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REVIEW ARTICLE

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Ultrasound guidance in regional anaesthesia<sup>†</sup>

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The technology and clinical understanding of anatomical sonography has evolved greatly over the past decade. In the Department of Anaesthesia and Intensive Care Medicine at the Medical University of Vienna, ultrasonography has become a routine technique for regional anaesthetic nerve block. Recent studies have shown that direct visualization of the distribution of local anaesthetics with high-frequency probes can improve the quality and avoid the complications of upper/lower extremity nerve blocks and neuroaxial techniques. Ultrasound guidance enables the anaesthetist to secure an accurate needle position and to monitor the distribution of the local anaesthetic in real time. The advantages over conventional guidance techniques, such as nerve stimulation and loss-of-resistance procedures, are significant. This review introduces the reader to the theory and practice of ultrasound-guided anaesthetic techniques in adults and children. Considering their enormous potential, these techniques should have a role in the future training of anaesthetists.

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The key requirement for successful regional anaesthetic blocks is to ensure optimal distribution of local anaesthetic around nerve structures. This goal is most effectively achieved under sonographic visualization. Over the past decade, the Vienna study group has demonstrated that ultrasound guidance can significantly improve the quality of nerve blocks in almost all types of regional anaesthesia. In addition, complications such as intraneuronal and intravascular injection can be avoided. A summary of the potential advantages of regional anaesthetic techniques performed under ultrasonographic guidance is given in Table 1.

The use of ultrasound guidance in daily clinical practice requires high-level ultrasonographic equipment and a high degree of training. Anaesthetists need to develop a thorough understanding of the anatomical structures involved, and they need to acquire both a solid grounding in ultrasound technology and the practical skills to visualize nerve structures. The successful performance of nerve block under direct ultrasonographic guidance varies with the operator's skill in a given regional anaesthetic technique. Experience from our group suggests that it is best to begin learning ultrasonographic block on peripheral nerves under supervision before going on to more central blocks. Despite a lack of specific learning curves for ultrasonographically guided regional anaesthetic nerve blocks, we have observed a rapid increase in the number of successful blocks

performed by anaesthetists experienced in regional anaesthesia, always depending on individual ability. To offer an improved background in ultrasonography and regional anaesthesia, interested anaesthetists should take part in specific workshops.

Our group has performed more than 4000 nerve blocks under direct ultrasound guidance since the technique was first implemented as a routine procedure 10 years ago. The success rate has been almost 100%. In addition to this high success rate compared with the conventional guidance technique of nerve stimulation, significant improvements have also been obtained in terms of sensory and motor onset times. This superior quality of perioperative analgesia has greatly improved patient satisfaction among adults and children alike.

In this review article, we discuss the present state of ultrasound guidance in regional anaesthesia by revisiting both our own findings and other recent publications available on the subject. The technological background is described, suitable equipment is recommended, and a detailed account is given of which types of nerve block lend themselves to sonographic guidance and how they can be performed in a straightforward and safe manner.

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<sup>†</sup>This article is accompanied by Editorial I.

**Table 1** Potential advantages of ultrasound guidance compared with conventional techniques of nerve identification in regional anaesthesia

Potential advantage	References
Direct visualization of nerves	13, 17, 21, 26, 27, 37, 39, 40, 52, 54, 62, 66
Direct visualization of anatomical structures (blood vessels, muscles, bones, tendons) facilitating identification of nerves	23, 26, 27, 31, 32, 33, 37, 38, 39, 40, 52, 54, 57, 62, 66
Direct and indirect visualization of the spread of local anaesthetic during injection with the possibility of repositioning the needle in cases of maldistribution of local anaesthetic	26, 27, 37, 38, 39, 40, 54
Avoidance of side-effects (e.g. intraneuronal injection of local anaesthetic, inadvertent intravascular injection)	20, 21, 26, 27, 37, 38, 39, 40, 54
Avoidance of painful muscle contractions during nerve stimulation (e.g. in cases of fractures)	40
Reduction of the dose of local anaesthetic	38, 39
Faster sensory onset time	37, 39, 40, 54
Longer duration of blocks	40
Improved quality of block	37, 39, 40, 54

## Rationale

Nerves are not blocked by the needle but by the local anaesthetic. The traditional guidance techniques used in regional anaesthesia have consistently failed to meet this perfectly logical requirement. 'Blind' blocks that rely solely on anatomical landmarks and/or fascia clicks (e.g. ilioinguinal nerve blocks) are known to produce serious complications.<sup>24,53</sup> Even the technique of nerve stimulation which has been recommended as the gold standard for nerve identification in regional anaesthesia over the past decade fails to ensure an adequate level of nerve block (e.g. in axillary brachial plexus blocks). In addition, it carries a risk of inflicting damage to nerve structures by direct puncture.<sup>14</sup>

Before the advent of ultrasound in regional anaesthesia, it was impossible to verify precisely where the needle tip was located relative to the nerves and how the local anaesthetic was distributed. Ultrasound visualization of anatomical structures is the only method offering safe blocks of superior quality by optimal needle positioning. In addition, the amount of local anaesthetic needed for effective nerve block can be minimized by directly monitoring its distribution.<sup>39</sup>

The use of ultrasound for nerve block was first reported by La Grange and colleagues in 1978, who performed supraclavicular brachial plexus blocks with the help of a Doppler ultrasound blood-flow detector.<sup>35</sup> These early reports did not have much clinical impact because the scope for visualizing anatomical structures by ultrasound was still limited. It was confined to identifying vessels by Doppler ultrasound. Over the past 10 yr, however, dramatic progress has been made. The latest ultrasound images<sup>40,50</sup> obtained for regional

anaesthesia have come a long way compared with several years ago.<sup>8,39,66</sup>

In two recent editorials, Greher and colleagues<sup>21</sup> and Peterson<sup>51</sup> discussed various important aspects of using ultrasound to identify nerve structures in regional anaesthesia. While both agree that ultrasound will be the guidance technique of the future, the transition from the conventional technique of nerve stimulation will take another 10 yr or even longer to complete. There are significant mental obstacles to be overcome, and the financial resources are not going to be redistributed rapidly. However, if our patients are entitled to optimal anaesthetic care, then the optimal technique of applying nerve block must eventually prevail.

## Equipment

Visualizing nerves by sound waves requires the use of high frequencies offering high-resolution images. However, the higher the frequency, the smaller the penetration depth. Most nerve block applications require frequencies in the range of 10–14 MHz. Broad-band transducers covering a band width of 5–12 or 8–14 MHz offer excellent resolution of superficial structures in the upper and good penetration depth in the lower frequency range.

The connective tissue inside the nerves (perineurium and epineurium) reflects ultrasound waves in an anisotropic manner. Essentially, the angle and intensity of the reflection depends on the angle of the ultrasound wave relative to the long axis of the nerve. The true echogenicity of a nerve is only captured if the sound beam is oriented perpendicularly to the nerve axis. Consequently, linear array transducers with parallel sound beam emission offer advantages over sector transducers, which are characterized by diverging sound waves, such that the echotexture of the nerves will only be displayed in the centre of the image.

Ultrasound-guided nerve block can be performed with most modern ultrasound systems. They should be equipped with software to visualize both superficial tissues and musculoskeletal structures. High-resolution ultrasound (HRUS) systems are provided with software that allows optimal visualization of tissue contrast. Colour and pulsed-wave Doppler imaging is also required to identify vessels. The equipment should include a high-capacity hard disk to store images and short film sequences, as well as a CD burner to store the data files directly in TIF, JPG, BMP and MPG4 formats.

Appropriate portable ultrasound units have also been developed in recent years. These units are significantly less expensive than large systems.

## Sonographic appearance of peripheral nerves

Peripheral nerves may have a hypoechoic (dark structures) or hyperechoic (bright structures) sonographic appearance,<sup>13,57</sup> depending on the size of the nerve, the

sonographic frequency, and the angle of the ultrasound beam. We perform most blocks on transverse scans, where the nerves appear as multiple round or oval hypoechoic areas encircled by a relatively hyperechoic horizon (Fig. 1). These hyperechoic structures are the fascicles of the nerves while the hypoechoic background reflects the connective tissue between neuronal structures. In a longitudinal view, each nerve appears as a relatively hyperechoic band characterized by multiple discontinuous hypoechoic stripes separated by hyperechoic lines (Fig. 2). As the fascicles are the main sonographic feature of peripheral nerves, their appearance has been described as a ‘fascicular pattern’, as opposed to the ‘fibrillar pattern’ of tendons, characterized by multiple hyperechoic continuous lines. The number of fascicles observed on HRUS does not reflect the true number of fascicles within the nerve, as the smallest fascicles cannot be visualized by ultrasound. The fascicular pattern seems to be typical of large peripheral (e.g. median, ulnar and radial)

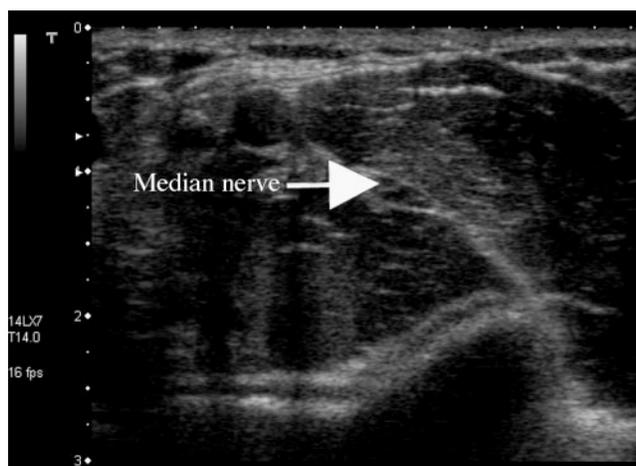
nerves and is not seen with smaller (e.g. recurrent laryngeal and vagal) nerves.

Most peripheral nerves can be visualized over their entire course. Their visibility is only limited where dorsal shadows of bone structures or large vessels are present.

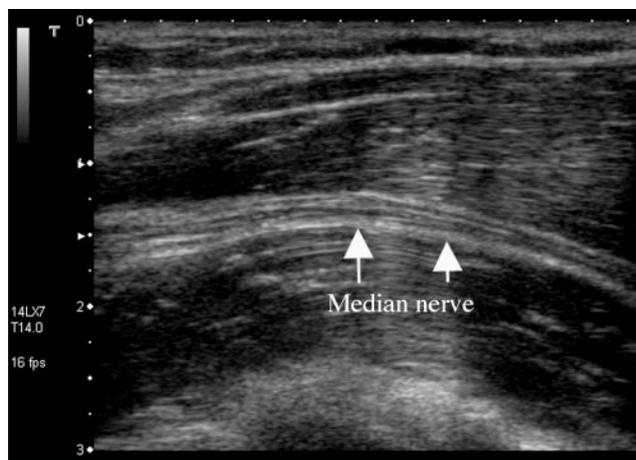
### Performing ultrasound-guided nerve block

The first step in ultrasound-guided nerve block is to visualize all the anatomical structures in the target area. All adjustable ultrasound variables, i.e. penetration depth, the frequencies, and the position of the focal zones, must be optimized for the type of block to be performed. Both the skin and the ultrasound probe need to be disinfected. Most conventional disinfectants can be used on ultrasound probes. A sterile ultrasound jelly will provide aseptic conditions for the nerve block (a jelly for urinary catheters can also be used). Alternatively, the probe can also be wrapped in a sterile glove.

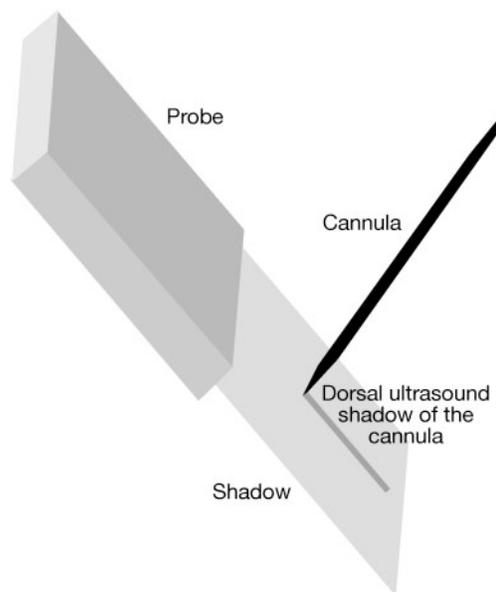
The next step is to perform subcutaneous infiltration in order to render the procedure painless. We use 22-gauge 40–80 mm needles with a facette tip (Pajunk™, Geisingen, Germany). Depending on the type of nerve block, the puncture will be performed 5–10 mm distal or proximal to the probe with ultrasound imaging in the transverse plane. Figure 3 illustrates that the identification of the needle is only possible when the needle crosses the ultrasonographic level of the probe. The needle itself is identified as a hypoechoic structure and a dorsal acoustic shadow is generated by the needle. In addition, the needle is also identified by



**Fig 1** Transverse section of the median nerve at the cubital level, using an Aplio system with an 8–14-MHz linear probe (Toshiba Medical Systems, Tustin, CA).



**Fig 2** Longitudinal section of the median nerve below the cubital level, using an Aplio system with an 8–14-MHz linear probe.



**Fig 3** Sonographic visualization of the cannula. The linear probe produces an image of rectangular cross-section depending on the dimensions of the probe, owing to the frequency-dependent penetration depth (the higher the ultrasound frequency, the smaller the penetration depth). The cannula can be adducted to any point of this cross-section and is identified as a hypoechoic structure with a dorsal acoustic shadow.

direct needle movement and tissue displacement. It is important to fill the needle system with local anaesthetic before puncture to avoid air inclusion. Once the needle is optimally in place, the local anaesthetic is administered under direct sonographic visualization until the nerve structures are surrounded by local anaesthetic. If the local anaesthetic spreads in the wrong direction, the needle can be repositioned accordingly.

Perlas and colleagues<sup>50</sup> suggested a technique of advancing the needle in a longitudinal direction relative to the ultrasound probe (long axis). This insertion path is, however, three times longer than the transverse route (short axis). In the transverse approach, the direction of the needle is similar to the one used for nerve stimulation. This is our preferred technique for most types of nerve block because the shorter insertion path is more comfortable for the patient.

The option of directly seeing the distribution of the local anaesthetic by ultrasonography minimizes the doses to be administered for effective nerve block, which is particularly relevant in multiple block procedures (e.g. 3-in-1 or sciatic nerve blocks). Older and sick patients benefit the most from this advantage.<sup>38</sup>

## Upper extremity nerve blocks

The brachial plexus is formed by the anterior portions of the C5–T1 nerve roots. In 60% and 30% of patients, respectively, it also encompasses the C4 and T2 roots. The roots pass dorsal to the vertebral artery through the intervertebral foramina. From there, they directly enter the posterior interscalene space where they descend towards the first rib and converge to form three (superior, medial and inferior) trunks, which bifurcate into an anterior and a posterior branch at the supraclavicular level. Having crossed the first rib, they separate into the posterior, lateral and median cords forming the terminal nerves, starting from the upper border of the clavicle. Some nerves descend from a more proximal location at the level of the trunks (e.g. the suprascapular nerve). In the ‘deviation zone’ at the level of the first rib, the cords of the brachial plexus rotate around the subclavian artery in a corkscrew manner. Thus, the lateral and posterior cords have a ventral and median position, respectively, directly below the clavicle. At this level, the median cord is located below the lateral cord. In other words, the nomenclature of these cords only applies at the axillary level.

### *Interscalene brachial plexus block*

This type of block is indicated for surgical procedures in the shoulder and upper arm area. Winnie originally placed the puncture at the level of the laryngeal prominence on the lateral border of the sternocleidomastoid muscle with the needle in a perpendicular direction.<sup>63</sup> This needle direction used to cause major complications, such as puncture of the epidural space,<sup>36,59</sup> or inadvertent administration of local

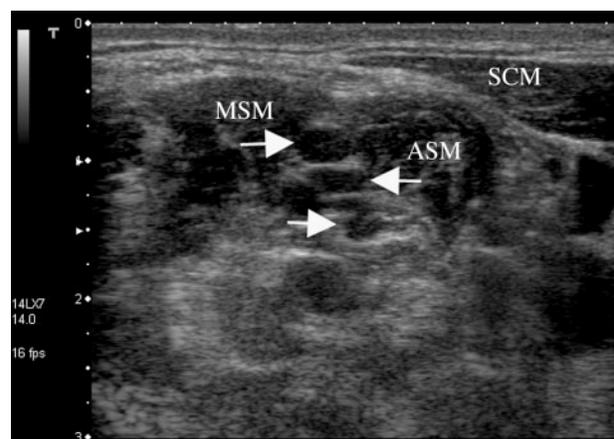
anaesthetic into the vertebral artery (with a risk of seizures).<sup>58</sup> The technique was later modified by Meier and colleagues, who used a more cranial puncture site with a more tangential orientation of the needle.<sup>41</sup> The success rate varies between 50<sup>11</sup> and 94%.<sup>10,58</sup>

The brachial plexus can be readily visualized by ultrasound imaging at the level of the posterior interscalene space (Fig. 4). Probing is started lateral to the larynx by visualizing the thyroid gland, the carotid artery and the internal jugular vein. Between these two vessels, the vagus nerve can be observed. As the probe is moved sideways to the lateral border of the sternocleidomastoid muscle with a slight caudal movement of the tip of the probe, the nerve structures become visible in a transverse view as multiple round or oval hypoechoic areas between the anterior and median scalene muscles.

After skin puncture 1 cm cranially to the probe, a 22-gauge 4-cm needle with a facette tip is placed in the interscalene space to inject the local anaesthetic under direct ultrasound visualization (Fig. 5). A dose of 10–15 ml is normally sufficient to induce complete brachial plexus block. The entire brachial plexus can be blocked from this position by slightly repositioning the needle to include the T1 root, which forms part of the ulnar nerve and is not blocked by nerve stimulation guidance. A catheter can also be inserted into the interscalene space if continuous brachial plexus anaesthesia is desired.

### *Supraclavicular brachial plexus block*

The Vienna study group developed an ultrasound-guided technique for the supraclavicular approach and compared it with the axillary approach, demonstrating that a high success rate could be obtained even with ultrasound



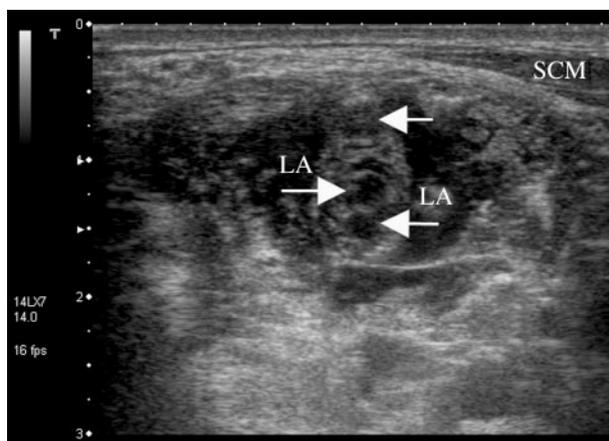
**Fig 4** Transverse view of the brachial plexus at the lateral border of the sternocleidomastoid muscle, at the level of the posterior interscalene space between the anterior and the median scalene muscles, using an Aplio system with an 8–14-MHz linear probe. The arrows indicate the roots of the brachial plexus, which are reflected as hypoechoic oval structures. ASM=anterior scalene muscle; MSM=median scalene muscle; SCM=sternocleidomastoid muscle.

equipment that was state-of-the-art in 1994.<sup>26</sup> More recently, Williams and colleagues<sup>62</sup> compared the same technique with nerve stimulation guidance and found that ultrasound guidance was superior, which is in accordance with other studies of upper and lower extremity blocks. They concluded that, while inexperienced users may prefer to use both nerve stimulation and ultrasound to verify the position of the needle, it is generally better to avoid nerve stimulation, thereby sparing the patient the painful muscle contractions associated with this approach.

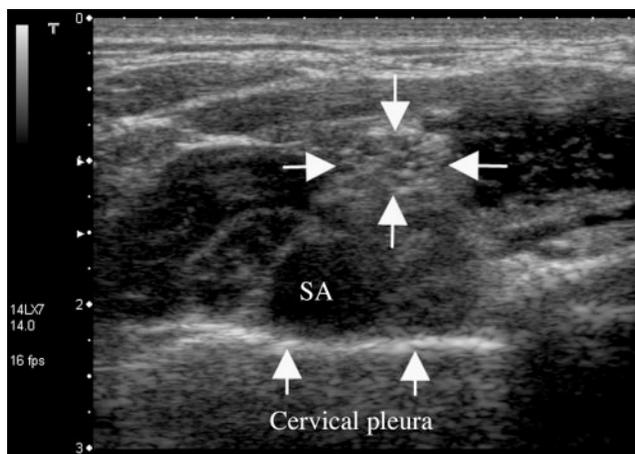
The entire brachial plexus near the subclavian artery can be visualized by moving the ultrasound probe away from the 'interscalene' position described above to a supraclavicular position (Fig. 6). As the structures of interest are close to the skin, a high-frequency linear probe (12 MHz or preferably 14 MHz) can be used for optimal resolution. While it is

difficult to identify each of the three trunks and the anterior and posterior divisions in a precise manner because of their close proximity, the individual structures of the brachial plexus at this level are adequately mapped for all practical purposes as the probe is slowly moved in a craniocaudal direction. The puncture site is located cranially to the ultrasound probe. Local anaesthetic should be administered to the extent of encircling the trunks (usually 10–15 ml).

Figure 6 illustrates the close proximity of the brachial plexus to the cervical pleura. It is therefore inappropriate to regard the supraclavicular approach as a routine procedure, no matter how much it is facilitated by ultrasound guidance. Rather, it should only be considered when the infraclavicular approach is not an option; e.g. if a cardiac pacemaker is implanted in the pectoralis major muscle.



**Fig 5** View of the interscalene space after administration of 15 ml local anaesthetic, using an Aplio system with an 8–14-MHz linear probe. The arrows indicate the nerve roots of the brachial plexus surrounded by local anaesthetic. LA=local anaesthetic; SCM=sternocleidomastoid muscle.



**Fig 6** Transverse view of the supraclavicular brachial plexus craniolateral to the subclavian artery. The arrows indicate the brachial plexus. The skin-to-pleura distance is 2.2 cm. SA=subclavian artery.

### *Infraclavicular brachial plexus block*

The vertical infraclavicular brachial plexus (VIP) block has been one of the most popular approaches to the brachial plexus since it was described by Kilka and colleagues in 1995.<sup>30</sup> The success rate varies between 88%<sup>45</sup> and 95%.<sup>21</sup> It has been said that anatomical landmarks can be readily identified with this approach, but serious complications have been described.<sup>46</sup> The puncture site is located halfway between the jugular notch and the ventral aspect of the acromion.

In an ultrasound investigation into the reliability of the 'VIP point', Greher and colleagues suggested a somewhat different position.<sup>21</sup> Their findings indicated that the predicted VIP point and the infraclavicular puncture site defined by ultrasound imaging coincided in fewer than 20% of patients. According to Greher and colleagues, the VIP point is only correct when the distance between the jugular notch and acromion is 22 cm. For each centimetre less or more, the puncture site should be moved 2 mm laterally or medially, respectively. Neuburger and colleagues<sup>47</sup> confirmed these observations in a clinical study and corrected the VIP points accordingly.

The findings of Greher and colleagues<sup>21</sup> suggest that all infraclavicular brachial plexus blocks should be performed under ultrasound visualization. The distance between the brachial plexus and the pleura can be increased by selecting a more lateral approach, to avoid inadvertent puncture of the cervical pleura.

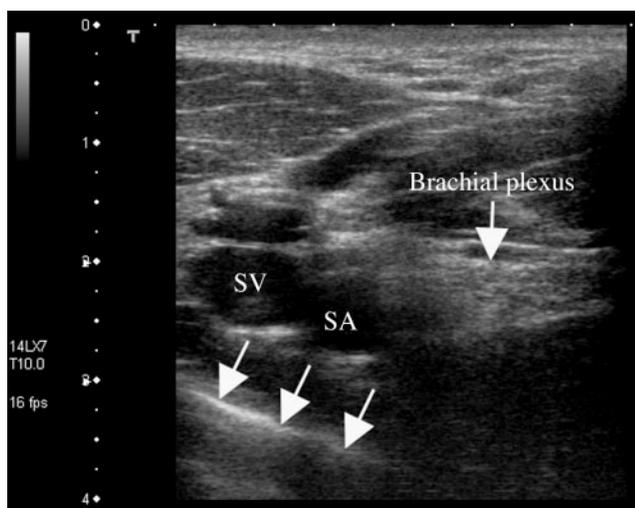
In 1999, Kapral and colleagues presented their lateral infraclavicular approach to the brachial plexus, which is as safe as the axillary approach in terms of complications while offering an additional spectrum of blocked nerves (musculocutaneous, thoracodorsal, axillary and medial brachial cutaneous nerves).<sup>29</sup> These findings were confirmed in children.<sup>12</sup> Figure 7 illustrates the brachial plexus lateral to the vessels around the puncture site for VIP block; Fig. 8 was obtained further laterally near the coracoid process. Both figures illustrate the greater distance of the brachial plexus

from the pleura at the approximate VIP point due to the deliberately lateral position of the ultrasound probe.

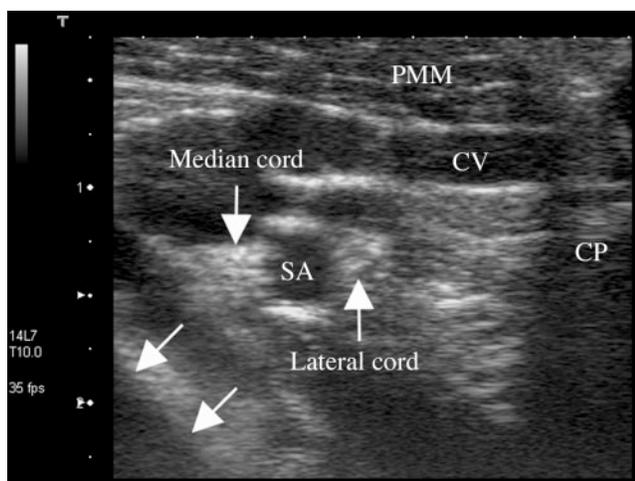
Sandhu and Capal reported a 90% rate of adequate surgical anaesthesia on performing ultrasound-guided infraclavicular brachial plexus blocks with a 2.5 MHz probe.<sup>54</sup> The concept of identifying nerve structures at low frequencies is in sharp contrast to our own experience. We use a 5–12 MHz linear probe for lateral infraclavicular nerve blocks. The ultrasound images of this approach will always remain inferior to those of other approaches because the high frequencies are absorbed by the interposed muscles. They

are still sufficient, however, to identify the brachial plexus in most patients. The needle puncture is made below or above the probe using a 22-gauge 8-cm needle with a facette tip. In children we use a 4-cm needle.

In a recent study by the Vienna group, ultrasound guidance for lateral infraclavicular block of the brachial plexus was found to be successful in 100% of children, providing both surgical anaesthesia and a complete spectrum of blocked nerves.<sup>40</sup> In addition, the acute pain caused by brachial plexus puncture under nerve stimulation guidance as a result of muscle contractions was totally eliminated by ultrasound guidance.



**Fig 7** Transverse view of the infraclavicular part of the brachial plexus at the median infraclavicular level, using an Aplio System with an 8–14-MHz linear probe. The arrows in the bottom left corner indicate the pleura. SA=subclavian artery; SV=subclavian vein.



**Fig 8** Transverse view of the infraclavicular part of the brachial plexus near the coracoid process, using an Aplio system with an 8–14-MHz linear probe. Lateral and medial to the subclavian artery, the lateral and median cords are visualized. The posterior cord is not visualized in this view. The arrows in the bottom left corner indicate the pleura. CP=coracoid process; CV=cephalic vein; PMM=pectoris major muscle; SA=subclavian artery.

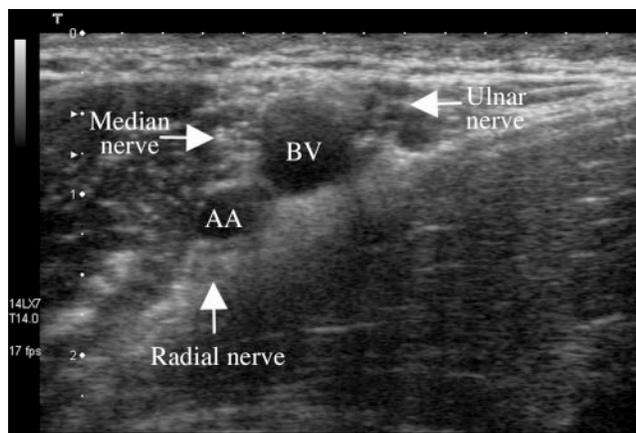
### *Axillary brachial plexus block*

This technique continues to be the most popular approach to the brachial plexus. Although complications are rare, one author reported three cases of permanent neurological injuries.<sup>56</sup> Also, the reported success rates of 70–80% are hardly acceptable.<sup>3,45</sup> These poor rates may be caused by failure to block the radial nerve after needle puncture above the axillary artery.<sup>42</sup> There are many open questions about the axillary approach despite its popularity.

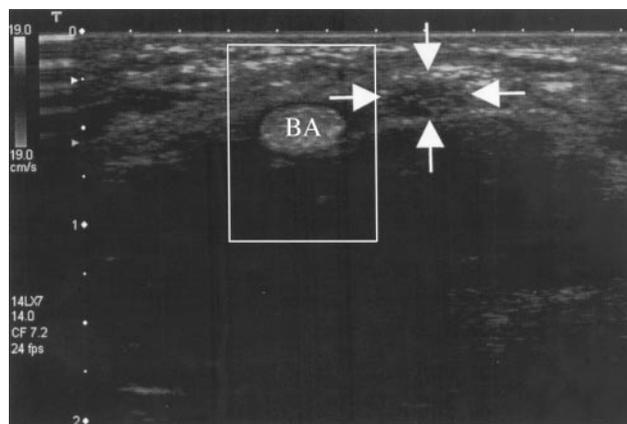
Retzl and colleagues described the use of high-resolution ultrasonography to identify nerves at the axillary level.<sup>52</sup> They observed that the position of the main nerves of the brachial plexus was not constant relative to the axillary artery but changed significantly on applying even mild pressure (e.g. during palpation of the axillary artery). This observation may help to explain the high failure rate of axillary brachial plexus blocks.

Ultrasound guidance for axillary brachial plexus anaesthesia should be performed with a high-frequency probe (12 MHz or higher). The median nerve can be readily visualized, as it is located next to the axillary artery all the way down to the cubital level. The ulnar nerve is located medial to the artery and remains closer to the skin surface than the median nerve all the way down to the proximal forearm. The radial nerve, which is located below the artery, may be somewhat problematical.<sup>42</sup> While it is sometimes difficult to visualize because of the acoustic shadow cast by the artery, the anaesthetist can still move the probe slightly in a dorsal direction to visualize the radial nerve at the level of the humerus, where it branches off from below the artery to enter the radial nerve sulcus.

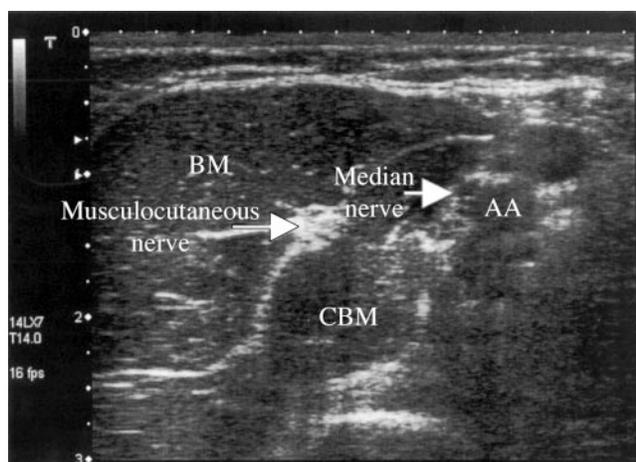
Figure 9 gives a view of all three nerves in the transverse plane. The brachial and antebrachial cutaneous nerves from the medial cord can also be visualized with a 14-MHz probe (not shown). From the indicated position, a 22-gauge 4-cm needle is inserted 1–2 cm below the artery (right-hand side in Fig. 9), blocking each of the three major nerves with 5–8 ml local anaesthetic. The reader is referred to Koscielnak-Nielsen and colleagues<sup>34</sup> and Fanelli and colleagues<sup>10</sup> for a detailed description of this multi-injection technique, which has remained essentially unchanged except that nerve stimulation has been replaced by ultrasound guidance. Although this has been denied in the literature,<sup>42,61</sup>



**Fig 9** Transverse view of the axillary part of the brachial plexus, using an Aplio system with an 8–14-MHz linear probe. AA=axillary artery; BV=basilic vein.



**Fig 11** Transverse view of the median nerve (arrows) next to the brachial artery visualized by colour Doppler, using an Aplio system with an 8–14-MHz linear probe. BA=brachial artery.



**Fig 10** Transverse view of the musculocutaneous nerve between the biceps muscle and the coracobrachial muscle, using an Aplio system with an 8–14-MHz linear probe. AA=axillary artery; BM=biceps muscle; CBM=coracobrachial muscle.

ultrasound visualization will even reveal septal structures between the nerves in around 10% of patients.

The musculocutaneous nerve originates in the lateral cord. Being located between the coracobrachial and pectoralis major muscles (Fig. 10), it is usually separated from the other nerves at the level of the axilla, such that it cannot be reached by axillary injection of local anaesthetic. In most patients, the musculocutaneous nerve can be readily visualized by ultrasound and effectively blocked by injecting another 3 ml of the local anaesthetic after moving the needle slightly in a cranial direction.

### *Peripheral nerve blocks of the upper extremity*

Ultrasound guidance is also very useful for peripheral nerve blocks in the upper limbs, as it allows the anaesthetist to minimize the dose of local anaesthetic and to advance the needle to the nerve swiftly and safely. Moreover, direct

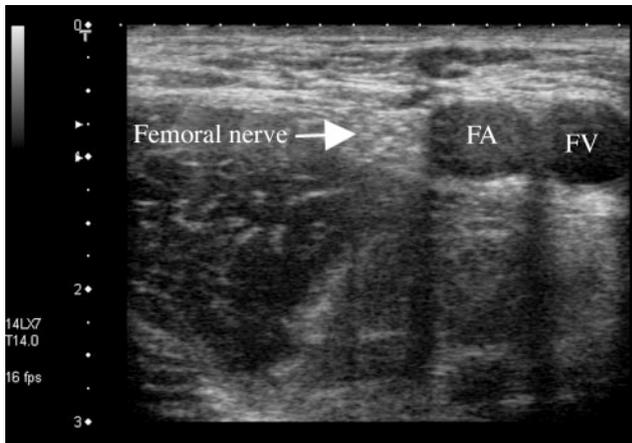
visualization of nerves facilitates the use of multiple puncture sites for upper extremity blocks. It is also possible to follow the anatomical structure of the nerves from the axilla distally to the wrist. Figure 11 shows the median nerve at the cubital level next to the brachial artery. Anatomical landmarks are no longer needed to identify nerves, and this task can be fulfilled by ultrasonography alone.

### **Lower extremity nerve blocks**

The lumbosacral plexus (T12/L1–S3/4) supplies the sensory, motor and sympathetic innervation of the lower limbs. The lumbar plexus is formed by the anterior roots of the upper four lumbar nerves and descends through the psoas muscle anteriorly to the transverse processes of the lumbar vertebrae. The sacral plexus, which is formed by the anterior roots of L4/5–S3/4, descends through the greater sciatic and infrapiriform foramina. While peripheral nerve blocks can replace neuraxial techniques, they still require two punctures. It is therefore useful to minimize the amount of local anaesthetic injected by ultrasound guidance, especially in older patients and in patients with cardiovascular disease.<sup>38</sup>

### *Three-in-one block*

Thirty years ago, Winnie and colleagues<sup>64</sup> succeeded in blocking the femoral, obturator and lateral cutaneous femoral nerves with a single inguinal perivascular injection. This approach came to be known as the ‘3-in-1 block’. Much like the upper extremity blocks guided by nerve stimulation, this technique has a failure rate of up to 20%.<sup>48,60</sup> The 3-in-1 block is ideally suited for ultrasound guidance with a high-frequency (10 MHz or more) linear probe because of the relatively superficial position of the femoral nerve distal to the inguinal ligament, lateral to the femoral artery, and below the iliopectineal fascia (Fig. 12). The puncture is performed 1 cm distal to the probe with a 22-gauge 4-cm



**Fig 12** Transverse view of the femoral nerve lateral to the femoral artery and femoral vein, using an Aplio system with an 8–14-MHz linear probe. FA=femoral artery; FV=femoral vein.

needle, injecting 20 ml of local anaesthetic. Ultrasound monitoring will allow the anaesthetist to reposition the needle in the event of maldistribution above the iliopectineal fascia.

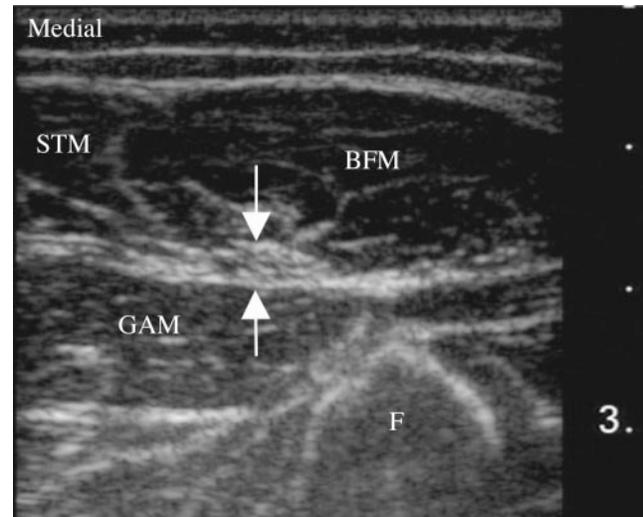
The Vienna group demonstrated that ultrasound guidance significantly improved the puncture-to-onset interval and the quality of sensory block in all three nerves while avoiding complications such as inadvertent arterial puncture.<sup>37</sup> We also showed that less local anaesthetic was required because it could be applied more accurately with ultrasound guidance compared with nerve stimulation.<sup>39</sup>

#### *Psoas compartment block*

This more central approach to the lumbar plexus is also suitable for direct visualization by ultrasound. A wide variety of approaches to the psoas compartment have been suggested,<sup>46,49,65</sup> along with different methods of nerve identification.<sup>6,49,63</sup> None of the approaches have success rates above 70–80%, and all involve serious complications.<sup>1,44,49</sup>

In 2001, Kirchmair and colleagues<sup>31</sup> reported their results on posterior paravertebral sonography to provide a basis for ultrasound-guided psoas compartment blocks. Using a 5-MHz curved-array ultrasound probe, they succeeded in visualizing the lumbar paravertebral region, but not the lumbar plexus, in 20 volunteers. In their next study, they performed ultrasound-guided punctures of the psoas compartment on cadavers with additional CT scanning and observed that the needle could be accurately placed in the psoas compartment in 98% of cases.<sup>32</sup>

Despite this seemingly good result, psoas compartment blocks are difficult to perform under ultrasound guidance because the lumbar plexus is located relatively deep at the level of the psoas compartment [5.5 (1.4) cm at L2/3; 5.5 (1.4) cm at L3/4; and 5.8 (1.3) cm at L4/5].<sup>31</sup> Therefore, the quality of ultrasound imaging is reduced, and clear anatomical reference points are not present. Also note that the needle must be orientated longitudinally to the ultrasound



**Fig 13** Transverse view of the sciatic nerve (see arrows) of a 5-yr-old child along the posterior part of the upper third of the thigh between the biceps femoris, the semitendinosus and the great adductor muscles, obtained with a Sonosite 180 Plus (Sonosite, Seattle, WA, USA) and a 10-MHz linear probe. BFM=biceps femoris muscle; F=femur; GAM=great adductor muscle; STM=semitendinosus muscle.

probe. More studies are needed to explore the potential of ultrasound guidance in psoas compartment blocks.

#### *Sciatic nerve block*

The good success rates reported for sciatic nerve blocks, in the range of 87–97%,<sup>5,7,43</sup> are presumably related to the large size of this nerve,<sup>17</sup> which, however, also increases the risk of inadvertent intraneuronal puncture. Ultrasound guidance can minimize this risk and increase the success rate to almost 100%. Subtotal anaesthesia may result from the fact that the sciatic nerve bifurcates into a tibial and a peroneus branch at the level of the infrapiriform foramen in 11% of patients.<sup>2</sup> Ultrasound guidance will allow the anaesthetist to detect this division and modify the procedure such that both branches are effectively blocked. Ultrasound guidance can also be used to block the posterior femoral cutaneous nerve, a branch of the sacral plexus innervating posterolateral thigh segments that cannot be blocked by conventional means because it is separated from the sciatic nerve at the level of the proximal thigh.

Preliminary attempts to visualize the sciatic nerve by ultrasound have involved a number of problems. First, the ultrasound beam has to be perpendicular to the nerve because of its anisotropic behaviour. The nerve is embedded in muscles, which filter out the high frequencies, thereby reducing the quality of the image. A 5–12 MHz linear probe can be used to visualize the nerve at all levels down to the popliteal region. Ultrasound-guided puncture should be performed in the subgluteal region, where the nerve is relatively close to the skin surface (Fig. 13).

The distal branches of the sciatic and femoral nerves, including the tibial nerve at the popliteal level and the

peroneal nerve distal to the head of the fibula, can also be selectively visualized. In addition, high-frequency linear probes can be used to visualize subcutaneous nerves, such as the medial sural cutaneous nerve (next to the small saphenous vein) and the saphenous nerve (terminal sensory branch of the femoral nerve next to the great saphenous vein). For optimal imaging of these superficial nerves, a jelly pad should be used.

## Epidural anaesthesia

The loss-of-resistance technique is the standard approach to identifying the epidural space during epidural anaesthesia. Although it has been used for a long time, only about 60% of punctures are successful at the first attempt.<sup>9</sup> Apart from the degree of personal experience, this high failure rate has been attributed to the quality of anatomical landmarks and of patient positioning. It may therefore be easier to identify the epidural space by ultrasonography whenever difficulties arise in connection with these variables.

Grau and colleagues demonstrated the usefulness of this approach in a number of studies. They first visualized the lumbar epidural space of pregnant women, since puncture is complicated in this group by weight gain, oedema and less elastic collagen fibres.<sup>18</sup> In their next study, they succeeded in identifying all relevant landmarks in the thoracic epidural space by ultrasonography.<sup>19</sup>

The quality of the images presented in these studies was poor. Also note that these studies did not involve the use of ultrasound to actually guide the puncture in real time, but were only performed to evaluate anatomical landmarks before, and anticipate the depth of, puncture. However, even this 'off-line' application significantly reduced the number of puncture attempts (1.3 (0.6) vs 2.2 (1.1) attempts).<sup>20</sup> Throughout these studies, Grau and colleagues used 5-MHz curved-array probes and a combination of transverse and longitudinal scans.

The potential of ultrasound-guided epidural puncture is somewhat limited by the interfering bone structure and the relatively deep position of the epidural space, which detracts from the quality of the images obtained. Further studies are needed to define the usefulness of ultrasound guidance in epidural anaesthesia.

## Indications for pain therapy

Ultrasound has been shown to offer excellent guidance in selective ganglion or nerve blocks for invasive pain therapy. Lumbar sympathetic and coeliac plexus blocks have been shown to yield similarly good results with ultrasound imaging as with CT scans.<sup>16,33</sup> Ultrasound guidance is useful to monitor the puncture site, needle position and spread of the local anaesthetic in stellate ganglion blocks.<sup>27</sup> Furthermore, it can be expected to increase the safety of these techniques by avoiding inadvertent vascular or subdural administration of local anaesthetic.<sup>28</sup>

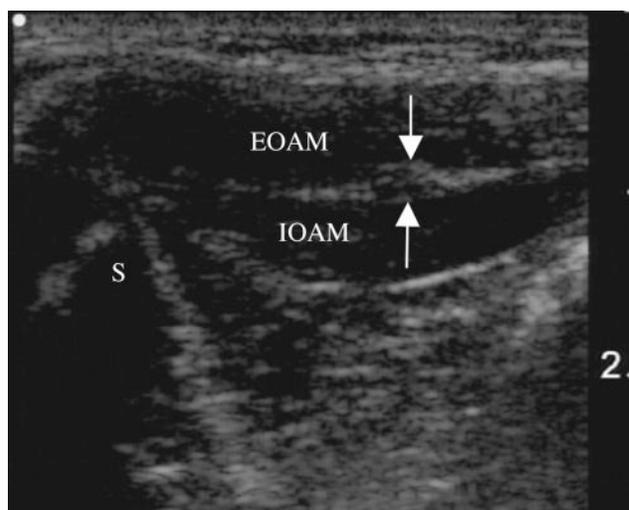
A new ultrasound-based approach to facet nerve block has been developed and tested on cadavers, volunteers and patients.<sup>23</sup> In the past, the only way to diagnose and specifically treat facet syndrome, a common cause of low back pain, has been to block the lumbar facet nerve under visualization by fluoroscopy or CT scanning. The newly developed approach based on ultrasound guidance is simpler and involves no exposure to radiation.

Studies involving the use of ultrasound guidance are also under way for cervical facet nerve block and several other types of acute and chronic pain management. The preliminary results of these studies are encouraging. All the results that have been obtained so far emphasize the great potential of ultrasound guidance in invasive pain therapy.

## Preliminary experience in children

The fact that regional anaesthesia is usually performed under general anaesthesia in children carries a high risk that nerve injuries may go undetected.<sup>25</sup> Ultrasound is therefore especially welcome as a guidance technique in this patient group. It can be used with most types of nerve blocks and helps to avoid serious complications, such as inadvertent puncture of the colon during ilioinguinal blocks<sup>24</sup> or of blood vessels during peripheral nerve blocks. However, it will take excellent study designs to formally establish the superior quality and safety of ultrasound guidance, since the incidence of nerve block-related complications is very low in paediatric patients.<sup>15</sup>

Children can be managed with high-frequency linear ultrasound probes (10 MHz or higher) because the nerves are very close to the skin. We routinely use ultrasound guidance for ilioinguinal nerve blocks, lower extremity nerve blocks (3-in-1, sciatic and popliteal) and brachial



**Fig 14** Transverse view of the ilioinguinal nerve (arrows) medial to the anterior superior iliac spine (S) between the external and internal oblique abdominal muscles (EOAM, IOAM), obtained with a Sonosite 180 Plus and a 10-MHz linear probe.

plexus blocks. The ilioinguinal nerve can be readily visualized medial to the anterior superior iliac spine between the external and internal abdominal oblique muscles (Fig. 14), with a small amount of local anaesthetic providing sufficient perioperative surgical anaesthesia. Despite its popularity, the success rate of this technique is poor when it is performed blind.<sup>55</sup> Better results can be achieved with ultrasound guidance.

Ultrasound guidance for infraclavicular anaesthesia is, in contrast, a well-established technique in paediatric patients. The Vienna study group compared the conventional guidance technique of nerve stimulation as described by Fleischmann and colleagues<sup>12</sup> with ultrasound guidance for lateral infraclavicular plexus anaesthesia in children undergoing surgery of the upper limbs.<sup>40</sup> Despite the superior quality of nerve stimulation, the sonographic approach involves less pain at the time of puncture by avoiding the muscle contractions associated with nerve stimulation. It offers significantly shorter puncture-to-onset intervals as well as longer durations of sensory block.

## Conclusions

Direct ultrasonographic visualization significantly improves the outcome of most techniques in peripheral regional anaesthesia. With the help of high-resolution ultrasonography, the anaesthetist can directly visualize relevant nerve structures for upper and lower extremity nerve blocks at all levels. Such direct visualization improves the quality of nerve blocks and avoids complications. The use of ultrasound seems to enhance not only the traditional brachial and lumbosacral plexus blocks but also the common techniques used in invasive pain therapy, such as stellate ganglion and facet nerve blocks. Further studies are needed to establish whether ultrasonography can improve neuraxial techniques. Promising results have also been obtained in children, in whom most types of block are performed under sedation or general anaesthesia.

The benefits of directly visualizing targeted nerve structures and monitoring the distribution of local anaesthetic are significant. In addition, ultrasound monitoring allows the anaesthetist to reposition the needle in the event of maldistribution. It is therefore justified to expect anaesthetists to acquire the skills to use ultrasound guidance in clinical practice. The technique can be established in a cost-efficient manner as portable ultrasound systems with high-frequency probes are now available. It is hoped that these systems will promote the routine use of ultrasound guidance in regional anaesthesia.

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