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REVIEW ARTICLE

Fifteen years of ultrasound guidance in regional anaesthesia: Part 1

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Ultrasound guidance for regional anaesthesia has gained enormous popularity in the past decade. The use of ultrasound guidance for many regional anaesthetic techniques is common in daily clinical practice, and the number of practitioners using it is increasing. However, alongside the enthusiasm, there should be a degree of informed scepticism. The widespread use of the various techniques of ultrasound-guided regional blocks without adequate training raises the danger of malpractice and subsequent impaired outcome. Adequate education in the use of regional block techniques under ultrasound guidance is essential. This review article addresses ultrasound guidance for regional anaesthesia, and is divided into two parts because of the size of the topic and the number of issues covered. This first part includes a review and preview of ultrasound guidance in regional anaesthesia and discusses all aspects of ultrasound for regional anaesthesia with a focus on recent technical developments, the positive implications in economics, further potential advantages (e.g. detection of anatomical variants, painless performance of blocks) and education. It also attempts to define a 'gold standard' in regional anaesthesia with the most recent findings in adequate volumes of local anaesthetics for peripheral nerve blocks. This standard should include an extraneural needle position, a high success rate, and wide application of ultrasound guidance in regional anaesthesia. The second part describes the impact of ultrasound on the development of nerve block techniques in the past 5 yr.

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The role of ultrasound guidance in regional anaesthesia is increasing. After simple descriptions of ultrasound-guided block techniques appeared in the mid-1990s, it rapidly became evident that this technique offers many advantages, but also is not without its problems. A large number of different ultrasound-guided regional techniques have now been described, and there is widespread interest in using these techniques in clinical practice. This interest carries with it responsibilities for clinicians developing these techniques as it is evident that not all the block techniques described are clinically useful and, indeed, some are potentially dangerous. Although descriptions of intraneural injection of local anaesthetic provide the most obvious danger,[9] some approaches are simply not useful.[4 37 38]

Some important questions can better be answered with the recent use of volunteer studies than with clinical studies. Investigation of the lowest local anaesthetic volume necessary to block a peripheral nerve is an example of a sophisticated volunteer-based study that has the long-term aim of increasing the safety of regional anaesthesia. This review article will serve as an 'update' of our 2005 review[35] and offers a critical view of this subject. The first part reviews the theoretical and scientific background of ultrasound guidance in regional anaesthesia; the second part describes recent developments in ultrasound-guided techniques.

Developments during the past 15 years

Ultrasound guidance has greatly influenced the practice of regional anaesthesia in the last 15 yr. Between 1884, the year when Carl Koller performed the first regional block for eye surgery in Vienna, and the late 1970s, the main developments were in new local anaesthetic drugs and the introduction of mainly anatomical methods for nerve identification. Unfortunately, anatomy is not exactly predictable and the natural variability of human anatomy led to poor success rates for many peripheral nerve blocks. Much of the antipathy towards regional anaesthesia has its origins in those arguably 'hit and miss' times. Part of this may have been a lack of understanding of the anatomy. The description of Winnie's 'three-in-one' block, in which a single injection of local anaesthetic around the femoral nerve should also block both the obturator nerve and lateral cutaneous nerve of the thigh, led regional anaesthetists to believe that there was a contiguous fascial sheath that swept proximally under the inguinal ligament and towards the lumbar plexus, which could be filled with large volumes of local anaesthetic to achieve a reliable triple nerve block. The inability at the time to determine the spread of local anaesthetic objectively led to misinterpretation of the anatomy. Conventional X-ray technology using radio-opaque contrast in the local anaesthetic solution showed that the three nerves were blocked by lateral, and not proximal, spread. However, one drawback of X-rays is their inability to visualize neural structures, and therefore the relationship between the local anaesthetic injected and the nerves affected can only be inferred rather than directly seen.

The introduction of ultrasound into clinical practice brought a solution to this problem closer. The first paper in this field was published in 1978:[31] a Doppler ultrasound blood flow detector was used to facilitate supraclavicular brachial plexus block. At this time, detailed knowledge of the ultrasonographic appearance of neural structures was poor, and the ultrasound technology was not suitable for visualization of nerves. The first direct use of ultrasound for a regional block was in 1994, again for supraclavicular brachial plexus block.[28]

In the ensuing 10 yr, ultrasound technology advanced in parallel with the understanding of its use and the development of block techniques which suited the use of ultrasound. The increased interest and investment in ultrasound led manufacturers to design machines specifically for regional anaesthesia, and software to facilitate peripheral nerve blocks. Better quality images should produce better quality blocks. Recent studies have demonstrated the cost-effectiveness of ultrasound-guided regional anaesthesia in daily clinical practice.[25]

The clinical science of ultrasound-guided regional anaesthesia has advanced as new approaches and techniques have been developed. However, some techniques have not proven to be clinically effective, practical, or safe,[4 9 10 12] and it may be difficult for the anaesthetist to differentiate between those likely to enjoy widespread clinical use and those unlikely to do so. Open debate about new techniques is obviously to be encouraged, but only practical implementation of new techniques and clinical experience will show if a particular approach or technique is safe and effective in daily clinical practice. It is also evident that every paper published in this field reflects in large part the individual opinions of the authors, often expressed after the performance of new blocks on a relatively small number of subjects. Therefore, large, multicentre studies are required to establish the advantages and disadvantages of new ultrasound-guided block techniques. Some of these larger studies may produce results that contradict earlier and smaller studies of a new technique, but even though large studies are expensive and difficult to perform, they are necessary in this important field. 'Ultrasound enthusiasts' tend to overestimate their manual skills and the success of their techniques, whereas sworn followers of a more 'conventional' technique tend to demonize ultrasound and neglect any potential usefulness of new techniques.[1–3 14] There needs to be a balance between the evangelical fervour of the innovative enthusiast and the resistance of the clinical Luddite. Open minds, healthy scepticism, and a desire to work together are likely to benefit patients the most. Much has happened in the last 15 yr, but it is that which happens in the next 15 yr that is likely to be more important from the clinical standpoint.

Have we established the gold standard in regional anaesthesia?

Regional anaesthesia makes a simple demand on the clinician: that the right dose of the right drug is put in the right place.[19] The argument for the widespread use of ultrasound is that direct visualization of the needle, the anatomy, the neural structures, and the spread of local anaesthetic can only enhance the anaesthetist's ability to satisfy this simple demand. However, there is still debate about the right place for the injection and the right dose of the drugs to be used.

Received wisdom accepts that an extraneural needle position during injection of local anaesthetic is safe and effective, whereas placement of the needle into the substance of a fascicle of a nerve, that is, sub-perineurally, is potentially dangerous. However, there is increasing evidence from studies using ultrasound that injections under the epineurium may be common and even safe. This evidence is controversial.[9 11] At present, there are few data to support the routine performance of sub-epineural injections, and even with modern high-frequency ultrasound, it is not possible to exclude the intrafascicular (sub-perineural) placement of a needle that has been deliberately placed into a nerve.

The volume of local anaesthetic that is needed to provide a successful nerve block is also the subject of debate. Large volumes of local anaesthetic have been used in the past to compensate for inexact, traditional anatomical techniques of nerve identification. In spite of these sometimes potentially dangerously large volumes, success rates for some regional techniques were disappointing. The most likely reason for this is the inaccurate placement of local anaesthetic relative to the nerve structures. Recent studies indicate that peripheral nerve blocks can be performed with much lower volumes of local anaesthetic than those described in the past. Successful ultrasound-guided ulnar nerve block is possible with <1 ml of local anaesthetic solution.[21] This study used an up-and-down statistical study design and a novel method for calculating the volume of local anaesthetic used that was based on the nerve's measured cross-sectional area (Fig. 1). Thus, a reliable estimate of the ED_{95} volume of local anaesthetic needed to block this particular nerve block was possible: 0.11 ml mm^{-2}, or about 0.7 ml for an adult patient. It is important to mention that such low-volume blocks can only be achieved with a multi-injection technique—even for single nerve blocks. With more sophisticated techniques such as interscalene or axillary brachial plexus blocks, a number of needle tip positions are required to produce a successful low-volume block. In fact, the spread of local anaesthetic during injection with a given needle tip position can never be predicted, and therefore adjustment of the needle tip after every injection is a prerequisite for the successful realization of this technique.

Similar results have been found for sciatic nerve block where a value for ED_{99} of 0.10 ml mm^{-2} cross-sectional nerve area was calculated.[32] The median cross-sectional nerve area was 57 mm^2 in that volunteer study, resulting in a median volume of 5.7 ml of local anaesthetic for sciatic nerve block. The lowest volume for a successful sciatic nerve block in that study was 1.7 ml, despite complete circumferential spread of local anaesthetic around the nerve not being achieved (Fig. 2). Thus, we may have to re-evaluate our belief that local anaesthetic has to surround the entire nerve for a successful block (the so-called 'doughnut sign').[30] The described ED_{99}[32] equates to a 99% success rate for peripheral nerve blocks and this could contribute to future considerations of a 'gold standard'.

The ultimate target of 100% success rate with no complications or side-effects has not yet been reached. A possible factor in this is that there are too many descriptions of scanning methods and block techniques. The scientific value of case reports or small observational studies is limited, and may lead to confusion rather than enlightenment. The use of ultrasound in clinical practice must advance hand in hand with its scientific evaluation. The achievement of a true 'gold standard' in a particular field requires both excellent science and the responsible implementation of a technique into clinical practice. Techniques with a reported mean success rate of 80%[7 8 26] can certainly not be described as being the 'gold standard'. However, the use of ultrasound for regional blocks has the potential to raise the standard and to drive forward success rates and safety. However, patient satisfaction is also an important factor in the clinical acceptability of a technique which will depend on whether it provides a pain-free and predictably successful outcome.

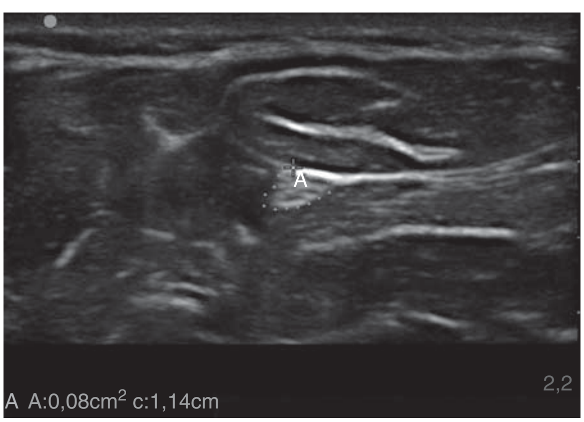

Fig 1 Measurement of the cross-sectional area of the ulnar nerve with ultrasound.

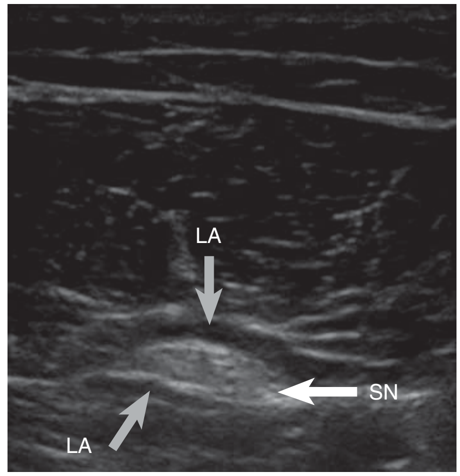

Fig 2 The sciatic nerve (SN) at the mid-femoral level partly surrounded by local anaesthetic, resulting in a successful block. The homogenous hypoechoic (dark) zone represents the local anaesthetic (LA).

Does ultrasound increase the safety of regional blocks?

This question divides regional anaesthesia practitioners into three camps: those who support the view that direct visualization of anatomy is associated with increased safety, those who oppose this view, and those who argue that the evidence to support it is lacking. The incidence of complications from regional anaesthesia is described as being between 0.0004%[5] and 14%.[15] This huge range makes grounds for further discussion and debate.

An analysis of 1010 ultrasound-guided blocks found neurological symptoms in 8.2% of patients after 10 days, 3.7% after 1 month, and 0.6% after 6 months.[22] The incidences of long-term neurological complications are similar to those seen with conventional techniques.[5 6 13] A comparison of 200 interscalene blocks performed with either ultrasound or nerve stimulator guidance found, after 1 week, an incidence of neurological complications of 8% with ultrasound and 11% with nerve stimulation.[33] It is important to state that perioperative neurological complications may be caused by a number of mechanisms such as positioning, tourniquets, and tissue swelling. Therefore, an evaluation of the true rate of neurological complications associated directly with regional anaesthesia is difficult. Even if the current literature does not support the safety of ultrasound guidance in regional anaesthesia, it seems to us obvious that the correct use of this technique should be associated with increased safety.

Technical developments, economical aspects, and education

Ultrasound for regional anaesthesia was not designed for exclusive use by a small number of experts. The aim should be to maximize the number of anaesthetists able to use this technique in their clinical practice. The main prerequisite for the widespread use of ultrasound in regional anaesthesia is high-quality education. Other important aspects are user-friendly and reliable ultrasound devices, and the use of scientifically validated techniques.

Ultrasound technology has evolved during the past decade, with developments in achieving higher ultrasound frequencies and thus better image resolution, and also in post-processing and user-friendliness. The current standard should be based on optimal two-dimensional (2D) ultrasound images. The interpretation of 3D or even 4D (real-time 3D ultrasound illustrations) ultrasound images is currently difficult and is therefore not yet suitable for everyday clinical practice.[17] Beside the large size and weight of the ultrasound probes, the overall quality of 3D and 4D images is poor when compared with 2D scans. The correct interpretation of real-time 2D images is the most important prerequisite for successful performance of regional blocks in daily clinical practice. Having too many complex technical features may distract the anaesthetist from the key aspects of a simple and successful technique: identification of the anatomical structures, continuous visualization of both the needle tip and the spread of local anaesthetic. Technical features such as multidimensional sonography may be helpful in the future,[23 24 39 47] but in current practice, all efforts should be focused on the optimal interpretation of high-quality 2D images.

The use of ultrasound will also be extended and simplified by the production of small, portable ultrasound devices. A reduction in costs may be observed that runs parallel to the downsizing of ultrasound equipment. Ten years ago, it was difficult to get a useful ultrasound machine for less than €80 000. Today, excellent equipment is available for less than €30 000. However, we should not consider only the costs of the capital purchase of ultrasound equipment. A recent study investigated the economic aspects of ultrasound-guided interscalene blocks for arthroscopic shoulder surgery.[25] The authors observed a decrease in the cost of greater than €170 per case when taking into account both direct costs (drugs, disposables, etc.) and indirect, workflow-related costs. The most important prerequisites for achieving cost savings were high block success rates and an optimal anaesthesia-related workflow. It is important to highlight the fact that €15 min^{-1} have to be allowed for every minute in the operating theatre, and therefore shorter anaesthesia induction and emergence times are the significant factors for cost reduction. Under appropriate conditions, greater than €100 000 per year per operating theatre can be saved without compromising care with the use of ultrasound-guided regional blocks.

The beneficial effects on cost and patient satisfaction can only be realized with an overall success rate for regional blocks of >98%. Good education and training is necessary to achieve this both laudable and achievable aim. Many anaesthesia meetings provide basic workshops that aim to arouse the interest of potential users of this technique. These basic workshops should be followed by advanced workshops. The anaesthesia community is at a very early stage in the development of guidelines for structured education in ultrasound. Recently, the American and European Societies of Regional Anaesthesia (ASRA and ESRA) published initial guidelines on the basic orientation and education for potential users of ultrasound in regional anaesthesia.[46] However, a universal agreement on how to teach ultrasonography for regional blocks is still lacking. A combination of basic and advanced workshops, and ongoing supervised practice, leads to the safe and effective performance of ultrasound-guided blocks.

Independent of the methods of education and training, each institution and anaesthetist involved in the use of regional anaesthesia should undertake critical reflection on: what is the overall success rate and complications of their regional anaesthesia? Is there room for improvement by changing the technique of nerve location? What need to be seen, learned, and done before introducing ultrasound safely into practice? How can any problems associated with the new technique be monitored and reviewed? Can problems that are inherent to the system be avoided?

Complex healthcare systems may not provide an environment for ready answers to the above questions. However, it is an important step in personal development for potential users of ultrasound in regional anaesthesia at least to ask themselves the above questions. A lot has already been achieved with regard to education and initiating a change in the mind of anaesthetists and those charged with funding anaesthesia, but there is still a long way to go to achieve a high level of the use of ultrasound guidance in regional anaesthesia.

What are the real advantages of ultrasound guidance in regional anaesthesia?

The potential advantages of ultrasound guidance in regional anaesthesia are still a source of some debate.

Hard evidence in this area is sadly lacking. However, we should be able to make a reasonable attempt at describing the clinically relevant points.

Direct visualization of neural and adjacent anatomical structures and the spread of local anaesthetic

Without any doubt, direct visualization of neural and adjacent anatomical structures is the main advantage of the use of ultrasound for regional block techniques.[19] A recent investigator-blinded study of ilioinguinal/iliohypogastric nerve blocks in children translates these theoretical considerations into clinical practice.[49] The authors used the conventional 'fascial click' method and observed the spread of local anaesthetic with ultrasound and found that the local anaesthetic was injected into the correct anatomical plane between the internal oblique and transversus abdominis muscles in only 14% of the cases. This study is a good example of the difficulties associated with landmark-based techniques.

Current ultrasound equipment allows much easier identification of very small neural structures than was possible with machines introduced only a few years ago (Fig. 3). In addition, adjacent anatomical structures can be identified. Identification of the cervical pleura, which is close to the brachial plexus at the peri-clavicular level, is an example of the importance of adequate anatomical orientation during regional anaesthetic techniques (Fig. 4).

An important objective for ultrasound is visualization of the spread of local anaesthetic during injection. Confirmation of the correct disposition of local anaesthetic avoids any maldistribution, such as epineural, perineural, or intravascular injection. In addition, an ability to perform blocks with small volumes of local anaesthetic is mainly based on an ability to observe the spread of the local anaesthetic directly.[20 21 32 50]

Detection of anatomical variants

Anatomical variation is one of the main reasons for block failure. A discussion of all the anatomical variations that lead to block failure is beyond the scope of this review. However, it is important to highlight ultrasound's ability to detect anatomical variations, for it is the only bedside method that can accurately determine local anatomy before the performance of regional blocks, such as the ultrasound appearance of variations of the brachial plexus at the interscalene level (Figs 5 and 6).

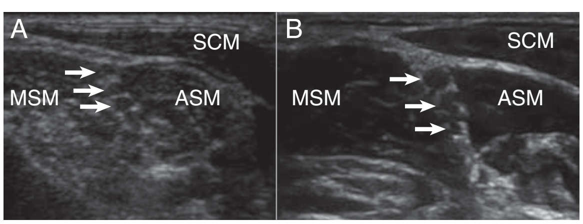

Fig 3 Comparison of an ultrasound image of the interscalene brachial plexus (the arrows indicate the C5–7 nerve roots; SCM, sternocleidomastoid muscle; ASM, anterior scalene muscle; MCM, median scalenus muscle) with two different qualities. (A) Illustration from 2004; (B) most recent illustration with improved image quality due to speckle suppression.

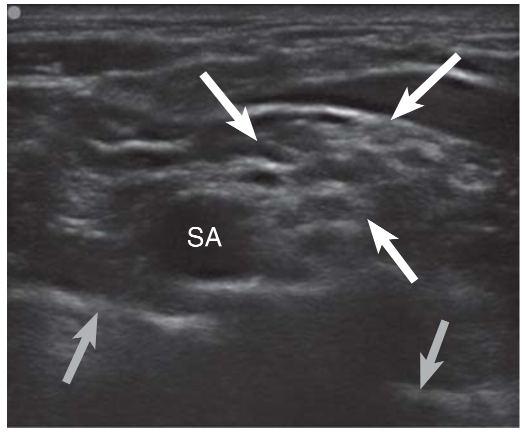

Fig 4 Ultrasonographic illustration of the brachial plexus (indicated by white arrows) at the supraclavicular level, adjacent to the cervical pleura (indicated by grey arrows). SA, Subclavian artery.

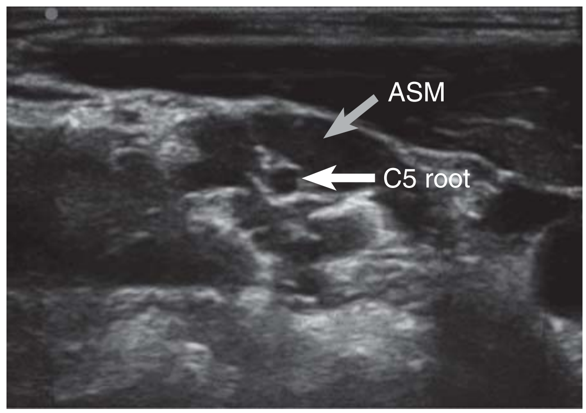

Fig 5 Cross-sectional ultrasound view of the brachial plexus at the interscalene level in which the C5 root is located within the anterior scalene muscle (ASM; right side, medial).

Reduction of the volume of local anaesthetic

Low-volume regional blocks are only possible if nerve structures are directly visualized and a multi-injection technique is used. Minimum effective volumes have been determined for the ulnar[21] and sciatic nerves.[32] The minimum effective volume for brachial plexus block at the axillary level has been described as 1 ml per nerve.[41] These studies that describe very low local anaesthetic volumes for blocks were performed by experts in ultrasound-guided regional anaesthesia and the purpose of the reports of these blocks is to show the minimum volumes that can be used. In clinical practice, a reasonable minimum volume to use might be two to three times these published volumes (Table 1).

Improvement in block quality

The method used for nerve location is only one factor that affects block quality. Other factors include the local anaesthetic drug itself, in addition to the volume and concentration given. Although it is likely that direct visualization will be shown to be associated with better quality blocks, this may be dependent upon the absolute quality of the 2D ultrasound images.

Most comparative studies have shown faster onset times[27 36 42 44] and longer duration[27 36 40] of blocks when using ultrasound in comparison with other nerve location techniques. These observations are of particular interest in relation to economical considerations related to short induction and recovery times and a lesser need for analgesic drugs,[25] and patient satisfaction, for example, less postoperative pain and fewer side-effects due to systemic analgesic drugs. There are currently few published data on patient satisfaction and its relation to the method of nerve location.

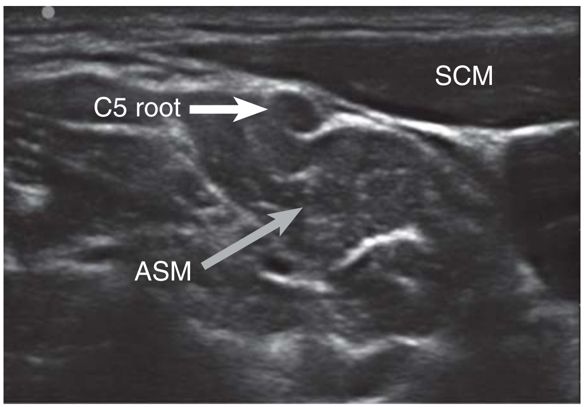

Fig 6 Cross-sectional ultrasound view of the brachial plexus at the interscalene level in which the C5 root is located outside the interscalene groove (SCM, sternocleidomastoid muscle; ASM; right side, medial).

Painless performance of blocks

Patient comfort is an important issue. Effective regional anaesthesia can provide painless surgical procedures. Unfortunately, some regional block techniques are painful to perform because of large needle size, blunt needle tip, or identification of nerves with electrical stimulation. Only a few studies have investigated pain during the performance of regional blocks. A reduction in procedural pain during popliteal block has been shown when ultrasound is used,[18] and ultrasound-guided brachial plexus blocks in children are associated with less pain when compared with nerve stimulator guidance.[36] Despite limited evidence in this area, it seems that ultrasound-guided regional blocks are likely to be associated with less pain for our patients.

Patient satisfaction

Patient satisfaction during a surgical procedure is an important issue. Patient satisfaction can be achieved by painless performance of the block and excellent block qualities providing long-lasting perioperative analgesia. Only a few studies have investigated patient satisfaction, but ultrasound guidance appears to be associated with an increase in patient satisfaction.[18 33 48]

Needle visualization and needle guidance techniques

The single greatest benefit of the use of ultrasound for peripheral nerve blocks is often said to be the ability to visualize of the needle throughout the performance of the

Table 1 List of publications on volume reduction of local anaesthetic in peripheral nerve blocks

Publication	Nerve structure	Minimum effective volume	Statistical method	Additional description
Willschke and colleagues (2006)[50]	Ilioinguinal/ iliohypogastric nerves	0.075 ml kg^{-1}	Clinical setting, modified step-up/ step-down approach	Children
Casati and colleagues (2007)[16]	Femoral nerve	ED_{50} 22 ml (95% CI, 13–36 ml)	Clinical setting, up-and-down staircase method	Relatively large volume despite the use of ultrasound
Riazi and colleagues (2008)[45]	Interscalene brachial plexus block	5 ml	Clinical setting, comparative study design (5 *vs* 20 ml)	5 ml equi-effective with 20 ml
Eichenberger and colleagues (2009)[21]	Ulnar nerve	ED_{50} 0.11 ml mm^{-2} nerve area	Experimental setting, up-and-down procedure according to the Dixon average method	Evaluation of the minimum effective volume of local anaesthetic based on the cross-sectional nerve area
O'Donnell and colleagues (2009)[41]	Axillary plexus	1 ml per nerve	Clinical setting, step-up/step-down study model	
Duggan and colleagues (2009)[20]	Supraclavicular plexus	ED_{50} 23 ml, ED_{95} 42 ml	Clinical setting, up-and-down procedure according to the Dixon average method	No difference to conventional methods of nerve identification
Latzke and colleagues (2010)[32]	Sciatic nerve at the mid-femoral level	ED_{99} 0.10 ml mm^{-2} cross-sectional nerve area	Experimental setting, up-and-down procedure according to the Dixon average method	Evaluation of the minimum effective volume of local anaesthetic based on the cross-sectional nerve area

block and adequate visualization of the needle is mandatory for safe and effective blocks. Close observation of the spread of the local anaesthetic is equally important for the performance of regional blocks.

The ultrasound visibility of different needles has been investigated in two media (a water bath and an animal model) with three different ultrasound machines and two different angles (0° and 45°).[34] This observational study found differences in the visibility of the needles and defined the following requirements for the 'ideal echogenic needle':

(i) good needle visibility, in particular its tip;
(ii) suitability for all kinds of tissue;
(iii) good visualization at all angles;
(iv) sharp depiction of the bevel of the needle;
(v) low artifact formation;
(vi) no shadowing;
(vii) extremely good detection and differentiation from the surrounding area.

However, no studies have investigated success rates with different needle types, so there is as yet no 'ideal needle', or any evidence that this will improve success rates or safety. There are continuing developments of new needles aimed at facilitating block performance and needle visibility. Piezoelectric vibrating needles are one example of recent potential developments.[29] Only the future will show if the evolution of such high-tech equipment is beneficial.

Needle visibility is only one aspect of the safety of block performance. From the first descriptions of ultrasound-guided regional techniques, most authors favoured in-plane techniques, in which the entire needle is visualized as it passes parallel to the long axis of the scanning head and directly under the ultrasound beam. A good example of such a technical controversy relates to the posterior approach to the interscalene brachial plexus—the 'Pippa approach'.[4 37 38] It is important to know that two nerves pass through the middle scalene muscle: the long thoracic and dorsal scapular nerves. These nerves can be damaged by a needle passing through the middle scalene muscle during an in-plane technique for interscalene brachial plexus block, with the possible consequence of paralysis of the serratus anterior muscle. The out-of-plane technique, in which the needle is passed in alignment with the interscalene groove and across the short axis of the ultrasound probe, is perhaps more logical from an anatomical point of view.[27] On the other hand, an in-plane needle guidance technique should definitely be used for the supraclavicular approach to the brachial plexus, both for technical reasons, to obtain the correct angle with the needle passing from medial to lateral, and safety reasons, to allow visualization of the needle and cervical pleura at the same time.[43] However, for many techniques, it does not really matter whether an out-of-plane or in-plane needle guidance technique is used. Peripheral nerve blocks can be performed in a safe and effective way with either technique. However, for some particular techniques, it is more sensible, from both anatomical and safety points of view, to use one technique in preference to another. Some may argue that these considerations are not supported by the literature, but clinical experience may sometimes guide practice where no hard scientific data exist.

What of the future?

Much has happened in the last 15 yr and if experience in other technological fields is to be used as a yardstick of the pace of development, the next 15 yr will see an exponential increase in the quality of both 2D images and 3D ultrasound images. However, the safety of any practical technique depends upon the training, experience, and skills of the operator, and we should be wary of believing that smarter technology will translate to better and safer blocks. It is also important that technology remains affordable. This will be an important factor of the wide implementation of ultrasound in regional anaesthesia.

Only high-quality training and careful supervision of trainees and novices in the art of ultrasound-guided blocks will ensure that we can put the burgeoning technology to safe and effective use for our patients. In addition, well-designed clinical studies with the main focus on outcome parameters are required for the definitive implementation of ultrasound-guided regional anaesthesia in everyone's clinical practice.

Conflict of interest

None declared.

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REVIEW ARTICLE

Fifteen years of ultrasound guidance in regional anaesthesia: Part 2—Recent developments in block techniques

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The use of ultrasound guidance for regional anaesthesia has gained enormous popularity in the last 10 yr. The first part of this review article provided information on safety, technical developments, economic aspects, education, advantages, needle guidance techniques, and future developments in ultrasound. The second part focuses on practical and technical details of individual ultrasound-guided nerve blocks in adults. We present a comprehensive review of the relevant literature of the last 5 yr with a commentary based on our own clinical experience in order to provide information relevant to patient management. Upper limb blocks, including interscalene, supra- and infraclavicular, and axillary approaches, are described and discussed. For the lower limb, psoas compartment, femoral, obturator, sciatic, and lateral cutaneous nerve blocks are described, as are some abdominal wall blocks. The potential role of ultrasound guidance for neuraxial block is addressed. The need for further large-scale studies of the role of ultrasound is emphasized.

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Keywords: anaesthetic techniques, regional; equipment, ultrasound machines; nerve block

The use of ultrasound guidance for regional anaesthesia has gained enormous popularity in the last 10 yr. This second part of our review focuses on practical and technical details of individual ultrasound-guided nerve blocks in adults. We present a comprehensive review of the relevant literature of the last 5 yr with a commentary based on our own clinical experience in order to provide information relevant to patient management.

Upper limb

Although the structure and innervation of the arm, shoulder, and lateral clavicular area is complex, the superficial location of the brachial plexus, its branches, and the surrounding structures allow high-quality ultrasound images to be achieved, thereby making upper limb regional blocks highly amenable to ultrasound-guided techniques.

Interscalene approach

It is possible, using ultrasound, to identify the phrenic nerve on the surface of the anterior scalene muscle[40] where it is in close proximity to the phrenic nerve C_5 root at the level of the cricoid cartilage. This close anatomical relationship explains the high incidence of ipsilateral phrenic nerve block after interscalene brachial plexus block, which can be of clinical significance in patients with lung disease.[25] It emphasizes the fact that the phrenic nerve may be at risk of damage during an interscalene brachial plexus block performed at the cricoid level.

An ultrasound-guided posterior approach to the brachial plexus using *Pippa's* technique has been described[85] and the feasibility of continuous brachial plexus block with this posterior approach demonstrated.[3 48] The efficacy of this technique was also demonstrated in a randomized, placebo-controlled study of 32 patients undergoing shoulder surgery.[47] The proposed benefits of a continuous posterior brachial plexus block are avoidance of the external jugular vein, a greater distance between the catheter entry site and the surgical field, and a lower incidence of catheter migration.[47] Nevertheless, a posterior approach to the brachial plexus—often termed a cervical paravertebral block—also has potential disadvantages. The needle has to be advanced through the muscles of the neck for some distance on its way to the brachial plexus. This can be painful for the patient. The needle has to pass through the middle scalene muscle, which contains two proximal branches of the brachial plexus: the long thoracic and dorsal scapular nerves. These nerves may therefore be injured by a needle approach that passes through the middle scalene muscle. Inserting the needle deep into the neck may make it difficult for novices to maintain full needle visibility when using an 'in-plane' technique in which the needle passes along the narrow ultrasound beam parallel to the probe head. If the needle is not well visualized, there is a risk that it may be inadvertently inserted towards the cervical spine. The lateral 'in-plane' approach to the interscalene brachial plexus also carries a theoretical risk of injuring the nerves lying within the middle scalene muscle, and needle advancement towards the midline when ultrasound visualization is poor can be hazardous.

In our opinion, an 'out-of-plane' approach using a needle entry point and direction of insertion similar to that used in the modified traditional lateral technique[51 52] seems to be the most logical and safe technique. The brachial plexus is superficial in this location (Fig. 1), and the depth of needle insertion is much less when compared with the 'in-plane' and posterior approaches. Moreover, the needle can be advanced at a very shallow angle almost parallel to the nerves of the brachial plexus. In our experience, injection of local anaesthetic lateral, medial, and in close proximity to the nerve roots with this approach produces an excellent nerve block.[35] A common argument against an 'out-of-plane' approach is poor needle and needle tip visualization during the block. However, we believe that if the needle is advanced slowly and carefully while closely observing the movement of the tissues around the roots of the brachial plexus, this is a safe and effective technique. The insertion of a catheter is made easier by the use of this technique as the catheter is more likely to pass parallel to and alongside the nerves during placement.

Supraclavicular approach

Since the introduction of ultrasound guidance, supraclavicular brachial plexus block has seen resurgence in popularity and now replaces infraclavicular approaches in the practice of many clinicians. The supraclavicular region offers excellent imaging conditions because of the superficial location of the brachial plexus and its surrounding structures: the subclavian artery, the pleura, and the first rib. As for the interscalene block, both 'in-plane' (Fig. 2) and 'out-of-plane' techniques are possible. Most regional anaesthetists use an 'in-plane' technique that seeks to minimize the chances of the needle hitting the artery or pleura. The optimal injection site has been described as being in the 'corner pocket', which is bordered by the first rib inferiorly, the subclavian artery medially, and the brachial plexus superiorly.[75] An alternative approach has been described in which a medio-lateral needle direction aims to avoid pleural puncture in cases in which the needle is poorly visible with ultrasound.[17] A study of 510 consecutive patients assessed success rates and the incidence of complications with both techniques.[60] Side-effects and complications included symptomatic diaphragmatic paresis (1%), Horner's syndrome (1%), vascular puncture (0.4%), and transient neurological deficits (0.4%). No pneumothoraces were seen. There were no statistically significant differences in success rates or complication rates between the latero-medial and medio-lateral needle direction techniques. Therefore, no firm recommendations can be made about which technique should be used, so the needle direction used in an 'in-plane' technique in this area can be left to the anaesthetist's discretion. Most anaesthetists use high-frequency linear array transducers to provide optimal ultrasound images for brachial plexus blocks. In a recently published retrospective case series, the combined use of a low-frequency (5–8 MHz) curved array transducer and nerve stimulation was reviewed.[81 82] Although success rates were equal to those reported in other publications on ultrasound-guided blocks,[60] the images presented did not match the quality of those produced by modern, high-frequency probes and equipment. We believe that ultrasound-guided brachial plexus blocks should be performed with the high-resolution images obtained with modern, high-frequency linear array transducers.

A dose-finding study[22] of the minimum effective volume of local anaesthetic for an ultrasound-guided

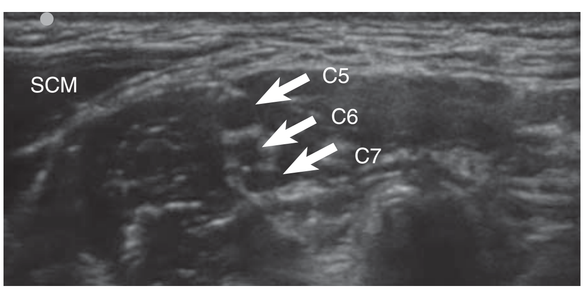

Fig 1 Ultrasound scan of the C_{5-7} nerve roots at the level used for the interscalene approach. SCM, sternocleidomastoid muscle; C_5, C_6, C_7, cervical nerve roots.

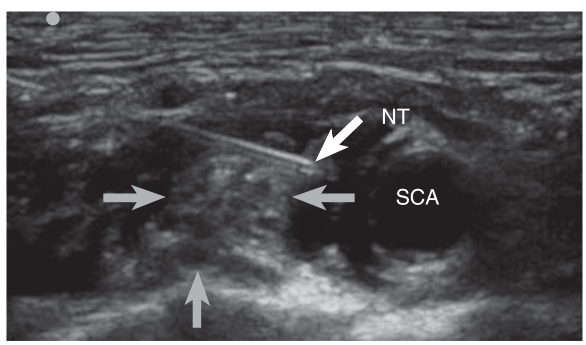

Fig 2 Ultrasound scan of the brachial plexus at the supraclavicular level using an 'in-plane' technique. The brachial plexus is labelled with grey arrows and lies directly above the cervical pleura. The hypoechoic area around the brachial plexus was created by the injection of 8 ml of local anaesthetic solution. NT, needle tip; SCA, subclavian artery.

supraclavicular brachial plexus block found a calculated minimum effective volume of 23 ml (of a 50:50 mixture of lidocaine 2% and bupivacaine 0.5%) and a calculated ED_{95} of 42 ml. Higher volumes for supraclavicular block when compared with interscalene block can be explained by the anatomical conformation of the supraclavicular part of the brachial plexus, which has a significant amount of connective tissue both surrounding and within the plexus.[53] These volumes may be reduced as practitioners gain experience with this particular technique.

A number of published clinical cases and case series show the usefulness of ultrasound guidance in the management of complex cases[21 28 61 71] or in avoiding serious complications.[84] The successful use of ultrasound-guided supraclavicular nerve blocks in an emergency setting has been reported.[77 78] However, there is some evidence that in spite of the above-mentioned advantages, ultrasound-guided supraclavicular brachial plexus block may not be as effective as is assumed when a single injection into the 'corner pocket' is used. In a comparison of this technique with a triple injection around the axillary artery in the infraclavicular region,[27] similar onset times were found but surgical anaesthesia was of significantly higher quality in the infraclavicular group, with fewer additional interventions. On the basis of our clinical experience, two to three injections are necessary to achieve complete and rapid spread around and within the supraclavicular brachial plexus. A single injection into the 'corner pocket' results not uncommonly in partial block failure. Optimal imaging conditions and careful needle guidance have made this block our first choice for surgical procedures between the shoulder and the elbow.

For operations on the hand and forearm, infraclavicular or axillary brachial plexus blocks are arguably more appropriate because it is easier to produce a reliable spread of local anaesthetic around the median, ulnar, and musculocutaneous nerves. A comparison[41] of ultrasound-guided supraclavicular and infraclavicular brachial plexus blocks in patients undergoing hand and forearm surgery, using multiple injections for both techniques, found the infraclavicular approach more effective in blocking the median and ulnar nerves. A limitation of this study was a heterogenous group of operators with different levels of experience. However, in a previous study, both techniques were found to be equally effective in terms of onset times and success rates.[4]

Infraclavicular approach

Ultrasound-guided infraclavicular plexus block can be managed by means of an 'in-plane' parasagittal or 'out-of-plane' approach. Using the 'in-plane' technique (also termed the 'coracoid approach'), the arm is abducted to $\sim 90^{\circ}$, thus limiting the technique's use in the management of upper limb fractures. We use a lateral infraclavicular approach (Fig. 3) with 'out-of-plane' needle guidance. With this technique, the arm is allowed to rest in a neutral position by the patient's side, and the needle distance from skin to plexus is at its shortest. However, both techniques are in regular clinical use and there is no evidence for advantages of one technique over the other. A complete and rapid onset of nerve block is achieved when the local anaesthetic is injected posterolateral to the artery, thus producing a U-shaped spread of fluid around the axillary artery.[19] Visualization of the pattern of local anaesthetic spread after radial or median nerve stimulation and subsequent injection in the infraclavicular area found a positive radial nerve response resulted in a 100% block success rate with local anaesthetic injection posterior to the axillary artery.[9] In contrast, a median nerve response resulted in local anaesthetic injection superficial to the artery and a lower success rate. Injection posterior to the artery has been described as producing the 'double bubble' sign.[80]

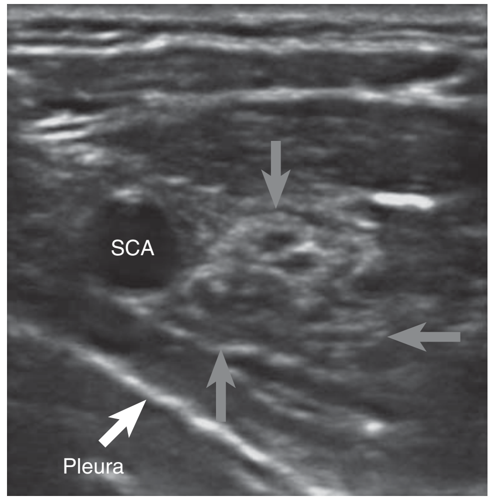

Fig 3 Ultrasound scan of the brachial plexus at the infraclavicular level below the pectoralis major and minor muscles. The three cords are labelled by grey arrows. SCA, subclavian artery.

Significant amounts of connective tissue surrounding and among the nerves of the brachial plexus are also seen at the infraclavicular region. A study of septa and their impact on local anaesthetic spread found that after injection with a lateral needle position, incomplete spread was noticed in 6 of 22 cases.[54] Limited local anaesthetic spread due to the presence of septa was found in four of these cases. It is a frequent finding that before injection posterior to the artery, a fascial click with subsequent rapid distribution of local anaesthetic around the artery is associated with a successful block.[43] A recent study showed no differences in terms of onset times and success rates when comparing single- and triple-injection techniques using a lateral parasagittal approach when the local anaesthetic is injected posterior to the axillary artery.[18]

Axillary approach

The use of ultrasonography has also revolutionized the performance and success rates of axillary brachial plexus block. Detailed anatomical knowledge, especially about the frequent variations in the organization of the axillary brachial plexus, is the key to clinical success. The anatomical variability of the axillary brachial plexus was recently highlighted.[15] It is now widely accepted that all four nerves (median, ulnar, radial, and musculocutaneous) should be blocked by separate injections around each nerve.[29] This will provide excellent surgical anaesthesia and tourniquet tolerance for procedures on the hand and forearm.[14 69] It has been demonstrated that each nerve is surrounded by connective tissue, thus being effectively located in its own tissue compartment.[5] In a series of 10 axillary plexus blocks, tissue barriers between the nerves were shown with three-dimensional (3D) ultrasonography.[16] Whether 3D ultrasound will ever find its place in routine clinical practice is a matter for debate.

In our routine clinical practice, local anaesthetic is injected around each of the four nerves separately.[73] In some instances, the radial nerve is difficult to visualize (Fig. 4) because of its close proximity to the brachial artery, and subsequent misinterpretation of the images can decrease success rates.[14] Nevertheless, the radial nerve shows a very consistent location between the 4 o'clock and 6 o'clock positions in relation to the brachial artery.[15] After injection of a small volume of local anaesthetic, the radial nerve reliably shows a significant increase in visibility and can therefore be easily identified and blocked.

Needle guidance for axillary brachial plexus block can be 'out of plane'[69] or 'in plane'[14 73] and we have found both to be highly effective. Nevertheless, in terms of safety, the 'in-plane' technique offers better needle visualization, which is particularly important during injections close to the nerves. Recently, intravascular injection has been reported.[65 91] The incidence of this complication can be minimized by pressing only lightly with the ultrasound probe before injection and thus not compressing the veins,

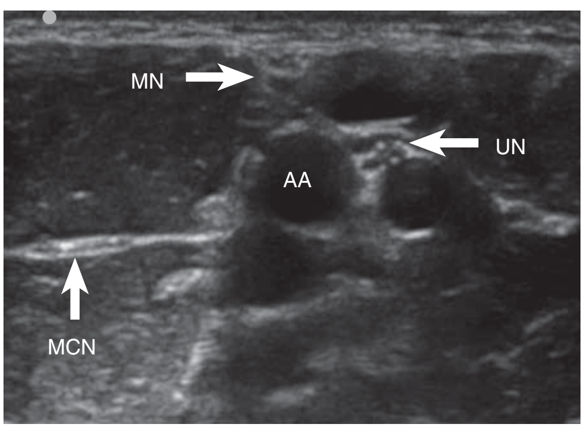

Fig 4 Ultrasound scan of the median (MN), ulnar (UN), and musculocutaneous (MCN) nerves at the axillary level. The musculocutaneous nerve lies between the short head of the biceps muscle (above) and coracobrachialis muscle (below). The radial nerve is not shown with this scanning head position. AA, axillary artery.

and aspiration tests are more likely to be positive if the needle is in a vessel.

Lower limb

In contrast to the upper limb, the sono-anatomy of the leg is straightforward. However, in spite of substantial technical advances in ultrasound probes and image processing in the last few years, ultrasound examination of the lower limb can still be very challenging because of the amount of muscle and fat that can surround nerves.[66]

Psoas compartment block

The use of ultrasound guidance for posterior lumbar plexus block, or 'psoas compartment block', was one of the first to be described. The well-recognized advantage of a posterior approach to lumbar plexus is a reliable block of the femoral nerve, obturator nerve, and lateral cutaneous nerve of the thigh with a single injection. Originally, an 'in-plane' technique was described based on the identification of the psoas major muscle in the transverse plane at the L_{3-5} level. In this area, the lumbar plexus, although deep, can be visualized using ultrasound. However, the use of nerve stimulation in addition to ultrasound imaging is still recommended to confirm the correct needle placement. This combined technique is still our standard practice when performing lumbar plexus block in the management of difficult cases such as hip fractures in elderly patients with significant co-morbidities. A slightly different technique based on imaging of the psoas major muscle in a paravertebral longitudinal view and advancing the needle 'in plane' in a cephalad direction has been described.[36] One concern about this technique is that systemic local anaesthetic toxicity might occur because of the rapid absorption of large volumes or because of inadvertent injection into one of the large paravertebral blood vessels. Bilateral spread is also a known side-effect of posterior lumbar plexus block. Interestingly, since we have introduced ultrasound guidance for these blocks into our practice, we have seen no instances of bilateral epidural spread.

In summary, posterior lumbar plexus block represents one of the most challenging techniques in terms of both ultrasound imaging and needle guidance. It should therefore only be performed or supervised by experienced clinicians. The clinical value of this technique has not yet been studied systematically.

Femoral nerve block

In femoral nerve block an 'out-of-plane' approach is used commonly. This is our routine clinical practice because skin-to-nerve needle distance is short and catheter placement is easy to achieve because the needle passes parallel to the long axis of the femoral nerve. Some clinicians use an 'in-plane' approach and guide the needle in a latero-medial direction[56] (Fig. 5). An oblique needle–probe alignment for catheter placement has been suggested to reach the posterior surface of the femoral nerve.[26] Occasionally, clear delineation of the femoral nerve may be difficult in some cases because of its position between the iliopsoas muscle and fascia. In order to avoid nerve damage in these cases, we recommend approaching the nerve as laterally as possible where it is more visible in cross-section when compared with an approach medial to the nerve.

An ultrasound-guided fascia iliaca block was found to be superior when compared with the traditional approach using 'loss of resistance' to identify the correct plane.[20] This technique requires higher volumes of local anaesthetic than the femoral nerve block but seems to be a useful alternative in cases of poor imaging conditions. In the vast majority of cases, we prefer the injection of smaller volumes of local anaesthetic close to the femoral nerve.

Saphenous nerve block

The indication for saphenous nerve block combined with a distal sciatic nerve block is surgery to the foot and ankle. An infrapatellar branch block can be used for analgesia after knee arthroscopy.

The saphenous nerve is a sensory terminal branch of the femoral nerve. It passes together with the femoral artery underneath the sartorius muscle where it can be accessed by means of a trans-sartorial approach in the middle third of the thigh. Subsequently, the femoral artery passes medially to enter the adductor canal and gives off the descending genicular artery, which passes distally together with the saphenous nerve. Ultrasound-guided block of the saphenous nerve is also possible at this location with the sartorius muscle as a major landmark (Fig. 6).[42] An ultrasound-guided block of the infrapatellar branch, at the level at which it separates from the saphenous nerve, proved effective in a small group of volunteers.[44] We use a trans-sartorial approach using an 'in-plane' technique.

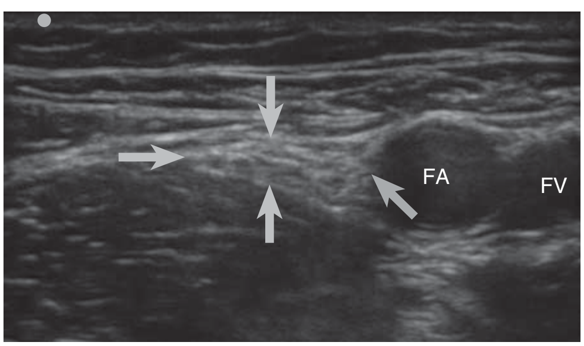

Fig 5 Ultrasound scan of the femoral nerve (labelled by the grey arrows) slightly distal to the inguinal ligament. FA, femoral artery; FV, femoral vein.

Obturator nerve block

There is an increasing interest in obturator nerve block for endoscopic urological procedures and the management of pain associated with major knee surgery. It has been shown that the obturator nerve provides a variable sensory supply to the medial aspect of the thigh and parts of the knee joint, and gives off branches to the hip joint as well. The feasibility of ultrasound imaging of the obturator nerve has been confirmed with nerve stimulation.[76] In a series of 22 patients, an 'out-of-plane' approach was used for the anterior branch of the obturator nerve, which is assumed to carry sensory fibres to the limb.[33] The anterior branch is shown as a flat, hyperechoic structure between the pectineus, adductor longus, and adductor brevis muscles (Fig. 7). In spite of these encouraging results, the detailed description of the underlying anatomy needs some refinement since the obturator nerve shows a considerable degree of variability at this level.[2 67] Recently, a proximal approach to the obturator nerve before its bifurcation was used successfully in a small series of chronic pain patients with hip, knee pain, and obturator neuralgia.[1]

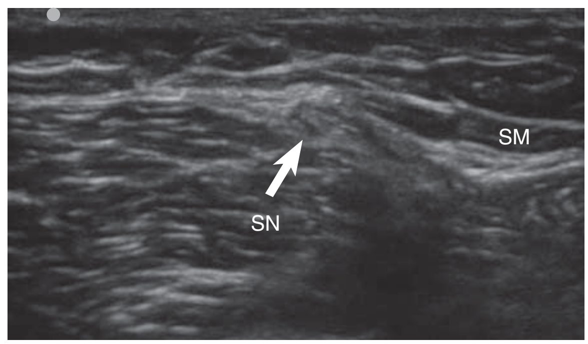

Fig 6 Ultrasound scan of the saphenous nerve (SN) below the sartorius muscle (SM).

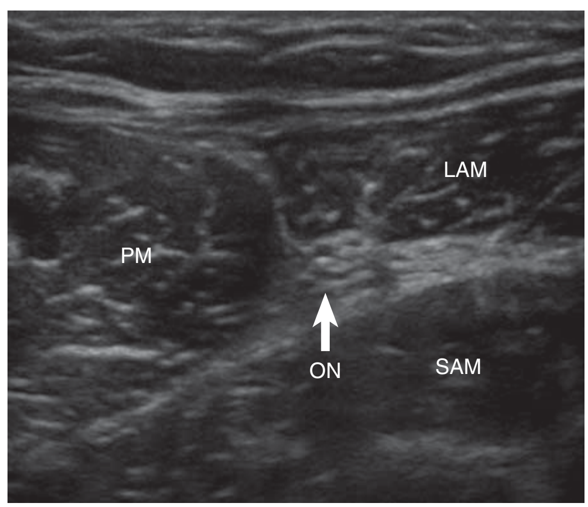

Fig 7 The anterior branch of the obturator nerve (ON) between the pectineus (PM), long adductor (LAM), and short adductor (SAM) muscles.

A completely different method using interfascial injections without the use of nerve stimulation and with an 'in-plane' technique has been described.[72] Local anaesthetic solution (5 ml) was injected in between the pectineus and adductor brevis muscles, and between the adductor brevis and magnus muscles, to surround both branches of the obturator nerve. In our practice, we identify the anterior branch of the obturator nerve between the pectineus and adductor brevis muscles, and use an 'in-plane' approach to inject a volume of 5–10 ml of local anaesthetic close to it.

Lateral cutaneous nerve of the thigh block

Using modern ultrasound equipment, even the smallest nerves can be visualized successfully. Block of the lateral cutaneous nerve of the thigh near the anterior superior iliac spine is useful when seeking complete anaesthesia of the thigh. It is also a valuable tool in the diagnosis and treatment of chronic pain in this area, and an ultrasound-guided technique has been used in a series of 10 patients.[34] A case report demonstrated the successful management of meralgia paraesthetica with an ultrasound-guided lateral cutaneous nerve of the thigh block.[83] This early clinical experience was supported by an anatomical study that showed the reliability of an ultrasound-guided approach below the anterior superior iliac spine.[55] A highly selective technique using ultrasound produced successful blocks with only 0.3 ml of lidocaine.[10]

Sciatic nerve blocks

Sciatic nerve blocks can be performed using a number of techniques and approaches. In general, the nerve can be blocked at any site in its course, provided good ultrasound images can be achieved. The sciatic nerve can be visualized by ultrasonography from the gluteal region to the popliteal fossa.[8 11 13 37 68] However, imaging of the sciatic nerve can be challenging for a number of reasons. The large amounts of muscle and fat surrounding the nerve can impair ultrasound visualization. Curved array probes operating at lower frequencies (5–8 MHz) provide better images, in particular for transgluteal and anterior approaches. The anisotropic behaviour of the sciatic nerve is a frequent cause of poor nerve visibility.

We use the *transgluteal approach* to block the sciatic nerve proximally and combine it with a posterior lumbar plexus block for the management of hip fractures in the elderly with significant heart disease such as severe aortic stenosis. The sciatic nerve gives off branches to the posterior aspect of the hip joint. The *anterior approach* to the sciatic nerve is a useful alternative in patients who are difficult to position. For reliable ultrasound imaging, the thigh has to be externally rotated by about 30°–45°, which limits its use in some patients with lower limb trauma. For most patients, the *subgluteal approach* is our method of choice, as it combines optimal imaging conditions and

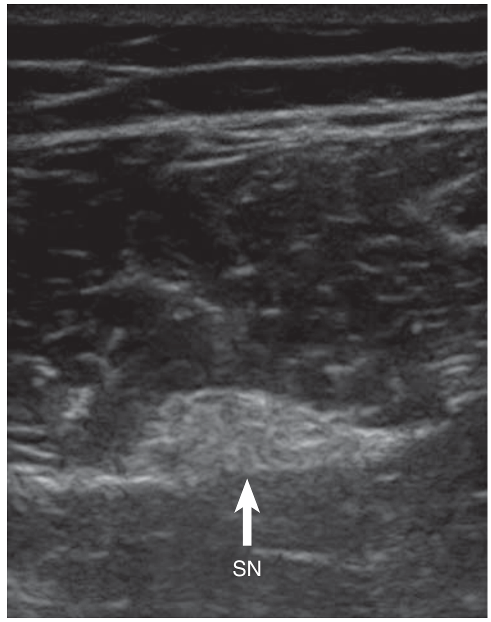

Fig 8 The sciatic nerve (SN) in the subgluteal region.

simple access to the sciatic nerve (Fig. 8). Knee surgery, vascular surgery, and leg amputations are the commonest indications for this block, which can be performed with the patient lying supine or in the lateral position.

More distal approaches to the sciatic nerve can be used for surgical procedures on the ankle and foot. Distal sciatic nerve blocks can be achieved using a lateral approach, advancing the needle 'in plane', or a posterior approach with 'out-of-plane' needle guidance. Initially, we recommend the performance of all distal sciatic approaches with the patient in the prone position if possible. Visualization of the sciatic nerve is better and needle guidance is easier with the patient in this position.

Peripheral nerve blocks

Although a *posterior tibial nerve* block at the ankle seems to be one of the easiest techniques, results are sometimes disappointing. Ultrasound-guided posterior tibial nerve block at the medial malleolus was shown to be significantly superior to the traditional landmark-based technique in a small group of volunteers, with an overall success rate of about 70%.[63 74] Ultrasound-guided sural nerve block at the ankle using the lesser saphenous vein as a major landmark has been described.[64]

Trunk blocks

Ilioinguinal/iliohypogastric blocks are described in children[87 89] and adults.[23] The initial description of ultrasound-guided ilioinguinal–iliohypogastric blocks was a randomized and comparative study in 100 children[89] and showed a success rate of 96% in the ultrasound group when compared with a 74% success rate in the 'fascial click' group. The ultrasound-guided technique is easy to perform with an in-plane or out-of-plane technique. Identification of the ilioinguinal and iliohypogastric nerves is usually simple at the level of the anterior superior iliac spine between the internal oblique and transversus abdominis muscles (Fig. 9). In a subsequent study using a volume reduction protocol, the same authors determined a local anaesthetic volume of 0.075 ml kg^{-1} as being sufficient.[87] The ilioinguinal and iliohypogastric nerves can be blocked selectively.[23]

The use of a *TAP block* is growing rapidly. It has been shown that the technique provides effective analgesia after a wide range of abdominal operations.[12 49 50 59] The concept behind this approach is to inject local anaesthetic solution into the plane between the internal oblique and transversus abdominis muscles to block intercostal nerves T_7–T_{12}, the ilioinguinal and iliohypogastric nerves, and the lateral cutaneous branches of the L_{1-3} dorsal rami. Initially, a blind 'two-pop' loss of resistance technique was described for the injection of local anaesthetic into the abdominal wall at the lumbar triangle—the Triangle of Petit.[50] A case report of liver trauma showed the potential dangers of blind injections into the abdominal wall.[58]

The use of ultrasound-guided TAP blocks in patients undergoing laparoscopic gynaecological surgery has been reported.[70] A subcostal oblique ultrasound-guided TAP block with a needle insertion point near the xyphoid process[32] and ultrasound-guided TAP blocks above the iliac crest[86] have been described.

Ultrasound imaging of the abdominal wall in the mid-axillary line reveals three muscular layers: the external oblique, the internal oblique, and the transversus abdominis muscles (Fig. 10). The needle is guided by an 'in-plane' technique and passes into the plane between the latter two muscles, allowing local anaesthetic solution to be injected into the TAP. A cadaver study showed that ultrasound-guided dye injection above the iliac crest mainly involves the T_{10}–L_1 dermatomes,[79] and a multiple injection technique to extend local anaesthetic spread has been proposed.[6]

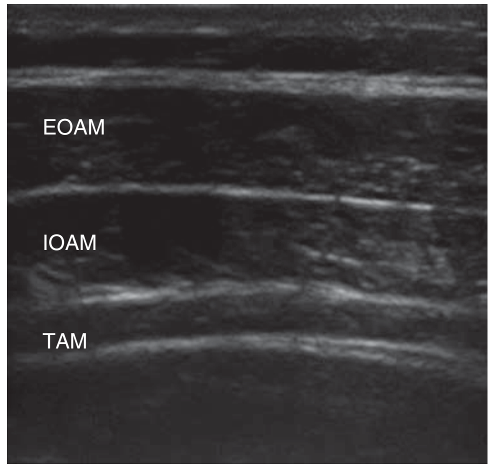

Fig 10 The lateral abdominal wall with the external oblique (EOAM), internal oblique (IOAM), and transversus abdominis muscles (TAM). The local anaesthetic needs to be injected between the inner two muscle layers.

Recently, several authors have been able to demonstrate the analgesic efficacy of ultrasound-guided TAP blocks in a number of different clinical settings.[7 24 57] To provide analgesia with a TAP block, total volumes of local anaesthetic of 30–40 ml have to be injected. High plasma concentrations have been measured 15 min after TAP block in 12 patients.[39] This raises concerns about the possibility of systemic toxicity and a possible systemic analgesic effect of the injected local anaesthetic resulting from the high plasma levels.

TAP block represents an interesting and effective regional anaesthetic technique for the provision of pain relief after abdominal surgery. Future studies should define its risks and benefits, and compare them with epidural techniques, which can be considered the 'gold standard' for the provision of abdominal analgesia.

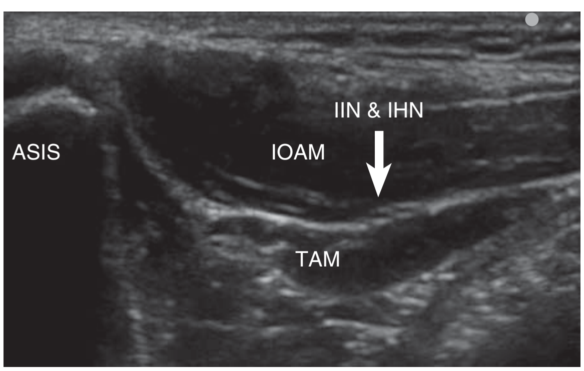

Fig 9 Transverse ultrasound scan of the ilioinguinal and iliohypogastric nerves (IIN and IHN) medial to the anterior superior iliac spine (ASIS). IOAM, internal oblique abdominal muscle; TAM, transversus abdominis muscle. Only the aponeurosis of the external oblique abdominal muscle above the IOAM is visible in this scan at that level.

Neuraxial techniques

The use of *ultrasound-guided neuraxial techniques* in adults is controversial. The results of the study[46] which observed a decreased ultrasound visibility of neuraxial anatomical structures with increasing weight and age in children can be translated and extended to adults, in whom high-quality images of neuraxial structures are hard to achieve. It is a harsh anatomical fact that bones interfere with ultrasound, resulting in greatly impaired visibility of relevant neuraxial anatomical structures.

An in-plane technique for epidural injection in 15 adults has been described[38] using a technique similar to that described in children,[88 90] and the authors were able to identify the epidural space in 14 of 15 cases. Anterior displacement of the posterior dura and the spread of local anaesthetic could be observed in eight of 15 cases. In common with their description of this technique for children, they used a combination of ultrasound and the conventional loss-of-resistance technique.[38] There are currently no comparative studies of the use of ultrasound-guided epidural injection or catheter placement in adults. Imaging of the epidural space in adults is at the limits of current technology and routine adoption of ultrasound-guided techniques must await further technical developments.

Paravertebral blocks are much more promising for ultrasound-guided techniques because of better visualization with ultrasound. The paravertebral space is located lateral to the vertebral column and appears as a wedge-shaped space. The anterolateral boundary is formed by the parietal pleura, and the medial boundary is formed by the posterolateral aspect of the vertebral body, the intervertebral disc, the intervertebral foramen and its contents, and the superior costotransverse ligament, which extends from the lower border of the transverse process above to the upper border of the transverse process below, forming the posterior wall of the paravertebral space. The apex of the paravertebral space is continuous with the intercostal space lateral to the tips of the transverse processes. The endothoracic fascia, which is interposed between the parietal pleura and the superior costotransverse ligament, divides the paravertebral space into two compartments: the anterior extrapleural and the posterior subendothoracic paravertebral compartments. The thoracic paravertebral space contains the intercostal spinal nerves, the dorsal rami, the rami communicantes, the sympathetic chain, intercostal vessels, and fatty tissue. The intercostal nerves and vessels are located behind the endothoracic fascia, whereas the sympathetic trunk is located anterior to it in the paravertebral space (Fig. 11). In an early study, ultrasound was used to identify the pleura lateral to the transverse process at the T_4 level to confirm the maximum depth of needle insertion.[62] Subsequently, a different technique was suggested,[30] but the authors were not able to identify the position of the needle. Recently, the same authors have proposed ultrasound-guided paravertebral blocks for breast surgery.[31]

More detailed information from a human cadaver study describes the relevant ultrasound anatomy.[45] Reliable identification of the superior costotransverse ligament and the paravertebral space was possible in 10 cadavers, resulting in the accurate administration of fluid. Catheter placement is associated with a high failure rate, with the tip of the catheter often found in the epidural, mediastinal, or pleural space. Once the paravertebral space is correctly identified lateral to the transverse process and below the superior costotransverse ligament, the needle can be introduced with an out-of-plane needle guidance technique. Depending upon the indication for the block, a puncture at one or two levels can be performed.

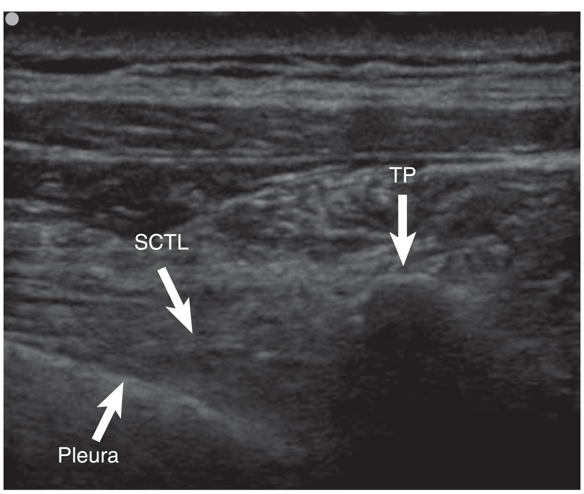

Fig 11 The paravertebral space between the transverse process (TP), the superior costotransverse ligament (SCTL), and the parietal pleura.

Summary

Ultrasound-guided regional anaesthetic techniques are now fully integrated into the everyday clinical practice of a large number of anaesthetists. Technological advances in the design of ultrasound equipment have allowed clear visualization of the majority of nerves. Notwithstanding this substantial growth in interest and in clinical practice, large outcome studies are still lacking and should be the focus of efforts in the next few years. However, our experience of 15 yr of the regular and routine use of ultrasound-guided blocks has shown that these techniques are both highly effective and safe. We can only hope that the increased interest in ultrasound will produce an increasing number of high-quality studies that will further develop both the science and art of regional anaesthesia.

Conflict of interest

P.M. has received funding to defray the expenses of attendance at conferences from SonoSite Ltd.

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