional anesthesia efficacy. Although most anesthesiologists are well aware of the challenges of vascular access and regional anesthesia (for both success and potential complications), the introduction of this technology presents novel challenges of acquiring new knowledge and skill sets to achieve these goals.

Consequently, the familiar training adage of “see one, do one, teach one” is no longer tenable. Ultrasound education must provide clinicians with a comprehensive and step-wise approach to understand the fundamentals of the equipment and acquire new skills to suit their unique practice needs and setting. Through an understanding of this technology at a clinical level, rather than simply teaching with specific technical agendas or checklists, individuals may continue to utilize ultrasound to its fullest capacity.

As with acquiring any new skill, there will be initial challenges for both the novice and experienced anesthesiologist. From correlating anatomy with sonography, and visualizing needles and fluid dynamics in real-time below the skin surface, ultrasound provides opportunities and unique challenges for vascular access and regional anesthesia. As our clinical practice evolves, so will the expectations placed upon us by patients, surgeons, hospitals, and governing agencies. Achieving the goals of improving patient safety, interventional effi-
cacy, and overall patient satisfaction will require the learner to set their own self-directed path towards defining their clinical interests, scope of practice, and skills self-assessment.

The following chapters provide a foundation for clinicians to approach, develop, and refine essential knowledge and skills to integrate ultrasound into routine anesthesia practice. By pairing the basic clinical principles of the ultrasound equipment with the most recent technological innovations in needle guidance, the goal is to optimize time devoted to reading and bench learning to the clinical setting and benefit patient care. This text is designed to provide the basis from which ongoing, self-directed learning through books, journals, and hands-on workshops may be facilitated.

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CHAPTER 1
Understanding Ultrasound Physics for Clinical Assessment

The ability to acquire, manage, and interpret an ultrasound image is a prerequisite to any other skill set. Therefore competency with ultrasound imaging must be achieved prior to interventional procedures. Appreciating the difference between three-dimensional patient anatomy and the two-dimensional screen image is fundamental for ultrasound-guided interventions. Even in the most limited discussions of ultrasound physics as it relates to our clinical practice, there are new concepts that present challenges upon first approach.

The Ultrasound Transducer – Source of Energy and Image
Each ultrasound transducer is required to a) create a source of energy that when applied to the skin safely penetrates the tissues, and b) receive any energy reflected back to the transducer from the tissues. To generate the ultrasound energy, an electrical current is applied to the crystal component within the transducer face. The current is then converted to mechanical (ultrasound) energy and transmitted to the tissues at very high (megahertz) frequencies. The ultrasound energy produced then travels through the tissues as pulsed, longitudinal, mechanical waves originating from the point the transducer contacts the skin.

The transducer (or ‘probe’) is potentially the most limiting component of any ultrasound scan or subsequent interventional procedure, as it determines the characteristics of the energy that is emitted, received, and subsequently processed for anatomical representation on screen (Fig. 1.1). Understanding how this component works is essential, because an inability to optimally select specific transducer characteristics will result in limited image acquisition, and therefore potentially impact safety and eventual block success.

Resolution
Our ability to ‘visualize’ the anatomy deep to the transducer in contact with the skin surface is dependent on the potential resolution for each scanned area. Resolution is determined by the extent to which the energy that leaves the transducer penetrates the tissues and returns to the transducer to accurately
represent the anatomical structures below. Unfortunately, once the vibrational ultrasound energy leaves the crystalline face of the transducer, it is immediately and progressively degraded as it contacts and enters the tissues. This concept of emitted energy that is ‘lost’ (not returned to the transducer) is known as the attenuation of ultrasound energy. It can occur through absorption, reflection, scattering, or refraction of the ultrasound waves (Fig. 1.2). The degree of ultrasound energy attenuation is directly proportional to the frequency of the energy emitted and the total distance the signal must travel in returning to the transducer from a structure of interest. This attenuation of the emitted ultrasound energy may contribute to the distortion or misrepresentation of anatomical relationships characterized on the ultrasound screen image.

Fig. 1.1 Schematic illustration of transducer with energy emitted and returned through tissues
Even with beam attenuation, it is still possible to visualize anatomical structures on screen when separated by less than one millimeter. The clinician’s task is to choose the best transducer for each scan, optimize the equipment settings, and remain aware of potential artifacts (and pitfalls) due to the attenuation of ultrasound energy. The physical properties of ultrasound waves travelling through tissues act not only to reveal anatomical relationships, but also to hide and misrepresent anatomical structures on screen. When examining anatomical representations on the two dimensional ultrasound screen, our resolution is determined by the ability to differentiate structures in the ‘X’ (horizontal) and ‘Y’ (vertical) axes. In the language of ultrasound imaging, these are described as Lateral Resolution and Axial Resolution respectively (Fig. 1.3).

Lateral Resolution describes the potential to visualize two structures that are in a plane perpendicular to the direction of the ultrasound beam. This is the ability to visualize two structures at the same tissue depth relative to the face of the ultrasound transducer in contact with the skin (appearing ‘side-by-side’ on screen). Lateral resolution can be improved by increasing either the frequency

Fig. 1.2 Schematic illustration of a) absorption, b) reflection, c) scattering, d) refraction
or diameter of the ultrasound transducer.

**Axial Resolution** describes the potential to visualize two structures that are situated in a plane parallel to the emitted ultrasound beam. These are structures located at different tissue depths relative to the face of the ultrasound transducer (one object appears ‘above’ the other on screen). Axial resolution can be improved by selecting transducers with higher frequencies.

Although both lateral and axial resolution are improved with higher frequency transducers, all ultrasound energy is progressively degraded as it travels further through tissues. This degree of attenuation (‘loss’) is proportional to the frequency of the energy applied. *Higher frequency energy is ‘lost’ to the tissues to a greater extent than lower frequency energy with progressive tissue penetration. Irrespective of frequency, lateral and axial resolution always decrease with increasing tissue depth* (Fig. 1.4).

For the lateral and axial resolution of superficial structures, ultrasound imaging should be performed with the highest frequency transducer available. When
imaging deep anatomical structures, energy from lower frequency transducers is less attenuated, potentially allowing more energy to return to the transducer, and generating a better representational image. To optimize the balance of resolution and penetration, select the highest frequency transducer that will provide the necessary tissue penetration characteristics. The resolution of a deep structure with a low frequency transducer will not be equivalent to the resolution of a superficial structure with a high frequency transducer. However, it will be better than imaging the same structure using a high-frequency transducer.

**Selecting an Ultrasound Transducer**

Frequency is a key property of each transducer, as it largely determines what ultrasound screen image representation is possible for any given anatomical territory. In addition to characterization by the Frequency of emitted energy, transducers are also described by their Array Configuration, and their physical Footprint.

With respect to frequency, transducers may be identified by frequency range. They are broadly categorized as high, mid, and low-frequency transducers.
Transducers typically characterized as ‘high-frequency’ usually operate above 10 MHz and are best suited to visualize structures less than 3 cm from the surface of the skin. These transducers have excellent resolution for shallow structures. But with increasing depth, structures are less readily visualized due to attenuation of the emitted and returning ultrasound energy. These transducers are commonly selected for examinations of superficial structures such as the interscalene brachial plexus, peripheral nerves, or superficial vessels.

‘Mid-range’ transducers are typically 5-10 MHz, and are used for imaging structures at approximately 3-6 cm below the skin surface. Although these transducers do not have the potential resolution capabilities of the high-frequency transducers for structures close to the surface, they provide better resolution at these tissue depths. Mid-range transducers are commonly selected for deeper structures such as imaging of the infraclavicular brachial plexus, sciatic nerve, or deeper vascular structures.

‘Low frequency’ transducers usually describe those operating below 5 MHz. They are specifically utilized to provide resolution of structures at even deeper tissue planes. Although not as commonly used perioperatively as the other transducers, they are very useful for imaging the spine, or in patients presenting with an increased body mass.

The Array Configuration refers to the arrangement of elements along the face of the transducer, which can take the form of a linear array or curved array relative to the scanning surface.

Linear Array transducers are characterized by a narrow series (<1mm) of piezoelectric elements arranged in a line along the middle of a flat-faced transducer. As the beam of ultrasound energy is emitted along the line of piezoelectric crystals, it provides anatomical visualization that is the same width at the at the skin surface in contact with the transducer as at greater tissue depths. The width of the ultrasound screen image reflects the scaled width (diameter) of the transducer itself, providing a relatively uniform field of visualization.

Curved Array transducers are characterized by a similar narrow line of piezoelectric elements aligned along the midline of the face of the ultrasound transducer. However, the face of the transducer is convex (curved) rather than flat. This creates a fan-like beam that widens with increasing penetration depth.
This results in a visualized anatomical field that is wider with progressive depth from the surface. The potential advantage of this curved array configuration is realized when structures of interest are deep to obstructing superficial anatomy (such as bone), as the fan-like window allows a wide field at depth from a narrow window near the skin. These configurations are useful when imaging around objects such as the clavicle or spinous processes. Although the curved array transducer has the aforementioned advantage of a wider field of view relative to transducer footprint, with increasing tissue penetration depth there is somewhat reduced lateral resolution compared to a linear array transducer of similar frequency and diameter.

The third identifying feature of the transducer taken into clinical consideration is the Footprint, or diameter of the transducer itself. The footprint of the transducer is selected to allow optimal scanning and needle placement within the anatomical surface confines of each patient.

The ideal combination of transducer footprint, array configuration, and frequency is based on superficial and deep anatomical patient characteristics to allow for acquiring the optimal scan image and subsequent needle intervention (Fig. 1.5).
Artifacts

With an understanding of the principles of ultrasound physics as it applies to selecting and managing a transducer for anatomical visualization, it is important to address imaging Artifacts that may cause the sonographer to be unaware of structures that are ‘hidden’, or to ‘perceive’ structures on screen that do not anatomically exist.

Acoustic Shadowing occurs when structures that are highly attenuating of ultrasound energy (such as bone) cast a ‘shadow’ immediately deep to the structure as the ultrasound energy is only partially transmitted through. This is clinically important because it may falsely appear on the screen image that there are no anatomical structures located in the area of the ultrasound ‘shadow’ (Fig. 1.6).

The converse phenomenon of Enhancement Artifact occurs when ultrasound energy passes through a structure that is less attenuating compared to adjacent tissues. Tissues beyond lower attenuating structures (such as blood vessels) are visually enhanced due to the relatively greater energy in the signal as it contacts those surfaces and is returned to the transducer. Enhancement artifacts may present the visual screen representation of a structure that does not exist (Fig. 1.7).

Reverberation Artifact is another common artifact that results from ultrasound waves striking a surface that is close to perpendicular to the incoming energy. Each successive ultrasound pulse emitted from the transducer produces a temporal ‘echo’ resulting in a series of parallel lines both above and below the actual object. This is commonly seen with highly attenuating wide-bore needles (Fig. 1.8).
Moving Beyond the Transducer

Once the ultrasound energy has been returned to the transducer, it must be converted to a meaningful visual representation. Although each clinician will have their own preferences for advanced scanning, there are fundamental settings that must be understood for optimal image representation and subsequent procedural interventions. Upon preliminary assessment of an anatomical field with initial structural identification, screen image optimization requires control of Depth and Gain features.

The selected Depth of the ultrasound screen image for viewing should reflect not only those structures of interest, but initially must allow for a survey of the wider anatomical field to establish areas of potential danger with the subsequent needle interventions (arteries, veins, and pleural spaces). Only after the field has been surveyed to exclude areas of concern should the depth be narrowed to focus on the target and adjacent structures. Initial anatomical scanning should place the objects of interest between the right and left edges of the screen, and with a depth of field that presents the target towards the bottom of the screen image while still allowing for visualization of structures at slightly greater depths (Fig. 1.9).

In tandem with modifications of screen viewing depth, the Gain control is used to amplify the ultrasound energy returned to the transducer for optimization of grey-scale to delineate structures (Fig. 1.10 a,b,c). It is important to note that the gain control acts as a form of brightness control to reduce or amplify the already received signals. This will not change the relative contrast between structures at the same depth as this is defined by their physical properties. Because different tissues present different imaging characteristics when translated on screen, the amount of gain required will vary depending on the absolute and relative echogenicity of structures in the field.
The strength of the ultrasound energy returning back to the transducer is characterized by the brightness of the image on the screen. This intensity of returned energy presents an image of relative *echogenicity* on the screen. The tendency for a structure to reflect back to the transducer more emitted ultrasound energy than those surrounding structures results in a *hyper-echoic* structure, which will be whiter on screen. When a structure has these characteristics it is *echogenic*. In contrast, when a structure reflects less energy than surrounding structures it is *hypoechoic*, with a darker image on screen. Structures typically seen as hyperechoic or echogenic include bone, tendons, pleura, and nerves below the clavicles. In contrast, blood, fluids, and nerves above the clavicles are hypoechoic.

Fig. 1.10 a,b,c Ultrasound images showing a) low, b) medium, c) high gain
CHAPTER 2
Learning to Scan

Understanding how anatomy affects transducer selection, and appreciating the limitations to on screen ‘visualization’ of anatomical structures, the ability to apply the transducer and conduct a thorough assessment is the next step towards safe and effective needle interventions. Ultrasound scanning can be defined by four fundamental transducer movements of *sliding*, *tilting*, *rotating*, and *angling*. Each of these movements is directed towards exploring the anatomical field and defining the preferred needle trajectories.

Before scanning, confirm the orientation of the transducer face relative to screen image. The symbol in the top left screen corner corresponds to the palpable ridge on one side of the transducer, which can be confirmed by touching one side of the transducer face with your finger to see a corresponding signal change on the screen image. Here is a useful step to provide a relative spatial connection between the two-dimensional screen image and the three-dimensional scanning plane: orient the transducer such that the left and right sides are consistent with the left and right sides of the ultrasound screen, and position the plane of the screen similar to the plane of the transducer (Fig. 2.1).

Descriptively, transducer application to the skin is usually with respect to surface anatomy body planes (i.e. transverse), whereas transducer motion is generally in reference to anatomical target structures. Application of the transducer in relation to surface anatomy reflects an initial attempt to visualize deep structures in cross-section based on knowledge of underlying anatomical relationships. Once the transducer is applied, the sliding, tilting, rotating, and angling of the transducer is used to optimize the image of the anatomical structure of interest.

An initial ultrasound survey of the anatomical field to identify landmarks is made with a transverse and longitudinal sliding motion over the superficial structures of interest (Fig. 2.2 a,b). Once the field has been preliminarily scanned for local anatomical relationships, a more detailed exam using a longitudinal sliding motion is used to define and confirm position and trajectory of structures. Having visualized a structure in cross-section through its longitudinal course, the clinician can identify the point at which it is most easily distinguishable and accessible for eventual needle intervention.
Fig. 2.1 Photograph illustrating corresponding planes of transducer and screen relative to patient
The obtained transverse image of anatomical structures is also referred to as a short-axis view. Although the transducer may be in a relative transverse position from the initial application to skin, the subsequent *tilting*, *rotating*, and *angling* of the transducer are subtle movements aimed at refinement of the ultrasound image (Fig. 2.3 a,b,c).

*Tilting* the transducer makes use of the physical properties of ultrasound energy to improve visualization of a structure with outgoing ultrasound waves contacting the structure as close to perpendicular as possible. As the incident angle of emitted energy approaches 90 degrees the intensity of reflected signals will increase and should provide a more distinct ultrasound image (Fig. 2.4 a,b). This change in reflected signal with a transition towards perpendicular incidence of emitted ultrasound energy is known as *anisotropy*.

The transducer movement of *rotation* is used to move from the short-axis representation of structures towards a longitudinal image with rotation through a full 90 degrees to achieve a long-axis view (Fig. 2.5 a,b).

The motion of transducer *angling* utilizes gentle pressure on one side of the transducer to direct the path of emitted energy at an angle not perpendicular to
the resting contour of the skin surface. Gentle pressure may be applied to one side of the transducer to maintain full contact along the skin surface in concave or confined fields, or when attempting to direct the beam under a superficial highly attenuating structure such as bone. If angling is not adequate to maintain skin contact or visualize past obstructions, a smaller footprint or curved array transducer should be selected.

Ultrasound scanning will be performed with left or right hands depending on the anatomical location of the structures of interest. Only after demonstrating the ability to effectively scan with both hands should needle techniques be introduced as part of the progression towards safe and effective ultrasound-based vascular access and regional anesthesia practice.

**Fig. 2.4 a,b** Ultrasound images of median nerve demonstrating anisotropy

**Fig. 2.5 a,b** Ultrasound images of blood vessel in a) short and b) long-axis views
CHAPTER 3
Principles of Needle Skills

Knowledge of ultrasound physics as it relates to equipment selection and image management for coherent ultrasound visualization is a prerequisite for acquiring the additional skill of directing interventional needles under ultrasound guidance.

Once a target structure has been optimally represented on screen in short-axis view, the transducer position should remain relatively unchanged for the remainder of the procedure. If the ideal ultrasound target image has been achieved, moving the transducer to find the needle only takes you further away from your anatomical goal. The needle should always be brought to the transducer beam plane, rather than the beam plane chasing the needle.

Transducer orientation is characterized as transverse and longitudinal in reference to the physical body planes (cross-sectional, parasagittal), and in relation to the ultrasound appearance of anatomical structures (short-axis, long-axis). Both the short axis and long axis ultrasound images are useful to correctly identify and differentiate anatomical structures in the field of view. However, with the introduction of needle techniques, there must be an additional characterization of the plane in which the needle is introduced relative to the ultrasound beam. When needles are introduced to the visualized ultrasound field, they are described as being In-Plane or Out-of-Plane with the ultrasound beam.

With the In-Plane (IP) needle technique, the needle is followed in real time from penetration of skin surface to deep anatomical target in the line of ultrasound beam plane visualization (Fig. 3.1 a,b). This has the advantage of constant visualization during advancement of the needle to minimize any aberrant needle direction and potential trauma to nearby structures. However, the conventional In-Plane approach requires refined technical skills to keep the needle within the sub-millimetre width of the ultrasound beam along its trajectory. This becomes increasingly difficult with the use of smaller diameter needles and with deeper target structures.
In contrast, the Out-of-Plane (OOP) needle approach does not allow for continual visualization of the needle as it passes through the tissues, but rather only as it passes through the thin anatomical plane of the transducer beam represented on-screen (Fig. 3.2 a,b). The Out-of-Plane technique conventionally does not indicate the relationship of the needle to anatomic structures either before or after it crosses the beam.

Fig. 3.2 a,b Photograph and ultrasound image of Tuohy needle and tofu model with Out-of-Plane (OOP) needle orientation
CHAPTER 4
Integrating Scanning and Needle skills

Learning fundamental scanning skills in the clinical setting is ideal because it offers the ‘true’ anatomical environment, and should not present any risk to the individuals being scanned, even with novice learners. However, with the potential for tissue injury in acquiring needle skills, a lower fidelity setting is required. There are many commercial and hand-made models that can facilitate the acquisition of needling skills prior to entering the clinical setting. Whatever model is selected, it should allow for skill acquisition to progress from basic to advanced needle to target imaging.

The shift from learning with a low fidelity model to the clinical setting requires the successful integration of ultrasound scanning and needle skills into one coherent activity. Although providing technical parallels to needle guidance in tissue, these models are not able to demonstrate the dynamic, real time perception of injected fluids, or soft tissue movement that contribute to the high fidelity environment of the clinical setting. Once proficient with needle techniques in the model setting, cautious advancement to clinical application is required. Clinical attention to paresthesias, resistance or pain with injection, careful aspiration, and visual confirmation of needle location and spread of local anesthetics temporally with injection will improve procedural outcomes and minimize patient risks.

Another prerequisite to success with ultrasound-guided procedures is patient education to set expectations and minimize anxiety. After informed discussion, the judicious use of intravenous benzodiazepine sedation in the monitored setting may also enhance patient satisfaction and reduce pharmacologic sensitivities to local anesthetics.

Needle Skills for Vascular Access
For learning both ultrasound-guided vascular access and regional anesthesia needle skills, a readily constructed tofu model will be demonstrated. For vascular access, equipment required will include a block of extra-firm tofu, small diameter flexible tubing (i.e. 3/8” latex tubing) to act as ‘vessel’, wood dowel to introduce the attached tubing through the tofu, stopcocks, and ties at either end for water-tight securing of the tubing and a 20cc syringe to create pres-
sure for arterial simulation in one tube. The equipment and design is shown in Fig. 4.1.

With the model prepared, both tubes are completely filled with water and the syringe remains attached to one stopcock to simulate arterial flow on ultrasound scanning through rhythmic plunger compression. Familiarization with Doppler imaging and assessment of arterial and venous flow characteristics should be performed on the model. With initial scanning, the model ‘vessels’ can be visualized in short and long axis views (Fig. 4.2).

Visualizing both ‘vessels’ in short axis, with rhythmic compression of the syringe, the application of colour Doppler or colour Power Doppler will demon-

![Fig. 4.1 Photograph of simple ‘vascular’ tofu model and required equipment](image1)

![Fig. 4.2 Ultrasound image of ‘vessel’ in a) short axis and b) long axis](image2)

![Fig. 4.3 Ultrasound image of 2 ‘vessels’ with colour Doppler applied](image3)

![Fig. 4.4 Ultrasound image of 2 vessels with waveform Doppler applied](image4)
strate flow differentially in the simulated arterial vessel (Fig. 4.3). Further definitive ‘vessel’ characterization is then completed with the addition of waveform Doppler assessment (Fig. 4.4).

Maintaining the transducer in short axis for an Out-of-Plane (OOP) approach to vascular access, or rotating through 90 degrees to achieve a long axis view for an In-Plane (IP) approach, vascular catheter placement may then be performed (Fig. 4.5 a,b).

**Needle Skills for Regional Anesthesia**

The tofu model for regional anesthesia needle skill acquisition requires a block of extra-firm tofu, small (~2mm) and large (~8mm) wood dowel for hypoechoic targets, and similar diameter wire for creating small and large hyperechoic targets.

Beginner level models are created by gently directing the large wood and wire ‘targets’ through the tofu, orienting them perpendicular to the surface planes.
Using the large targets and large diameter needles (such as a Tuohy) for easier visualization facilitates initial needle to target practice (Fig. 4.6 a,b).

After demonstrating the ability to reliably maintain the needle In-Plane along the entire course from surface to target with both hands, the model may be used for progressively more challenging tasks. Targets may next be presented in the same spatial orientation within the model but with smaller diameters, and then as small diameter targets with oblique trajectories relative to surface planes (Fig. 4.7). As final increments of complexity, the size of needle used is reduced from the Tuohy to conventional block needles, and targets may be reduced in length and completely embedded within the model so that there are no physical cues as to echogenicity, size, or location.

This low fidelity model will allow self-assessment of both scanning and needle skills from visualization and the tactile feedback of the needle contacting the target. With each desired increase in model complexity, transition using sequentially smaller target and needle diameters.
SECTION 2

ULTRASONIX GPS FOR NEEDLE NAVIGATION

The previous chapter addressed some of the technical challenges of integrating ultrasound scanning and needle skills. An inability to identify the needle tip as it passes through the tissues may reduce the potential benefits when using ultrasound for vascular access or regional anesthesia. Needle tip visualization is a key clinical focus when integrating ultrasound and needle skills into practice.

CHAPTER 5

Using GPS for Needle Navigation In-Plane and Out-of-Plane

Identifying the location of the needle tip can be challenging for both the In-Plane and Out-of-Plane ultrasound-guided needle techniques. There may be difficulties in maintaining visualization of the needle along its entire length when In-Plane. There can be uncertainty in the Out-of-Plane technique when the needle tip may have passed beyond the thin ultrasound beam image and only part of the shaft is being represented on screen (Figs. 5.1, 5.2).

Fig. 5.1a,b  Photograph and ultrasound image of In-Plane needle orientation with tip projecting distal to needle visualized on screen
The introduction of Ultrasonix GPS technology to assist in visual needle navigation for vascular access and regional anesthesia allows the path of the needle to be projected on screen even before the needle enters the tissues. Using magnetic energy that is integrated with the needle and ultrasound screen image, the orientation of the needle at the skin surface as directed by the clinician’s hand allows a virtual path towards the target to be projected on the ultrasound screen. This screen ‘path’ represents the actual needle trajectory that would be followed if the needle were to enter the skin with that three-dimensional orientation. The clinician is now able to ‘virtually’ direct their needle towards a vascular or neural target with real-time modifications of direction to ensure the needle is travelling along the desired course, using either the In-Plane or Out-of-Plane technique. With this virtual needle trajectory projected on screen, needle to target localization is facilitated for the novice and skilled clinician alike. The likely result is fewer needle manipulations in the tissues to achieve the desired clinical outcome.

**In-Plane GPS Needle Navigation**

One of the principal challenges of the In-Plane ultrasound needle technique is maintaining visualization of the needle along its entire trajectory from the point of entering the skin to desired target. This often requires adjustments to the previously optimized ultrasound probe orientation that may permit needle visualization, but with less than ideal anatomical imaging. GPS needle navigation allows the clinician to orient the needle In-Plane from the point of contact with the skin (at one edge of the transducer) to the desired target (across the length of the transducer face) without movement, once anatomical goals have been established.
Following optimization of anatomical target image, the needle is oriented in the usual In-Plane fashion along what is perceived to be the middle of the long axis of the transducer. To assist in this spatial orientation of needle with transducer, the GPS needle navigation system utilizes In-Plane Orientation Bars to highlight the correct three-dimensional needle and hand position. These Orientation Bars are located on the left and right side of the ultrasound screen image field (Fig. 5.3).

The objective when using the In-Plane GPS technique is to achieve ‘green’ indicator Orientation Bars on both the proximal edge of the transducer (where the needle is introduced), and the distal edge of the transducer (where the target is located), by hand orientation prior to needle penetration of skin. The first task is to orient the needle along the perceived middle of the long axis of the transducer at the edge where the needle will initially contact the skin surface. As the needle emerges In-Plane, the colour of the Orientation Bar on the corresponding side of the ultrasound screen will transition from red, to yellow, to green (Fig. 5.4 a,b,c).

Assistance with In-Plane alignment of the needle along the entire transducer is initially aided through the ‘Face’ Orientation Bar in the lower right corner of the screen that projects a face-on view of the needle and contact surface of
the transducer. Rather than only visually attempting to determine the midline of the transducer, this Face Orientation Bar projects the position of the needle in relation to the midline with a similar transition from white to green with increasing orientation towards an In-Plane trajectory (Fig. 5.5 a,b). This provides direction for preliminary orientation of the needle that is then refined with the aid of Orientation Bars on the left and right side of the screen during real-time imaging and needle introduction.

Once the proximal needle edge is established as In-Plane with a green Orientation Bar, subsequent hand movements allow the trajectory to be refined along the entire length of the ultrasound beam as the Indicator Bar on the distal side of the transducer Bar transitions from red, to yellow, to green. With the needle In-Plane along the length of the transducer, all three screen Orientation Bars will be green, and the virtual needle projected on screen may be directed towards the appropriate target depth by the clinician elevating or lowering their hand (Fig. 5.6).
Out-of-Plane GPS Needle Navigation

In contrast to the In-Plane technique, the Out-of-Plane technique allows for the desired needle tip placement to be achieved from any orientation of needle relative to the ultrasound probe at the skin surface. Although the same considerations remain for conventional Out-of-Plane techniques, the addition of GPS needle navigation overcomes one major drawback for Out-of-Plane needles - the final needle tip position can be localized definitively within the beam plane at the desired target location.

As with the In-Plane technique, the optimal anatomical site for intervention must be identified before any needle intervention is considered. With GPS needle navigation engaged and the needle in proximity to the skin surface, the virtual trajectory at which point the needle tip would cross the ultrasound beam is visualized on screen as a red Target Indicator circle (Fig. 5.7). Using this technique, the red Target Indicator circle may be translated to different horizontal and vertical locations at the beam plane on screen by the three-dimensional hand movements of the clinician. With the Target Indicator positioned at the desired anatomical location, as the needle reaches the beam plane, the Target Indicator colour changes from red to green to indicate that the needle tip is at the beam plane (Fig. 5.8). As long as the tip is maintained at the beam plane, the Indicator remains green, and will revert back to red should the needle move proximal or distal out of the beam plane. This warning avoids the common concern with the conventional Out-of-Plane technique, whereby the tip of the needle projects beyond the plane of the ultrasound beam, and only the shaft is perceived on screen.
The ability to obtain vascular access for assessment and intervention is one of the anesthesiologist’s defining skill sets. Increasingly, there has been an interest, and in some regions a mandate, to move beyond superficial landmarks and anticipated anatomical relationships for percutaneous venous and arterial cannulation. The addition of ultrasound technology not only facilitates vascular access for all levels of practice. It also illustrates why these typically routine procedures can on occasion become surprisingly challenging as anatomical variability is made readily apparent.

The ultrasound-guided approach to vascular access is based on the same fundamental anatomical knowledge and sterile percutaneous approach as conventional practice. However, the use of ultrasound and GPS needle navigation under real-time visualization, in place of the conventional ‘blind’ technique with the endpoint of needle aspiration for a blood-filled syringe, does require slight procedural modifications. This chapter demonstrates the approach to real-time ultrasound imaging with the addition of GPS needle navigation technology for vascular access using the internal jugular vein as an illustration.

CHAPTER 6

Ultrasound Characteristics of Arterial and Venous Flow

For vascular access, arteries and veins are conventionally approached from their anticipated anatomical relationships with surface landmarks. This principle remains relatively unchanged in the ultrasound-guided approach. Typical cues such as the visual tissue distension for veins or the tactile pulsatility of arteries still guide our application of transducer to skin. However, from this point
onwards it is the characteristics of veins and arteries on ultrasound that guide our needle placement for safe and effective vascular access.

Using the basics of ultrasound scanning and image management previously established, the focus shall now be on the specifics of ultrasound imaging as it relates to the identification of vascular structures and needle access. In addition to using depth and gain controls for image optimization, the Doppler capability is essential to distinguish hypoechoic structures as vascular vs. non-vascular before introducing needles to the field.

With Doppler imaging of blood vessels, the flow of blood towards or away from the transducer results in a screen image that differentiates blood flow from the rest of the ‘static’ tissues by assigning colour to the area of flow within the vessel. The ultrasound energy emitted will be returned to the transducer at a different frequency depending whether it encounters blood flow towards or away from the source energy. This is known as the Doppler shift in frequency. Blood flow moving towards the ultrasound source reflects energy at a relatively higher frequency (positive Doppler shift), and at a relatively lower frequency (negative Doppler shift) when flow is away from the transducer. In Colour Doppler mode, any blood flow towards the transducer will be red on screen, and flow away from the transducer will be blue on screen. *It must be emphasized that colour does not necessarily characterize arterial or venous flow. Depending on the angle of the transducer placement on the skin relative to flow, arteries or veins may each be represented as red or blue* (Fig. 6.1 a,b).

If there is no colour signal from a suspected blood vessel (no Doppler shift), the structure being assessed may not be vascular, may not have any flow within it.

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**Fig. 6.1a,b** Ultrasound screen image showing same vessel with both red and blue Doppler signal.
(as is the case with a thrombosed vessel), or the transducer may be oriented perpendicular to the flow and is therefore not being detected. For this latter reason careful ultrasound assessment of every field must be made using all transducer motions to avoid a false-negative vascular assessment (Fig. 6.2 a,b).

In addition to Colour Doppler mode, there is the feature of Colour Power Doppler. This mode offers the advantage of detecting very slow flow, and is largely independent of incident beam angle (detection of flow even when the emitted ultrasound beam is near perpendicular to the vessel). The Colour Power Doppler function is a more sensitive indicator of vascular flow and is therefore often useful as a scout scan before defining venous or arterial characteristics (Fig. 6.3 a,b). However, Colour Power Doppler mode does not provide any information about the direction of flow relative to the transducer as there is no red-blue colour differentiation.

Although Colour Doppler and Colour Power Doppler may be used to detect blood flow following assessment based on anatomical location, vessel shape, pulsatility, and compressibility, neither of these modes is adequate to defini-
tively characterize blood flow as arterial or venous. Following recognition of flow through Colour Doppler or Colour Power Doppler examination, Spectral Doppler Waveform examination is required to definitively characterize the vessel as arterial or venous. The **Spectral Doppler waveform** characteristics of arteries and veins are depicted in Fig. 6.4.

**Fig. 6.4** Ultrasound image of spectral Doppler waveforms for arterial (a) and venous (b) flow
CHAPTER 7

Ultrasound-Guided Vascular Access Line Placement

Internal Jugular Vein Vascular Access

Anesthesiologists frequently select the Internal Jugular Vein (IJV) for central vascular access because its anatomical position relative to surface and deep structures is well established. Based on this familiarity, the IJV will be utilized to demonstrate the addition of ultrasound imaging for venous vascular access. Arterial catheter placement follows a similar methodology to that described here described for the IJV.

On ultrasound short-axis imaging the IJV appears as a hypoechoic structure that is typically slightly irregular in shape, and lies lateral to the smaller and rounder carotid artery in the neck. There are many hypoechoic round structures in this field (including the nerves of the brachial plexus), and both carotid artery and IJV are frequently pulsatile. Therefore, definitive identification of this structure requires Colour Doppler or Colour Power Doppler assessment to identify characteristics of flow, and then further distinction between artery and vein using Spectral Waveform analysis.

Known anatomical surface relationships and fundamental scanning techniques allow the transducer to be transversely oriented over the anticipated IJV territory of the neck. Initial ‘scout’ scans will reveal the sternocleidomastoid superficially, and two deeper hypoechoic structures of varying diameter, shape, compressibility, and pulsatility. Using Doppler techniques the anatomical position of the carotid artery and IJV are identified on the ultrasound screen image. With a confirmed identification of carotid artery and IJV, the IJV is optimally visualized in the centre of the screen and then may be approached using either an In-Plane or Out-of-Plane needle technique (Fig. 7.1).

The In-Plane vascular access approach to the IJV requires a longitudinal view of the vessel. Once clearly establishing the IJV in short axis, rotate

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**Fig. 7.1** Ultrasound showing centred IJV
Fig. 7.2 Photograph illustrating probe and needle position for In-Plane (IP) IJV access
the transducer through 90 degrees to capture the vein in long axis (be careful not to lose the vessel in the field of view). If the vessel image is lost, return to the short axis view for confirmation once again before rotating to the long-axis view. Note that it may be difficult to capture colour Doppler or Spectral Waveform Doppler analysis in the long axis view because the transducer often rests perpendicular to the flow of blood. With the optimal ultrasound image of the defined vessel achieved, engage the GPS function to enable needle navigation and bring the vascular access needle to rest on the skin (Fig. 7.2).

When the needle is correctly In-Plane and all three Orientation Bars on the screen image are illuminated in green, define the vertical needle trajectory as desired on screen by elevating or lowering the needle in hand (Fig. 7.3). At this point introduce the needle under direct visualization towards the centre of the IJV.

With the needle held securely and tip In-Plane within the vessel, the probe is placed on the sterile field, and the sensing introducer is removed with the free hand for introducing the guidewire. At this point there will be the usual venous backflow of blood through the needle from venous pressure before introducing the guidewire. Following easy insertion of the guidewire, the ultrasound probe is then reapplied to the skin under normal long-axis view (non-GPS imaging) to visualize the guidewire and needle within the lumen of the vessel (Fig. 7.4). With intraluminal guidewire position correctly identified, the probe is once again placed on the sterile field, the needle removed, and the usual catheter-over-guidewire technique completed.
Fig. 7.5 Photograph illustrating probe and needle position for Out-Of-Plane (OOP) IJV access
For the Out-of-Plane approach to the IJV, the same process of vascular structure identification is carried out to distinguish and confirm arterial from venous vessels. Now rather than rotating the transducer to obtain a long-axis view of the vessel, an optimized short-axis view is maintained and the desired point of needle entry from the skin surface is established (Fig. 7.5).

With GPS needle navigation engaged, the trajectory to IJV target is established on screen, and the needle is slowly advanced until the Target Indicator transitions from red to green, indicating that the needle tip is at the desired point at the beam plane (Fig. 7.6, 7.7).

Once again with the needle firmly held against the skin, the probe is rested on the sterile field and the free hand now removes the sensor to reveal the backflow of venous blood as the guidewire is introduced. Following the introduction of the guidewire, with non-GPS imaging, the probe is applied to re-confirm
venous guidewire placement (Fig. 7.8). Then the probe is released, the needle removed, and the vascular catheter is placed over the guidewire using conventional catheter techniques. If desired, following catheter placement and prior to guidewire removal, the entire intraluminal assembly may be documented by ultrasound assessment (Fig. 7.9).

Note that for vascular access, it is often easiest to image and place catheters using specific probe configurations depending on either an In-Plane or Out-of-Plane approach. For the In-Plane approach, using a small footprint (linear or curvilinear) probe often allows greater access to the skin surface and facilitates the technical aspect of percutaneous puncture. In contrast, with an Out-of-Plane approach, a wider footprint probe allows for a larger cross-sectional representation of anatomical structures. Based on the attributes of In-Plane and Out-of-Plane needle imaging, individual patient anatomy, and the clinical setting, the clinician can select their preferred technique.
CHAPTER 8

Femoral Nerve Block

The femoral nerve originates from the 2nd through 4th lumbar roots, and emerges in the leg after passing deep to the inguinal ligament, just lateral to the femoral artery. The femoral nerve (and potentially overlapping obturator and lateral femoral cutaneous nerve distributions) is blocked at this point to provide anesthesia for procedures of the anterior aspect of the thigh and knee, and the medial aspect of the distal lower extremity. The surface landmarks for femoral nerve block include the femoral artery medially, inguinal canal superiorly, and sartorius muscle laterally (Fig. 8.1).
With the patient comfortable in a supine position and the operative leg slightly abducted, visually inspect the femoral triangle. Inspection of patient anatomy and palpation of the femoral artery will provide information for transducer selection and an initial landmark to begin scanning. Femoral nerve block in most patients will be performed with a mid- or high-frequency, linear array, large footprint transducer.

Place the selected transducer over the femoral artery with a slightly oblique-transverse orientation, and initially identify the femoral artery and vein with previously established scanning skills. Refining the ultrasound image should allow for a more detailed assessment of the anatomical field to include identification of the hyperechoic femoral nerve deep to fascia lata and fascia iliaca, lateral to the femoral artery (Fig. 8.2).

Sliding the transducer in a cephalad-caudal direction along the femoral artery will allow visualization of the proximal bifurcation of the lateral circumflex femoral artery. The femoral nerve should be approached at this anatomical level, as fewer branches will have already separated from the nerve and more complete neural blockade may be achieved.

Once an optimal image of target structures has been achieved for any nerve block, prior to any needle intervention, the Doppler capabilities must be engaged to locate previously unseen vascular structures in the final field of view.

With the patient comfortably positioned, ultrasound image optimized, and an assistant to manage local anesthetic delivery and nerve stimulation as desired, subcutaneous local anesthetic is first injected through the prepped skin field in a trajectory towards the nerve target location. Although unlikely with small
infiltrating needles, inadvertent spread of local anesthetics in close proximity to the nerve itself may reduce nerve stimulator responses if sought. If the planned nerve block is to be performed In-Plane, the infiltrating needle and local anesthetic should be visualized on screen as they pass through the tissues. Following adequate subcutaneous infiltration, the block needle is brought to the skin surface with GPS navigation engaged. The desired trajectory to the deep margin of the nerve is then achieved with hand positioning (Fig. 8.3).

With steady needle advancement and visualization on screen, the tip of the needle should be placed deep to the nerve and clearly lateral to the femoral artery. If nerve-stimulation is utilized, muscular contraction may produce superior displacement of the patella. Following negative aspiration, with no undue resistance, pain, or paresthesias, an assistant incrementally administers the desired local anesthetic solution with continuous ultrasound visualization of spread.

Confirmation of ideal needle tip position will be with circumferential spread of local anesthetic solution around the nerve. Small manipulations of needle tip position may be required to ensure complete circumferential spread of local anesthetic, resulting in an increasingly hyperechoic nerve structure relative to surrounding hypoechoic fluid (Fig. 8.4).
CHAPTER 9

Brachial Plexus Blocks

The brachial plexus is formed from C5-T1 nerve roots that align into trunks, divisions, cords, and the terminal median, radial, ulnar, axillary, and musculocutaneous nerves that innervate the shoulder and upper extremity. The brachial plexus may be approached from an interscalene, supraclavicular, or infraclavicular location to provide complete anesthesia of a desired anatomical region with a single needle pass and injection of local anesthetic. The interscalene brachial plexus block provides anesthesia of the distal clavicle, shoulder, and proximal humerus. Both supraclavicular and infraclavicular brachial plexus blocks are performed to achieve complete anesthesia of the entire upper extremity distal to the shoulder.

Interscalene Brachial Plexus Block

The interscalene brachial plexus lies deep to the anatomical landmarks of carotid artery, sternocleidomastoid, and anterior and middle scalene muscles at the level of the cricoid cartilage (Fig. 9.1).

With the identification of the interscalene groove at the level of the cricoid cartilage, a high-frequency, linear array, medium footprint transducer is selected and contacts the skin in a slightly oblique, transverse orientation. The initial scan should identify the carotid artery, internal jugular vein, and sternocleidomastoid muscles superficially along the top of the ultrasound screen. Sliding the transducer in a lateral/posterior direction, the anterior and middle scalene muscles will appear deep to the sternocleidomastoid. Refinement of transducer position and ultrasound image will reveal several hypoechoic circles linearly arranged between the anterior and middle scalene muscles. These are the roots of the brachial plexus (Fig. 9.2).

The hypoechoic ultrasound appearance of nerves above the clavicle requires careful ultrasound assessment, as blood vessels and nerves may appear very similar. Because the brachial plexus is highly vascular, intermittent use of Doppler imaging is essential for correct ultrasound differentiation of neural and vascular structures.

With the brachial plexus identified between the anterior and middle scalene muscles, a complete scan from proximal roots to the clavicle should be conducted to confirm neural anatomy and identify the optimal location for needle introduction.
The patient should be comfortable in a supine position with the head and shoulders slightly elevated from the bed to allow needle manipulation from the lateral aspect of the neck. With optimal ultrasound image achieved, local anesthetic is injected through the prepped field along the subcutaneous path to be taken by the regional block needle. Following adequate infiltration, the block needle is brought to the skin surface with GPS navigation engaged, and the desired trajectory to the deep margin of the brachial plexus is established (Fig. 9.3).

**Fig. 9.1** Illustration of interscalene brachial plexus anatomy

**Fig. 9.2** Ultrasound image of interscalene brachial plexus and local anatomical structures

**Fig. 9.4** Ultrasound of the interscalene brachial plexus with IP needle and fluid spread
The block needle is steadily advanced with continuous visualization of trajectory on screen, the tip coming to rest at the deep margin of the plexus between the anterior and middle scalene muscles. Nerve-stimulation in this field may result in muscular contraction of the proximal arm if utilized. With the needle tip visualized in the desired location, following negative aspiration and without pain, paresthesia, or resistance to injection, an assistant incrementally injects local anesthetic. Slight modifications of tip placement may be required to ensure circumferential spread around the nerve roots of the interscalene brachial plexus (Fig. 9.4).

**Supraclavicular Brachial Plexus Block**

The supraclavicular brachial plexus is identified posteriorly to the clavicle as it passes just lateral and superficial to the subclavian artery (Fig. 9.5). The block at this level requires ultrasound imaging within the supraclavicular fossa for the lateral to medial introduction of the regional block needle.

Each individual’s supraclavicular fossa surface anatomy will determine the optimal transducer selected. However, these are generally high-frequency, small footprint transducers with either a linear or curved array configuration. The
transducer is oriented longitudinally along the posterior margin of the clavicle and directed postero-inferiorly for initial identification of subclavian artery, 1st rib, and pleura to establish boundaries of caution (Fig. 9.6).

Follow the nerve as it appears as a clustered hypoechoic structure slightly superficial and lateral to the pulsatile artery, now refining the ultrasound image to identify the ideal point for needle introduction along the trajectory of the supraclavicular brachial plexus. The nerve bundle should be approached at a location where it appears ‘closely packed’ and with no vascular structures identified on Doppler assessment along the planned needle trajectory.

With optimal position for needle introduction defined and the transducer stable, subcutaneous local anesthetic is administered from a lateral to medial trajectory towards the nerve target through the sterile prepped field. The
block needle is rested on the skin surface at point of local infiltration, and with GPS navigation engaged, the desired trajectory to the deep margin of the supraclavicular brachial plexus nerve is established (Fig. 9.7).

The block needle is slowly advanced with visualization of trajectory on screen, and the tip coming to rest at the inferior border of the plexus and clearly lateral to the subclavian artery and superficial to the 1st rib. When close to the nerve bundle, stimulation through an insulated needle may produce contraction of the muscles of the forearm. With the needle tip established in the ideal location, an assistant confirms negative aspiration through the syringe, and without pain, paresthesia, or resistance to injection, incrementally injects local anesthetic and circumferential spread around the nerve is established (Fig. 9.8).

Although modifications of needle tip position are occasionally required to
achieve desired local anesthetic spread (which is typically easily done), deeper nerve blocks may tether fine stimulating needles along tissue planes and prevent subtle distal manipulation. In these situations, the block needle is slightly withdrawn to release the needle, and then it is redirected without changing transducer position.

**Infraclavicular Brachial Plexus Block**

The approach to ultrasound-guided infraclavicular brachial plexus block relies on only a few superficial anatomical structures. The distal clavicle and coracoid process are the key surface landmarks. Infraclavicular brachial plexus block is performed with the ultrasound transducer contacting the skin in a para-sagittal orientation, and positioned slightly medial to the coracoid process at the inferior aspect of the clavicle. As complete anesthesia of the upper extremity can be achieved through either an infraclavicular or supraclavicular block, selection of desired peri-clavicular site is based on patient anatomy for optimal ultrasound imaging.

Given the depth of nerve targets, the desire to optimize scanning windows around bony structures, and the sometimes limited needle access at the edge of the clavicle, the transducer commonly selected for this block is a mid-frequency, small footprint, curved or linear array probe. The preliminary scan of

![Photo of infraclavicular block with needle and probe](image-url)
the infraclavicular plexus should identify the clavicle, pectoral muscles, and axillary artery and vein. If the transducer is moved medially while maintaining the parasagittal orientation the pleura will also come into view. The characteristic hyperechoic appearance of nerves will be identified at the posterior, inferior, and superior borders of the axillary artery. The posterior cord lies posterior to the artery, the medial cord inferior to the artery, and the lateral cord appears superior to the artery (Fig. 9.9).

Optimizing the images of the cords requires medial-lateral sliding and superior-inferior angling of the transducer to obtain the best visualization around the artery. With an In-Plane approach, the needle is introduced at the immediate inferior border of the clavicle. Therefore final positioning of the transducer must leave adequate space between transducer and clavicle for desired needle position. With the three cords of the infraclavicular plexus optimally visualized around the axillary artery, and the location of the axillary vein and pleura previously identified, local anesthetic is administered subcutaneously through the prepped skin field towards the posterior aspect of the artery. With the block needle now in contact with the skin surface at the desired point of entry, and with GPS navigation engaged, the preferred trajectory towards the most posterior border of the artery and the posterior cord is established (Fig. 9.10).

The block needle is carefully advanced with visualization of trajectory on screen, and the tip placed near the posterior cord immediately posterior to the artery. Similar to that described for the supraclavicular block, nerve stimulation in this region would be expected to produce contraction of muscles of the forearm.
With the needle tip location established, an assistant confirms negative aspiration through the syringe and without pain, paresthesia, or resistance to injection, incrementally injects the desired local anesthetic. The local anesthetic should be deposited posteriorly to the artery to allow for optimal posterior, inferior, and superior spread and achieve a ‘horseshoe’ like distribution (Fig. 9.11).

The relatively deep anatomical position of the infraclavicular plexus, and the steep orientation of block needle in relationship to transducer face for in-plane approaches, may present challenges in visualizing the needle along its entire trajectory. These challenges are significantly reduced when utilizing the GPS needle navigation and tracking capabilities for infraclavicular blocks.
CHAPTER 10

Sciatic Nerve Blocks

The sciatic nerve originates from the L4-5 and S1-3 roots. Blockade of this nerve provides anesthesia to the entire lower leg except for a portion of the medial aspect of calf and foot, which is supplied by the saphenous branch of the femoral nerve. The sciatic nerve can be approached proximally at the subgluteal region, or distally at the popliteal fossa before the nerve branches into tibial and common peroneal components.

Proximal Sciatic (Subgluteal) Nerve Block

Proximal blockade of the sciatic nerve using the subgluteal approach requires localization of the nerve deep to the gluteus maximus muscle, midway between the ischial tuberosity and greater trochanter (Fig. 10.1). With the patient resting in the lateral position on the non-operative side, the operative limb is flexed at the hip so that the distal leg rests on the bed. Having identified the surface landmarks of greater trochanter and ischial tuberosity, a low to mid-frequency, curved array, large footprint transducer is selected. The transducer is

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**Fig. 10.1** Illustration of subgluteal sciatic nerve anatomy
then applied to the skin along a visual axis connecting greater trochanter and ischial tuberosity to orient the greater trochanter laterally, ischial tuberosity medially, and gluteal muscle superficially on screen.

With an optimized anatomical ultrasound image, the nerve should be identified as a hyperechoic structure located between the bony landmarks and deep to gluteus maximus to determine the optimal point for blockade. It can be approached with the block needle from either side of the transducer to facilitate the best access. Following subcutaneous infiltration of local anesthetic along the eventual needle path towards the nerve target, and with an assistant to manage final injection and nerve stimulation if desired, the GPS navigation is engaged and the projected trajectory of the block needle towards the deep border of the nerve is defined (Fig. 10.2).

The needle is then inserted through the prepped skin field and carefully advanced with needle tip placement optimized under direct visual identification on screen and plantar flexion of foot if nerve stimulation utilized. Following negative aspiration, and without pain or paresthesia, incremental administration of local anesthetic is delivered. Fine adjustments to the needle tip position are made as required to ensure to ensure circumferential spread around the nerve (Fig. 10.3).

**Distal Sciatic (Popliteal) Nerve Block**

When blockade of the proximal sciatic nerve distribution is not required (such as for foot and ankle surgery), an alternative approach is distal sciatic nerve block at the popliteal fossa. Because the sciatic nerve divides just above the popliteal fossa to form the posterior tibial and common peroneal nerves, approaches to sciatic block at the popliteal fossa must identify the nerve above this branching and identify the site of the bifurcation (Fig. 10.4).

The popliteal sciatic block can be performed with the patient in the prone or supine position. The ease of performing the block in the supine position, which is typically more comfortable for patients, will be described. With the patient resting supine, the lower leg is elevated and stabilized with pillows or blankets.
Fig. 10.2 Photograph of patient in left lateral decubitus position with hip flexed, illustrating probe and needle position for In-Plane subgluteal sciatic block
Then the relevant surface landmarks of the superior aspect of the patella, biceps femoris, and vastus lateralis are identified. Access to the popliteal fossa must be adequate to apply a mid-range, large footprint, linear array transducer across the posterior aspect of the leg.

The transducer is positioned transversely in the popliteal fossa at the level of the proximal patellar margin, and an initial scan is conducted with a proximal-distal sliding motion. The sciatic nerve at the popliteal fossa is usually identified as anatomically superficial and lateral to the popliteal artery, and medial to biceps femoris. This makes the artery a good point of initial anatomical reference. Once the nerve is tentatively identified by anatomical location and characteristic hyperechoic ultrasound appearance, active plantar- and dorsi-flexion of the foot may demonstrate the nerve appearing to ‘rotate’ around its long axis. A detailed anatomical assessment must be made to clearly identify the nerve at a point before the two distal tibial and peroneal branches are seen to separate (Fig. 10.5).
It will be noted on initial scanning of the popliteal fossa that the orientation of the transducer is inverted relative to screen image. This is because, for the first time, the transducer is pointing upwards in three-dimensional space and projecting from posterior to anterior anatomically. As a result, the orientation of superficial to deep structures anatomically will not correspond with a ‘top to bottom’ representation on the ultrasound screen. The needle moving with an anatomically superficial trajectory (physically ‘downwards’ towards the transducer face), will be represented by a visually ‘upwards’ trajectory on the screen (towards the screen position for the face of the transducer).

With the patient resting comfortably, and the transducer stable to provide a confirmed and optimal image of the sciatic nerve at its bifurcation, local anesthetic is injected through the prepped skin field towards the nerve target location. With an assistant to manage the syringe for local anesthetic delivery and nerve stimulation as desired, the GPS navigation function is engaged to project the needle path towards the deep border of the nerve before penetrating the skin (Fig. 10.6).

Once the ideal trajectory is established, the regional block needle is advanced from a position typically just anterior to the long head of biceps femoris, towards the deep aspect of the popliteal sciatic nerve. Confirmation of correct needle placement is through ultrasound visualization of needle tip and potentially from plantar flexion of foot from nerve stimulation if utilized. Following negative aspiration, an assistant incrementally delivers the desired local anesthetic without resistance, pain, or paresthesia, and circumferential spread is visualized on screen around both nerves (Fig. 10.7).
Fig. 10.6 Photograph of patient in supine position with leg raised, illustrating probe and needle position for In-Plane popliteal sciatic block
Epidural and subarachnoid blocks are generally routine procedures for anesthesiologists. However, in some patients, the absence of landmarks or presence of abnormal anatomy makes these tasks more challenging. The use of ultrasound imaging for neuraxial blocks allows for visualization of vertebral body levels, intervertebral spaces, and estimations of depth from skin to ligamentum flavum and dura.

Ultrasound is valuable for helping identify optimal neuraxial needle trajectories, but for epidural anesthesia it most often acts as a preliminary step before the definitive block is placed. For subarachnoid anesthesia, the routinely used 25 gauge (and smaller) needles are placed through more rigid larger diameter introducer needles. In challenging anatomical settings, the ultrasound-guided positioning of these introducer needles may facilitate the accurate eventual position of the subarachnoid needle. The ultrasound assessment for neuraxial blocks is most frequently directed towards defining midline, interspinous spaces, vertebral body level, estimating target structure depth, and projecting needle trajectories before the clinician places the sterile block as per usual technique.

**Defining the Midline and Interspinous Spaces**

With a patient comfortably positioned in the preferred sitting or lateral decubitus position, having identified the region of the lumbar spine with anatomical landmarks, a low frequency, large footprint, curved array transducer is placed in contact with the patient using a transverse orientation to the spine at the perceived midline. This short-axis view of the spine will be used to confirm midline and interspinous spaces for eventual needle introduction.
A sliding motion with the transducer over the spine in a cephalad-caudal direction demonstrates alternating superficial hyperechoic signals from the spinous process bone, followed by a generally lower intensity image from the soft tissues at the interspinous spaces (Fig. 11.1 a,b). Observing this repeating pattern as the transducer is moved cephalad and caudal, and keeping the hyperechoic spinous process signals at the horizontal centre of the ultrasound screen, allows for the correlation of the anatomical midline with the centre of the ultrasound probe as positioned on the patient. The location of the spinous processes may then be indicated on the skin to identify midline and reflect the interspinous spaces (Fig. 11.2).

Defining Vertebral Body Level and Tissue Depth
Having identified the midline and interspinous spaces, the transducer is oriented in a para-sagittal orientation to the spine, approximately 2-3 cm lateral to midline. With the transducer positioned lateral to the spinous processes, a tilting motion is used to medially direct the beam towards the dural sac. The goal is to utilize the parasagittal plane to optimize soft-tissue windows, and minimize interference from bone. Through medial-lateral and cephalad-caudal sliding, and tilting towards the midline, the characteristic ‘saw-tooth’ junction of the lumbar vertebrae and sacral prominence can be visualized (Fig. 11.3).

Once recognizing the L5-S1 junction, sliding the transducer in the same parasagittal plane allows the level of each cephalad vertebrae to be established to reach the desired interspace. When the desired lumbar interspace is positioned at the centre of the horizontal screen image, a visual mark is then made on the skin at the corresponding mid-point of the transducer to indicate the
Fig. 11.2 Photograph of lumbar spine with indicators of midline spinous processes above transducer
cephalad-caudal interspace position for future needle placement (Fig. 11.4).

After identifying the desired interspace, an estimation of the depth from skin to ligamentum flavum/dura is then carried out. With the probe positioned to provide an ideal parasagittal image, gently place the GPS needle in contact with the patient’s skin from the eventual desired midline or opposite paramedian approach (Fig. 11.5). Using the GPS navigation feature, orient the needle and project the tip to the point at which it reaches the ligamentum flavum/dura structure and record the estimated depth from the on-screen calculation (Fig. 11.6).

With midline, interspinous spaces, vertebral body level, and approximate epidural or subarachnoid depth established by ultrasound, the clinician returns to their customary technique for spinal or epidural blockade.
Fig. 11.5  Photograph of GPS needle and paramedian probe using previous midline and interspace indicators to establish needle position and trajectory
CHAPTER 12

In-Dwelling Catheters for In-Patients and Out-Patients

The transition from single-shot nerve blocks to continuous catheter placement maintains the same approach for ultrasound imaging of anatomical targets and managing needle trajectory previously addressed. The principles for placement of indwelling regional anesthesia catheters provide straightforward procedural steps to include with the already established ultrasound-guided skills. The femoral catheter technique described below may be generalized to other anatomical areas for continuous nerve blocks based on previous single-shot nerve block practice.

Having established the technique for single-shot femoral nerve blocks, a few specific considerations must be added for continuous catheter placement. Basic additions to the clinical set-up will include sterile drapes and gown for an extended sterile field, and a continuous catheter set of the clinician’s preference. Procedural highlights will include the need to track a suitable length of catheter subcutaneously on insertion so that it remains in a stable position at the desired site, and when placing indwelling catheters, ultrasound imaging is temporarily discontinued during periods of catheter through needle manipulation.

There are also considerations unique to the placement of indwelling continuous regional anesthesia catheters. Specifically, there must be a focus on patient selection and overall suitability for both in-patient and out-patient care settings, as well as an integrated care system for ongoing follow-up after initial catheter placement.
Continuous Femoral Catheter Placement

Following an initial ‘scout’ scan of the anatomical field, with sterile technique the patient is then prepped and draped by the clinician to create a wide sterile field. A small amount of ultrasound gel is applied to the scanning surface of the selected transducer, which is then covered with a sterile sleeve for scanning. When ready to proceed, sterile ultrasound gel is applied to the skin to maintain sterility and ensure good contact between transducer sleeve and patient (Fig. 12.1).

Similar to the single-shot femoral nerve block technique, under ultrasound visualization, local anesthetic is injected along the trajectory that will be taken by the larger introducer needle towards the nerve. For catheter stability, needle insertion at the skin should be slightly further away from the edge of the transducer to create a longer subcutaneous path and avoid the need for subsequent tunneling. With GPS guidance and confirmed trajectory, the needle is then passed through the anesthetized tissues towards the deep border of the femoral nerve. When needle tip placement is confirmed by visualization and nerve stimulation as desired, the hand holding the needle is then supported against the skin and remains ‘fixed’ for the remainder of the procedure. With the needle position held firmly in one hand, the ultrasound transducer is released onto the sterile field and the free hand introduces the catheter through the needle (Fig. 12.2). If desired, 2-3 mL of D5W may be carefully inserted through the needle to gently separate tissue planes and facilitate catheter insertion. Catheter insertion should be easy with few, if any, transient paresthesias.

With attention to needle length and incremental markings on the catheter, the catheter need only be placed 1-2 cm beyond the tip of the needle, providing there has been adequate subcutaneous distance for stability. While still holding the needle after catheter insertion, the catheter is released and the ultra-
sound image is reacquired to confirm the position of the needle and catheter tip in relation to the nerve (Fig. 12.3). If using a stimulating catheter set, the point of nerve stimulation can be changed from the introducer needle to the catheter itself to confirm stimulation of the nerve with final catheter position.

When final catheter position is established, the transducer is placed on the sterile field and both hands are used to stabilize the catheter while removing the introducer needle. With the needle removed, catheter depth is then noted at the level of the skin. The catheter is then held securely against the skin with one hand as the other hand uses the transducer to re-confirm position of the distal catheter tip.

Fig. 12.3 Ultrasound image of IP needle and catheter at deep margin of femoral nerve

Fig. 12.4 Ultrasound image of catheter and circumferential fluid at femoral nerve

Fig. 12.5 Photograph of femoral catheter securely taped under sterile dressing
Following negative aspiration, an assistant slowly administers local anesthetic through the catheter ensuring minimal resistance and no pain or paresthesias, while the clinician observes the hypoechoic fluid accumulating around the nerve (Fig. 12.4). To minimize superficial tracking along the catheter, the volume of local anesthetic should be injected slowly with minimal pressure. To maintain intact dressings secure the catheter only after the initial medication bolus (Fig. 12.5).
The first six Sections of this text focused on the core knowledge and skill sets required for safe and effective ultrasound-guided vascular access and regional anesthesia. However accomplished one is with this new technology, there are challenges to implementation within our daily scope of practice. The expectations of patients, surgeons, and our hospitals all must be addressed to ensure successful integration of ultrasound in clinical anesthesia practice.

**Patient Expectations**
As skilled as we may become with ultrasound-based procedures, success is ultimately limited by the patient care experience. The patient is likely to convey their views of the anesthetic experience to their surgeon, family, and friends. Although less relevant for vascular access (as most commonly performed after induction of general anesthesia), the patients’ peri-operative regional anesthesia experience is critical to the success of these programs.

**EDUCATION**
Most patients have little experience with anesthesia. What presents even greater challenge is that many patients only consider, and expect, a general anesthetic for surgery. The clinician should describe for the patient the ultrasound-based regional anesthesia techniques to be used for both intra-operative and post-operative care, ideally in a pre-admission facility well ahead of surgery. Informing patients in this manner may promote greater interest in their anesthetic care and ease concerns about the interventional nature of the procedure. In addition to the potential for improved pain control and decreased side effects of general
anesthetics and multiple pain medications, the technology itself often positively promotes further inquiry and patient interest.

**COMFORT**
Patients tend to be uneasy of needle placement deep to the skin while they are awake, and this can be a challenge for any form of regional anesthesia. Thus providing adequate information and emphasizing patient comfort during all ultrasound-guided regional anesthesia is an essential part of block success. Using local anesthetics and low-dose benzodiazepines before block placement is important to minimize patient discomfort, reduce anxiety, and ensure a positive experience. Once comfortable and at ease, many patients engage with the ultrasound screen image as the block is performed, thereby ‘participating’ in their clinical care.

**WHEN TO ‘DEFER’**
Despite embracing the role of ultrasound-guided regional anesthesia for improving peri-operative care, we must address patient’s or surgeon’s doubts or hesitation towards performing a regional block. Adding ultrasound to regional anesthesia practice does not lessen our need to be vigilant in preventing negative outcomes - this is important to emphasize as we implement this new technology. The growing use of ultrasound and its increasing application to regional anesthesia will not eliminate the reporting of observed complications, and therefore careful consideration of all regional blocks is critical to the long-term success of each program.

**Surgical Expectations**
A lack of communication with our surgical colleagues may defeat a new ultrasound program before it has taken hold. Therefore, there are some common themes to address at the outset in this regard.

**TIMELINESS**
Whatever efficiencies may be eventually realized perioperatively, there is little room to accommodate anesthetic delays due to innovation and learning curves. Each individual clinician and setting will determine the optimal process and schedule for transition from pre-operative anesthesia care to intra-operative surgical care. Regardless of the process established, a key component to timeliness is defining your block outcome before surgical start to establish the exact anesthetic plan (light vs. deep sedation) and avoid undue challenges or delays.
EFFICIENCY
Acquiring ultrasound-based regional anesthesia skills is time intensive, at least initially. However, anesthetic time savings will be realized within each operating room once programs are established and integrated with overall patient care. Such efficiencies in well-developed ultrasound-regional anesthesia programs can improve analgesia after discharge, increase patient case loads, and allow a transition from inpatient to outpatient care strategies.

PATIENT FEEDBACK
There is often limited knowledge of the anesthesiologist’s role in patient analgesia peri-operatively. It is personally gratifying to realize the positive impact of our care, however, positive patient experiences conveyed to our surgical colleagues may be even more important to achieve the full impact of regional anesthesia as it extends to the post-operative patient disposition. Repeated accounts of the care experience, when combined with operating room efficiencies, will go a long way to establishing ultrasound-based regional anesthesia programs.

Hospital Expectations
The limitations of our individual hospital settings are uniquely, and strongly defined by administrative priorities. With limited knowledge of the numerous facets of hospital administration, our potential to engage the hospital as a key collaborator in supporting the clinical interests of our patients is potentially lost.

HOSPITAL MANDATES AND PRIORITIES
In many regions, hospitals are increasingly emphasizing initiatives to improve peri-operative pain control, increase out-patient surgery, and increase the number of patients that can be managed with the same or reduced budgets. Using ultrasound for regional anesthesia may accommodate such hospital priorities. Therefore, hospital administration could be supportive collaborators in implementing new care strategies, and anesthesiologists must hone their communication skills to show how we can align our patient care goals with those of the surgeons, and hospitals, through development of ultrasound-based regional anesthesia programs.
The cost of implementing a new care strategy determines, at an early stage, a hospital’s willingness to invest in the required resources. But, the anesthesiologist’s role may not always be clear to hospital administration. Efforts to demonstrate our key role in innovative care strategies are essential to tap funding from general operating budgets as well as private donors. A coherent patient-care initiative that highlights the anesthesiologist’s ability to improve peri-operative pain control, increase the number of patients treated, decrease length of stay, and reduce inpatient costs has strong resonance to gain administrative support.

Enhancing awareness of how the interests of patients, surgeons, and hospital administration may be collectively realized through investment in innovation is key to the successful launch of ultrasound-based anesthesia programs.
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Brian Pollard is a Staff Anesthesiologist at St. Michael’s Hospital in Toronto and an Associate Professor of Anesthesia at the University of Toronto, Canada. As a clinical educator, he emphasizes the perspective of the learner from the introduction of fundamental concepts through to consideration of individual practice settings and goals. This well written and fully illustrated handbook provides a foundation for implementing ultrasound imaging and needle guidance technology into peri-operative anesthesia practice.

Ultrasonix Medical Corporation innovates, designs, and manufactures ultrasound imaging systems to make ultrasound accessible for more clinicians in more areas of patient care. Our latest breakthrough innovation, SonixGPS, is a needle tracking system that allows clinicians to accurately predict the needle’s trajectory during procedures for vascular access and regional anesthesia. SonixGPS projects the needle’s virtual path through the tissues to facilitate access to an anatomical target at variable depths, from any angle, in-plane or out-of-plane. Recognizing that clinicians will be treading new ground with this technology, we are pleased to support Dr. Pollard’s handbook for learning techniques of ultrasound imaging and needle guidance for vascular access and regional anesthesia procedures.

Please visit our website for more information: ultrasonix.com/GPS