

# Ultrasound-guided regional anaesthesia

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## Key points

Ultrasound in regional anaesthesia offers a new standard in nerve location and identification, allowing real-time imaging of nerves and direct needle guidance.

All needles show up equally well on ultrasound, but it is imperative that the needle tip is in the field of vision at all times.

The aim is not to touch the nerve but place the needle close to it; nerve identification can be confirmed by the combined use of peripheral nerve stimulation.

A successful block is one in which the local anaesthetic is seen to spread around the nerve under direct vision.

Ultrasound location offers the opportunity to improve success, reduce complications, and enhance teaching of regional anaesthesia.

Diagnostic medical ultrasound (US) uses high-frequency sound waves (2–15 MHz), in real-time visualization of both superficial and deep structures. From its early application in obstetrics, it has now developed into the most commonly used imaging technique accounting for >40% of all radiological examinations. Technological advances in piezoelectric materials, electronics, and software have enabled improved probe design and software capability; this has led to the development of small, portable 2D machines with good resolution and penetration available for bedside ‘point-of-care’ use.

High-frequency probes (5–15 MHz) with improved resolution now allow visualization of superficial structures including arteries, veins, muscles, tendons, and nerves. This, with the incorporation of Doppler technology, has led to an expansion in the use of US in anaesthesia and intensive care. Following the introduction of NICE 49 (2002) guidelines<sup>1</sup> recommending the use of US for the placement of central venous catheters, the availability of portable US machines within anaesthetic departments has significantly increased. US is now used routinely for cardiac imaging and cardiac output monitoring, vascular access and simple diagnostics, and aspiration in ICU (pleural effusion, abscesses).

Regional anaesthesia is another developing area of US use.<sup>2</sup> Portable 2D US allows the clinician to place needles with precision, guided by a real-time image of the patient’s actual anatomy and not that implied by surface anatomical landmarks. Such techniques offer potential advantages over established techniques including: improved success rates; reduced complications; and enhanced teaching. In order to benefit from these advantages, clinicians require training in this new technique as well as access to appropriate equipment and consumables. US is a dynamic technique and, as such, very operator-dependent.

In the last 10 yr, ultrasound has been used sporadically by enthusiasts to perform a variety of regional techniques. The machines employed initially were inadequate to obtain the images of sufficient quality to sustain both reliability

and interest. However, the use of modern higher specification cart-based machines have confirmed the potential of US in regional anaesthesia, and the presence of smaller portable laptop-type machines (e.g. Sonosite demands) have now made US-guided regional anaesthesia a reality.

## Basic principles of ultrasound

Ultrasound imaging is based on sound waves that are transmitted from, and received by, an US transducer utilizing frequencies of 2–15 MHz (human hearing operates at 1–20 kHz). Most transducers use artificial polycrystalline ferroelectric materials (ceramics) [e.g. lead zirconate titanate (PZT)], which have piezoelectric properties. When a current is applied across the crystal, it expands and contracts as the polarity of the voltage changes. This produces a series of pressure waves (sound waves). This also works in reverse; when the sound wave returns, it squeezes and stretches the crystal generating a voltage change across its surface which is amplified and forms the receiving signal.

The speed of sound in tissue varies according to its density and compressibility. The US beam is reflected at the interface between different structures; reflectivity is dependent on the difference in acoustic impedance between those structures and also the angle of the US beam. These interface reflections form the basis of the grey US image which is presented as a matrix of picture elements or pixels. When there are small differences in acoustic impedance, more of the US beam will be transmitted through to deeper structures. However, if there is a large difference in acoustic impedance between tissues, a greater proportion of the beam is reflected, obscuring deeper tissues (air/tissue interface—99% reflected) (Table 1).

Reflectivity is greatest when the object being visualized is perpendicular to the angle of the US beam. As the angle of incidence decreases from 90°, the US beam is reflected away from the transducer and will not form part of the image. As sound passes through

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**Table 1** Reflection of sound waves by various tissue interfaces

Interface	Reflection coefficient	% Beam reflected
Muscle–fat	0.01	1
Tissue–bone	0.5	50
Tissue–air	0.999	99

tissue, a proportion is reflected as useful echoes; some are scattered by tissues and some are absorbed as heat. Only the reflected sound waves contribute to the image. Sound absorption is directly proportional to the frequency of the US beam. As low-frequency waves are less attenuated, they will penetrate tissues better than high frequencies. High-frequency probes give good resolution, but lack the ability to penetrate, whereas low-frequency probes, although penetrating deeper, have reduced resolution.

### Advantages of US guided regional anaesthesia

Nerve location and identification have historically been achieved by the use of surface anatomical landmarks with either paraesthesia or peripheral nerve stimulation (PNS) being used to confirm needle position and nerve identity. These are essentially ‘blind’ techniques. Ultrasound offers an alternative method, a ‘seeing’ technique with real-time visualization of the nerve/needle interaction which can be used in conjunction with PNS or on its own.

The advantages of the ultrasound technique include:

- (i) ability to visualize and identify the target nerve(s) and their relationship to surrounding structures (e.g. arteries, veins, lung, other nerves);
- (ii) allow for patient variability (e.g. size, shape, anatomical variations);

- (iii) determine depth, angle, and path of the needle to the target nerve;
- (iv) real-time visualization of the technique and guidance of the needle to the target;
- (v) visualization of the spread of local anaesthetic (encircling nerve) and placement of a catheter;
- (vi) allow the procedure to be carried out on anaesthetised patients safely (e.g. children) and even to be repeated if ineffective;
- (vii) portability and safety (no ionizing radiation).

### Peripheral nerves

A nerve is a collection of axons linked together by support tissue (endoneurium, perineurium, and epineurium) into an anatomically defined trunk. The axon may be motor or sensory, myelinated or non-myelinated. The US appearance of a nerve is primarily dependent on its size and the amount and make-up of the support tissue (epineurium, perineurium). Axons, or in reality fascicles (collection of axons), appear black (hypoechoic) and the supporting tissue appears bright (hyperechoic). At different levels (roots, trunks, and peripherally), the same nerve may vary in appearance from being hypoechoic (bubbles/holes at the roots) to hyperechoic ovoid, triangular or flattened structures in the periphery. This is possibly because of the changing nature of the fascial covering of the nerve as they divide and pass through different tissues (Table 2).

### Scanning techniques

Not all nerves and plexuses are suitable for US-guided techniques. Ideally, superficial nerves or plexuses are easier to visualize (e.g. brachial plexus). Large nerves are commonly easier to see with the exception of the sciatic nerve in the buttock which,

**Table 2** Sonographic appearance of peripheral nerves and surrounding tissues

Tissue	Ultrasound appearance
Arteries	Anechoic (black circles, tubes), pulsatile
Veins	Anechoic (black circles, tubes), compressible
Tendons (strongly anisotropic) <i>Fibrillar pattern</i>	Longitudinal, tubular structure. Internal architecture, loosely packed continuous blurred bright lines (hyperechoic), pale surface. Transverse, circular structure with pale halo (tendon sheath). Internal architecture hyperechoic (semi-bright) dots (tendon fibrils) loosely packed, within hypoechoic (darkened) surroundings, granular appearance
Nerves (weakly anisotropic) <i>Fascicular pattern</i>	Longitudinal, tubular structures, bright surface. Internal architecture multiply broken bright (hyperechoic) lines. Transverse, circular structure with bright surface (epineurium). Internal architecture multiple hypoechoic black dots (nerve fascicles) with bright outlines within bright surroundings (connective tissue, perineurium), speckled appearance
Pleura	Hyperechoic line(s), one or two with movement.
Lung	Multiple grey echoes, unable to see into lung
Bone	
Periosteum	Hyperechoic ++ line.
Cortex and medulla	Anechoic, black (acoustic shadow, due to reflection of beam by periosteum)

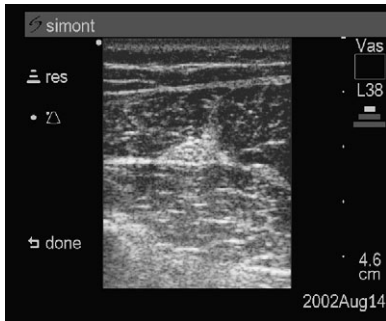


Fig. 1 Sciatic nerve—short-axis view.

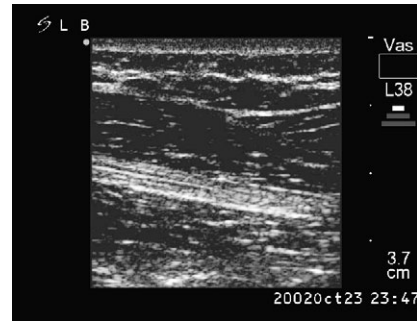


Fig. 2 Sciatic nerve—long-axis view.

because of the attenuation of the US beam by the surrounding muscle, is often difficult to visualize. When the nerves are accompanied by or are in close proximity to vessels, this often aids identification, as contrast is improved and vessels easily identified. Air and bone reflect large amounts of the US beam and, as such, any nerve hidden or obscured by bone or air is impossible to see (e.g. intercostal nerve).

### Ultrasound equipment and settings for regional anaesthesia

Either a laptop- or a cart-based machine is applicable. The most commonly used probe is a high-frequency, linear array probe (5–10 MHz), as this gives good spatial resolution for the nerves and plexuses, which are usually superficial (1–5 cm deep). A low-frequency curvilinear probe (2–5 MHz) can be useful for deeper nerves and plexuses, but it is limited by its poor spatial resolution at increasing depth. Most machines have preset factory setting (e.g. musculoskeletal, vascular, nerve) to optimize tissue visibility and picture quality. Further adjustment of depth and gain will focus the beam to the correct level and allow an improved grey/white scale. Access may be limited by the size of the probe (footprint) and therefore smaller probes may be needed in certain anatomical locations and patients (supraclavicular, paediatrics).

### Needling techniques

All needles show up equally well with US, although larger needles and certain needle tip designs (Tuohy) have a brighter echo. The angle at which the needle is introduced beneath the US beam is very important; reflectivity of the needle is greatest when the needle is parallel to the probe face.<sup>3</sup> As the angle of the needle is increased beyond 45°, the needle becomes increasingly difficult to see.

When scanning in regional anaesthesia, the view encountered by the US beam will either be a short-axis view (SAX), the nerve being visualized in section (Fig. 1) or a long-axis view with the nerve visualized longitudinally (Fig. 2). Each of these views have their advantages, but usually for the purposes of introducing a needle, the SAX is preferred, as it is easier to hold the nerve in view while introducing the needle.<sup>4</sup> The needle can then be

introduced either along the long axis of the probe (long-axis technique, LAT) or across the short axis of the probe (short-axis technique, SAT) (Fig. 3). The advantages and disadvantages of these approaches are summarized in Table 3. The only safe approach or needling technique is one in which the needle is visualized throughout the entire procedure.

### Practical application

The probe is placed lightly on the skin over the target plexus or nerve, ensuring an air-free contact using gel or alcohol spray. The probe is orientated so as to mirror hand movements (all probes have a mark which corresponds to a dot on the screen). Gently move the probe, visualizing the target and noting its relationship to other important structures (arteries, veins, and pleura). Gentle pressure will usually distinguish arteries from veins (arteries—pulsatile anechoic, veins—compressible anechoic). The image quality is maximized by adjusting depth, scanning parameters, and gain as appropriate. With the target in the middle of the screen, the skin is gently pressed as this will help to determine the optimum entry point which is infiltrated with local anaesthetic.

The site is cleaned with alcohol solution (isopropyl alcohol 70%), draped, and the probe is covered. Air is the worst medium for ultrasound (99% of the beam is reflected from an air–tissue interface obscuring any view of deeper structures) and it is therefore important to ensure an adequate layer of gel on the probe and remove all air from the injectate to prevent ‘whiteout’. Using a needle of your choice (insulated or non-insulated), the needle is introduced either along the long axis of the probe (LAT), or at

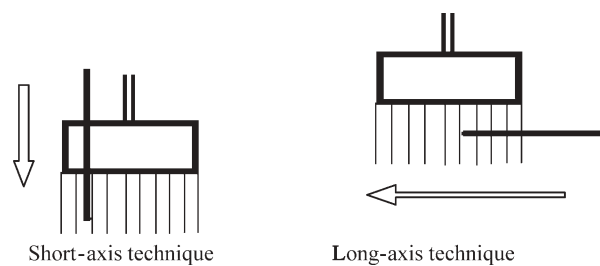


Fig. 3 Needling techniques.

**Table 3** Advantages and disadvantages of the LAT or SAT of needle insertion when using the SAX

Needle insertion SAX	Advantages	Disadvantages
LAT Parallel to US beam—along the long axis of the probe	Needle visualized in entire length. Good visualization of needle–nerve proximity.	Difficult to keep needle in view. Unusual needle entry point. Longer distance—skin to nerve. Often passing through muscle—painful.
SAT At right angles to the beam—across the short axis of the probe	Uses normal entry points (Winnie’s—interscalene block). Shortest distance skin–nerve. Less painful—not through muscle.	Needle only visualized as a bright dot when in the US beam. Poor vision of needle–nerve proximity.

right angles to the beam (SAT). After passing through the skin, the needle is identified within the US beam and directed to the target, positioning it beside the nerve (do not deliberately contact the nerve). A peripheral nerve stimulator can be used in conjunction with the US. This confirms position, identity of the nerve, and aids teaching. Finally, the local anaesthetic is injected in 1–2 ml aliquots and the spread of solution (encircling nerve) is observed. If this is unacceptable, the needle is repositioned under direct vision and re-injected.

Commonly used regional techniques utilizing ultrasound are summarized in Table 4.

### Common artefacts

All US pictures are a mixture of real and artefactual images, and one needs to be aware of common artefacts that may be seen. These include:

*Post-cystic enhancement:* increased brightness behind fluid filled structures—cyst, large veins/arteries.

*Acoustic shadowing:* highly reflective surfaces (bone) reflect almost all of the sound beam, throwing a shadow over all deeper structures.

**Table 4** Commonly used regional techniques: US parameters, needling technique, and common findings

Technique	Suggested probe/depth to nerve	Scanning level approach/needleorientation	Common findings
Interscalene	L probe/5–10 MHz, 1–2 cm	Oblique C6 level interscalene (classical Winnie’s) 50 mm, SAT	Follow sternomastoid muscle laterally hypoechoic bubbles, between scalenus anterior/medius Commonly see upper three roots C5, 6, 7.
Supraclavicular	L probe/5, 10 MHz narrow footprint 25 mm, 0.5–2.0 cm	Para-sagittal or oblique coronal plane (above the clavicle) 50 mm, SAT/LAT	Hypoechoic holes supero-posterior to subclavian artery (trunks/divisions)
Infraclavicular	L probe/5–10 MHz if plexus <5 cm CL probe/2–5 MHz if plexus >5–6 cm	Deltpectoral groove para-sagittal view (subcoracoid) 50–100 mm SAT/LAT	Identify axillary vein and artery (ant → post), artery surrounded by hyperechoic structures (cords) at 2,5 and 10 O’clock
Axillary	L probe/5–10 MHz, 1–2 cm	Axilla, transverse plane 50 mm SAT/LAT	Variability in position/number of nerves, artery, and veins Radial nerve often difficult to visualize
Peripheral nerves median, ulnar, and radial	L probe/5–10 MHz, 0.5–2 cm	All in transverse plane <i>Radial</i> , one hands breadth above lateral epicondyle <i>Median</i> , elbow crease <i>Ulnar</i> , mid-forearm 50 mm SAT/LAT	Radial, close to humerus, triangular hyperechoic structure Medial, medial to brachial artery, oval shape Ulnar, accompanied by ulnar artery mid-forearm
Ilioinguinal	L probe/5–10 MHz, 0.5–5 cm	Horizontal plane at ASIS level 50 mm SAT/LAT	Good visualization of rectus sheath and abdominal muscles, ilioinguinal nerve between internal oblique and transversus abdominis muscles
Sciatic	L probe/5–10 MHz, if nerve <5 cm CL probe 2–5 MHz if nerve <5 cm 3–7 cm	Transverse plane subgluteal or mid-thigh level 50–100 mm SAT/LAT	Hyperechoic, flattened/oval nerve (<3 cm in width), often identified easiest in LAX view Post cutaneous nerve of thigh, medial
Femoral	L probe/5–10 MHz, 1–5 cm	Horizontal plane at inguinal ligament level (Winnie’s 3:1) 50 mm SAT/LAT	Med → Lat, Vein/Artery/Nerve Visualize as close to inguinal ligament as possible—before nerve divides. Triangular hyperechoic structure, inject beneath iliopectineal fascia
Popliteal	L probe/5–10 MHz, 2–6 cm CL probe/2–5 MHz	Transverse plane Supine, lateral approach Prone, lateral/posterior approach 50–100 mm SAT/LAT	Hyperechoic structures, sciatic nerve divides into tibial/common peroneal, 5–12 cm above popliteal crease (find division if possible—single injection above/double below). Tibial nerve superficial to popliteal vessels
Spinal/epidural	CL probe/2–5 MHz Large footprint 60 mm (adult)	Paramedian, para-sagittal plane, at lumbar level	Spinal, impractical for procedure, only used to confirm level. Epidural/caudal, good visualization only in neonates and small infants

*Anisotropy*: the image of certain tissue is highly dependent on the angle to the US beam at which they are viewed (90° good picture, <60° no picture). Nerves are weakly anisotropic.

*Air*: the ultrasound beam will not pass through air (whiteout/dirty picture). It is therefore not possible to see through or into air-filled cavities. It is important to ensure a layer of gel on the probe to provide air-free contact with skin.

### Brachial plexus block (axillary approach)

Most commonly used approaches to the brachial plexus can be performed using US guidance;<sup>5,6</sup> the axillary approach is the most popular, as it is intrinsically safe with few serious or lasting side-effects. Unfortunately, it has a surprisingly poor success rate if used as a single-injection technique and, to block reliably all nerves (median, ulnar, radial, and musculocutaneous), multiple injections are required. The explanation for this is illustrated in ultrasound studies of the anatomy, which demonstrate a tremendous variability in positioning of nerves, veins, and arteries within the axilla.<sup>7</sup> Also, the spread of local anaesthetic as visualized by US (P. Marhofer, personal communication) confirms previous studies indicating the presence of septae within the sheath restricting free spread of local anaesthetic.<sup>8,9</sup> The US guidance offers an alternative technique that can allow for these anatomical variations ensuring consistent spread of local anaesthetic around all nerves. The benefits of this can be seen in studies showing improved success rate, decreased onset time, and the requirement for reduced volumes of local anaesthetic.<sup>10</sup> Decreased incidence of complications, including vascular puncture and nerve damage, should logically follow. However, as yet, this has not been demonstrated, probably because of the small numbers in most studies.

### Conclusion

At present, there are few randomized controlled studies comparing the use of US in regional anaesthesia with established techniques. Most published studies use a cart-based machine costing up to £125 000 which, although giving the state-of-the-art imaging, are not easily transported or accessible for theatre use. Portable hand-held machines are filtering into hospitals on the back of the

NICE guidelines and are being used by enthusiasts. Their benefits in regional anaesthesia, although obvious in theory, will be more difficult to prove in practise. The major limitation to the routine use of US in regional anaesthesia is the cost and availability of these portable machines. Basic machines cost upwards of £10 000, with more sophisticated and multipurpose machines costing £15–30 000. Once purchased, training and support is essential.

US offers a unique opportunity for the future development of regional anaesthesia. It allows us to look at established techniques with fresh eyes, enabling us to refine these techniques, improve training, and complement existing practice.

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Please see multiple choice questions 17–21