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*Review article*

# *Ultrasonographic guidance in pediatric regional anesthesia part 1: theoretical background*

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## *Summary*

Recent findings support the use of ultrasonographic guidance in pediatric regional anesthesia. This review article illustrates basic knowledge in physics of ultrasound and ultrasonographic appearance of neuronal structures, which are prerequisites for the safe application of this technique in daily clinical practice. A critical view on education and ethics in science should emphasize future developments in ultrasonography for pediatric regional anesthesia.

***Keywords:*** ultrasound; pediatric regional anesthesia; physics of ultrasound; education

## Introduction

Regional anesthesia plays an important role in the perioperative management of children and particularly of babies and neonates, where one should avoid or minimize airway manipulation whenever possible. Perfect block techniques are required for an improved perioperative outcome. Interestingly, many peripheral regional techniques are not adequately described, resulting in complications and low success rates whereas central techniques are well described with ensuing high success rates.

Although it has not yet been sufficiently described in an 'evidence-based' manner, ultrasonographic guidance for a broad spectrum of regional anesthetic techniques results in safe and effective blocks. Recent publications have illustrated the use of ultrasonography for central (1–4) and peripheral blocks (5–9) for children also. The initial results encouraged scientific study groups to increase their efforts to develop new ultrasound-guided regional techniques targeted towards children, in an effort to introduce these techniques into clinical practice in the future.

The review article introduces pediatric anesthesiologists to the theoretical background, current knowledge and the daily practical use of ultrasonographic-guided regional anesthetic techniques.

## History of ultrasound

Pierre and Jacques Curie described the piezoelectric effect in 1880, and in 1881 Gabriel Lippmann detailed the inversed piezoelectric effect, both of which are the scientific principles behind ultrasonography. As is nearly always the case, their application in medicine was not the reason for the initial developments in the field. Ultrasound played a vital role in World War I, where it was used to detect and subsequently destroy German submarines.

K.T. Dussik, an Austrian neurologist, was the first to attempt to use ultrasound in diagnostic imaging. He tried to depict the cerebral ventricles, but the brain, being entirely surrounded by bone, is poorly

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amenable to ultrasound imaging and many of his 'ventriculograms' were later shown to be mere artifacts.

Despite this setback, after World War II scientists around the globe focused their efforts on demonstrating the use and applicability of ultrasound imaging in medicine and developed new technologies. Howry and Wild pioneered the compound-contact procedure in 1952. Moving pictures became possible with the introduction of the real-time process in 1965 by Krause and Soldner. Duplex sonography has made flow imaging possible since 1983, and the implementation of endosonography in 1985 and 3D-sonography in 1995 have opened new frontiers in medical diagnostic imaging.

In 1978, la Grange *et al.* reported the use of a Doppler flow ultrasound detector to facilitate supraclavicular blockade of the brachial plexus. To our knowledge, this was the first study in which an indirect sonographic approach was used for regional anesthesia (10). Since two-dimensional images could not be obtained with a high resolution, more advanced applications of ultrasound were out of reach at the time. In 1994, Kapral *et al.* published the first report on direct sonographic visualization in regional anesthesia. They investigated supraclavicular blockade of the brachial plexus in adults and even succeeded in viewing the spread of local anesthetic (11).

Improvements in ultrasound technology during the past decade have made it possible to visualize even minute anatomical structures. Today, as a result, the majority of anatomical structures and landmarks can be seen via ultrasound guidance even in small children (4,8).

## Physical properties of ultrasound

### *Ultrasound*

Ultrasound is defined as the frequencies above the human hearing ranging from 20 kHz to 10 GHz. Its primary clinical application today is as a diagnostic tool and as a means to display anatomical structures, for which frequencies between 2 and 15 MHz are most commonly used.

Some values necessary for understanding ultrasound physics are:

- Amplitude ($A$) is the maximum expansion, i.e. height of the wave.
- Frequency ($f$) is the vibrations per second, measured in Hertz (Hz).
- Wavelength ($\lambda$) is the distance between two points in the same state of movement; it is inversely proportional to the frequency $f$. $\lambda$ is a rough measure of discrimination; in the frequencies between 2 and 15 MHz structures as small as 0.1–1 mm can be depicted. Structures below this size threshold cannot be discriminated individually. It is important to note that the higher the frequency, the smaller the wavelength and the size of individually distinguishable structures.
- Sound velocity $(v) = f \times \lambda$. Sound velocity depends very much on the properties of the tissue in which it is traveling. While it is quite similar in fatty tissue, blood, muscle tissue and nerves, about 1500 $\mathrm{m{\cdot}s^{-1}}$ for $f = 1$ MHz, it shows considerable differences in air and bone (353 and 2650–4040 $\mathrm{m{\cdot}s^{-1}}$, respectively).

The fundamental principle on which diagnostic ultrasound is based is the emission of short-generated bursts of ultrasound whose reflected echoes are subsequently recorded. This impulse–echo principle allows us to deduce the depth of the received echo. Knowing the sound velocity and elapsed time, this is calculated as $[2s = v \times t]$ ($s$ being the distance between the ultrasound emitter and reflecting object, and thus $2s$ equals to the distance traveled by the sound; $v$ is the sound velocity; and $t$ is the elapsed time).

The impedance $Z$ (acoustic resistance acting against the sound wave propagation) is a measure of the hardness of the tissue or medium. It is defined as the product of material density and the velocity of propagation $[Z = p \times v]$.

Differences in impedance along boundary layers result in various physical phenomena:

*Reflection and transmission.* When an ultrasound wave hits an acoustic boundary layer, a part of it is thrown back (reflected). The intensity of the echo is determined by the impedance differences of the bounding layers. Reflection is described in the Fresnel equation: echo intensity $\sim E_r/E_e = [(Z_2 - Z_1)/(Z_2 + Z_1)]$ ($E_r$ is the reflected sound wave, $E_e$ is the arriving sound wave, $Z_2 - Z_1$ is the difference in impedance).

 

In practice, this signifies that when an ultrasound wave meets bone or air (e.g. air-filled intestine, layer of air between the skin and the ultrasound probe) the greatest part of the ultrasound wave is reflected, as there is a high difference in impedance between bone or air and soft tissue (high $Z$ in the former, low $Z$ in the latter). In this case, there is almost no sound transmission and the structures behind the boundary layer are not depicted. This is also the reason why contact gel is so important in ultrasound. In a homogenous medium or tissue no echoes are produced.

*Refraction.* A sound wave meeting a boundary layer at an angle $i$ will undergo a change of direction as it enters the next medium – this is termed refraction. The cause of refraction is the change in the velocity of propagation. If the velocity is greater in the first medium, the refraction occurs towards the perpendicular; if it is greater in the second medium, the refraction occurs away from the perpendicular.

Snellius' law of refraction: $\sin \alpha_B / \sin \alpha_A = v_B / v_A$($\alpha_B$ is the angle of refraction, $v_B$ is the propagation velocity medium B, $\alpha_A$ is the angle of incidence, $v_A$ is the propagation velocity medium A).

*Absorption.* Absorption plays a major role in diagnostic ultrasound, because it is the main cause of the energy loss of ultrasound in biological tissue. When sound waves enter a body, friction causes kinetic energy to be converted to heat energy (thermal relaxation). The energy lost in this way cannot be used to build up an image any more.

Absorption is dependent on the tissue itself (high absorption in bone, causing acoustical shadows or even deletion) and on the frequencies employed. These behave proportionally to the absorption coefficient $\tau$. Therefore, higher the frequency, the greater the damping and the less the maximum depth of penetration.

*Scattering.* Small objects (red blood cells, muscle or connective tissue fibers) reflect the ultrasound waves in many directions, scattering the ultrasound beam and distorting the resulting image. The type of distortion and scattering can help to differentiate tissue structures. Fluid-filled cysts scatter the ultrasound beam less and are more permeable to it than solid tumors.

*Divergence.* Sound waves originating from a narrow emitter fan apart with increasing distance. Divergence depends only on the geometry of the ultrasound probe and is not influenced by the type of tissue it traverses. Divergence also dampens the ultrasound wave in its direction of propagation.

## Technical background

*Generation and reception of ultrasound waves.* When an alternating voltage is applied to a polar crystal such as barium titanate or lead zirconate, the crystal undergoes periodic deformation and sound waves are created. This is known as the piezoelectric effect. The reverse piezoelectric effect signifies that reflected sound waves cause charge shifts in the crystals that can be measured as alternating voltage. The same crystal can therefore be used as both emitter and receptor.

The piezoelectric and reverse piezoelectric effect are responsible for the ability to both generate and receive sound in an ultrasound probe and are fundamental to the application of diagnostic ultrasound in a medical setting.

*Configuration of an ultrasound probe.* The adaptation layers on the patient side of the probe insure that the ultrasound is optimally transmitted into the tissue. The piezoelectric element lies next and is usually made of a ceramic material. This is followed by a dampener that prevents sound waves from being reflected within the probe and insures a larger bandwidth. The entire assembly functions with electricity.

In the B-mode probes most often used in diagnostic ultrasound, the piezoelectric element is composed of various ceramic layers, which explains the sensitivity of ultrasound probes to mechanical shocks.

*Types of ultrasound probes.* Ultrasound probes are named after the geometric arrangement of their piezoelectric elements. We usually distinguish two types of probes:

- Linear probes: the piezoelectric elements are arranged in parallel. They can be activated singly or in groups. The resulting image is square, with good resolution in the near field but narrow depth.

 

- Sector probes: the sound waves are emitted from a single point and diverge fan-wise. This gives good resolution and depth penetration but structures in the vicinity of the probe are rather poorly imaged.

*Sound field.* The sound field of a focused sound wave has three parts:

- The near field: it delivers images of very erratic quality and cannot be used for diagnostic purposes. The near field is the most erratic in sector and convex probes, but the disturbance can be can reduced by interposing a gel cushion to remove the near field from the zone of interest.
- Focus zone: the sound cone is at its narrowest and allows for the greatest resolution.
- Far field: here, the resolution is reduced by the divergence of the sound waves and the absorption of the sound in the tissue.

*Resolution.* Resolution describes the smallest possible distance between two points that still allows them to be discriminated. We can differentiate axial and lateral resolution.

The axial resolution $\Delta s$ is determined by the direction of the sound spread. It is dependent on the impulse length and the ultrasound frequency. In order to prevent interference, the echo impulse should be at least twice as long as the wavelength ($2\Delta s > 2\lambda$, from which follows that: $\Delta s > \lambda = v/f$). Therefore, the higher the frequency, the better the resolution.

The lateral resolution is vertical to the direction of the sound wave and is determined by the width of the ultrasound probe and the image line density. As a rule of thumb, the narrower the sound cone and the greater the surface of the probe, the better the lateral resolution. It is greatest in the focus zone, but altogether two to three times less than the axial resolution and its discrimination power lies around four to five wavelengths.

*Artifacts.* Artifacts refer to physical or technical structures visible in the ultrasound image that have no anatomical correlate. These structures are the result of discrepancies between the ideal tissue used for the image calculation and the real object of examination.

In general, these artifacts can make the interpretation of images and tissues very difficult; sometimes, however, they can help diagnose certain conditions.

In order to avoid wrong diagnoses, it is important to examine structures that appear pathological in at least two ultrasound planes. Real structures will be visible in both, while artifacts cannot be reproduced.

We can differentiate following typical artifacts:

*White noise:* This phenomenon is due to small and medium-sized low-intensity echoes that are caused by too much gain especially in superficial echo-poor areas (bladder, gallbladder). White noise can be reduced by lowering the gain or shifting the focus deeper.

*Repetitive echoes:* Also known as reverberation artifacts, these are caused by repeated reflection of ultrasound waves on boundary layers with different acoustical resistance. They appear as bright bands or comet-tails and their intensity decreases with increasing distance from the probe. They are usually the result of insufficient coupling.

*Mirror artifacts:* A strong reflecting surface such as the diaphragm can mirror the echo of a real anatomical structure. Due to the delay in the return of the sound wave, the reflected echo appears in greater depth and in a different location. When the probe is moved, the mirror artifact will move to the direction opposite to the probe.

*Echo shadowing:* There is often a dark, echo-free area behind strongly reflecting or absorbing surfaces such as bone, stones or metallic implants. Although this prevents the tissue in this area from being examined, dorsal echo shadowing is useful when diagnosing kidney or gallbladder stones.

*Lateral shadow marking:* Due to refraction and scattering, a sound wave hitting a cyst will be deflected and cause a braid-like hypo-echoic structure to appear along the edges behind the cyst.

*Sound amplification:* The (relative) dorsal sound amplification is another important criterion in diagnosing cysts. The wave traveling through a liquid-filled cavity with a low absorption rate and impedance close to that of tissue will be absorbed less than waves traveling through tissue, and the structures behind the cyst in the path of the same sound wave will appear with higher echo intensity.

*Delay artifacts:* If the discrepancy between the calculated and true sound velocity is too great, anatomical structures can appear convex and bloated. This effect is particularly impressive in neighboring structures with different propagation velocities, such as cartilage and muscle.

*Boundary layer artifacts:* These occur particularly along boundary layers with high acoustical impedance (cyst edges) and show a fringe of fine, soft echoes that can sometimes be mistaken for sediments.

*Secondary cone artifacts:* Secondary cones can originate along strong reflecting surfaces. A convex line in the image results when the echoes from these secondary cones are ascribed to the primary sound cone. This artifact only occurs in one plane and disappears when the direction of the sound cone is changed.

*System configuration.* Sonographic images must be optimally configured to effectively visualize tiny anatomical structures. The following guidelines will make it easier for anesthesiologists to optimize their ultrasound investigations and related clinical procedures.

*Image depths:* Target structures are significantly more difficult to interpret once the individual pixels become visible at larger magnifications. An appropriate balance must be found between overview and detail.

*Gain:* The gain must be carefully optimized for the existing image depth. Some ultrasound systems offer independent gain settings for different image sections. This function is known as time gain compensation. Gain options of other systems are more basic (surface/depth gain).

*Focus:* The focus of the ultrasound image must be adjusted to capture the level of the target structures as distinctly as possible because vertical anatomical relations are considerably smaller in children. High-end systems enable the operator to select different focal zones, i.e. the zone of optimal resolution is progressively reduced as smaller focal zones are selected. Defining two or three focal zones would be a typical compromise.

*Biological effects and possible damage.* Although energy is transmitted to the tissue during every ultrasound examination, to date there have been no indications that the clinical use of ultrasound can compromise health. As far as is currently known, ultrasound waves with an energy value below 100 $mW \cdot cm^2$ do not cause significant tissue warming. This is a limit that is not usually transcended in routine B-mode diagnostic ultrasound. Some of the effects of ultrasound that have been shown under laboratory conditions such as the disruption of cell membranes, cavitation, and formation of free radicals have not been demonstrated in the human body. To our knowledge, diagnostic ultrasound does not represent a risk factor for tissue damage.

## Ultrasonographic appearance of peripheral nerves

The connective tissue inside the nerves (perineurium and epineurium) reflects ultrasound waves in an anisotropic manner. In other words, the true echogenicity of a nerve is only captured if the sound beam is oriented perpendicular to the nerve axis. Consequently, linear probes with parallel sound beam emission offer advantages over sector probes, which are characterized by diverging sound waves.

Peripheral nerves may have a hypo-echoic (dark structures, Figure 1) or hyperechoic (bright structures, Figure 2) appearance in ultrasonography, depending on the size of the nerve, the sonographic frequency, and the angle of the ultrasound beam (see above). We perform all blocks on transverse scans, where the nerves appear as multiple round or oval hypo-echoic areas encircled by a relatively hyperechoic horizon. These hyperechoic structures are the fascicles of the nerves while the hypo-echoic background reflects the connective tissue between neuronal structures.

Most peripheral nerves can be visualized over their entire course, which allows a safe differentiation from tendons. Their visibility is only limited

 

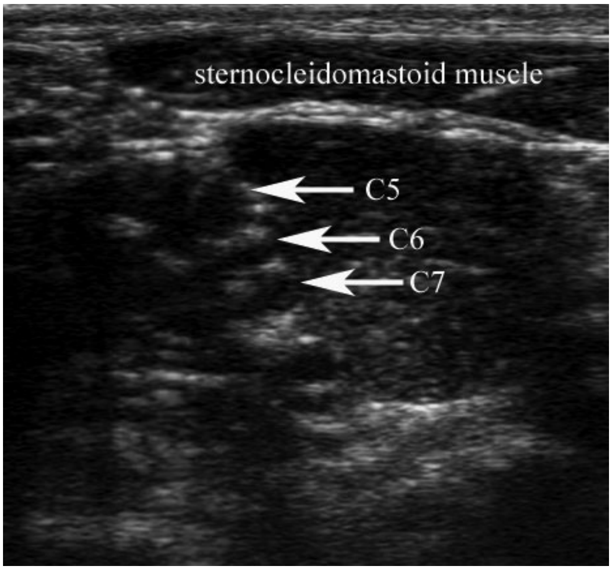


**Figure 1**
Ultrasonographic appearance of the C5–7 nerve roots in a transverse view as hypo-echoic round structures.

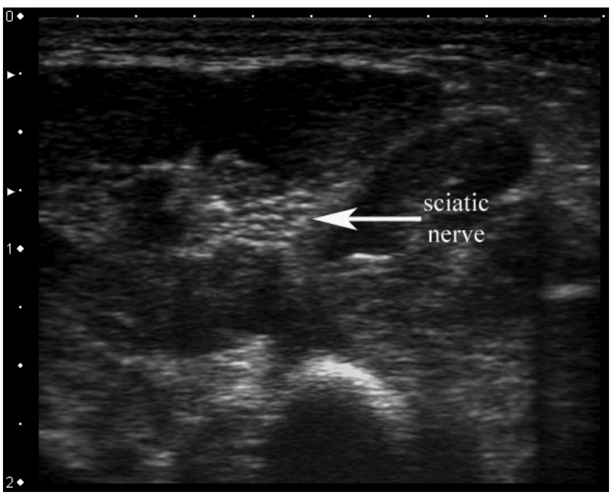


**Figure 2**
Ultrasonographic appearance of the sciatic nerve in a transverse view as hyperechoic oval structure. The hyperechoic dots inside the nerve represent the fascicles.

where dorsal shadows of bone structures or large vessels are present.

In very view techniques, direct ultrasonographic visualization of the nerve structures is not possible. One example is the rectus sheath block, where the local anesthetic should be administered inside the posterior rectus sheath of the rectus abdominal muscle. In these cases, the target structures are not a nerve, but also for these techniques direct ultrasonographic imaging of anatomical structures during performance of the blocks offers significant advantages compared with blind infiltration techniques.

## Background of ultrasonography in pediatric regional anesthesia

This has been mentioned before but bears repeating: children are not undersized adults. This fact is of particular importance in pediatric regional anesthesia, where most of the techniques are not described precisely enough, relying on anatomical landmarks for blind infiltration techniques. Poor knowledge of the particulars of pediatric anatomy may be a reason for poor results, particularly regarding peripheral techniques.

Precise anatomical documentations and descriptions are uncommon in children and decrease age-dependently, with only marginal knowledge on the guiding structures in infants and neonates. Yet, a fundamental understanding of anatomical topography is mandatory for the safe and successful realization of peripheral and central blocks. A means to directly image sensitive structures with a close anatomical relationship would therefore be invaluable in pediatric regional anesthesia.

Today, ultrasonography is the only noninvasive bedside method to allow direct imaging of anatomical relationships as well as the performance of regional anesthesia techniques under real-time control. We do not wish to conceal that this technique can be associated with some problems, but after 10 years of experience with ultrasonography in adults and in children we are able to declare that advantages are significant compared with the problems. It is also clear that the technique, though sophisticated from our present point of view, is still in its infancy and could eventually herald a revolution within our specialty.

### *Advantages*

Most of the advantages of ultrasound-guided regional anesthesia techniques in children have been evaluated in adults. Only a few case series and controlled studies are published that refer to children (4–9), and therefore, we must deduce the list of possible advantages from a more or less 'expert-based opinion'.

The main advantages conferred by ultrasonographically guided techniques in children are the imaging of all anatomical structures and the possibility to directly ascertain the position of the tip of the cannula relative to the nerve. As a consequence, inadvertent trauma of surrounding structures (e.g. cervical pleura during periclavicular brachial plexus blocks, peritoneum during abdominal wall blocks) or puncture of nerves or neuraxial structures with subsequent damage can safely be avoided. Another advantage is the direct control of the distribution of local anesthetic. This may sound simplistic, but the tip of a needle does not block nerves, the local anesthetic blocks them. Therefore, a prediction of the success of a block is possible, and in cases of misdistribution of the local anesthetic a correction of the needle position is possible.

Additional advantages lie with the faster onset of sensory and motor blocks, longer duration of blocks (6), increased block qualities (6–8) and reduced volumes of local anesthetics (7). Because muscle twitches during nerve stimulation are avoided, nearly painless blocks in only lightly sedated or awake children are possible (6).

Once again, only a few publications support the advantages described above of ultrasonography for pediatric regional anesthesia, and further investigations are necessary to transform these conclusions from 'expert-based' to 'evidence-based'.

## *Problems associated with the technique*

Two major problems are associated with ultrasonography for pediatric regional anesthesia: the need for appropriate equipment, and adequate education and training.

A frequently stated argument against ultrasonography for regional anesthesia is the high cost of ultrasonographic equipment. Recently, however, the market has seen the arrival of high-end portable ultrasonography sets approaching laptop format, which are considerably cheaper compared with large machines and may enable a larger number of anesthesiologists to perform ultrasonographically guided blocks in children. An exact analysis of costs considering cheaper needle equipment (avoidance of electric cable and insulated needle shaft), reduced volumes of local anesthetics and improved block qualities and success rates with a very low rate of conversions to general anesthesia will result in significantly lower costs for each of the blocks. Thus, the amortization of the ultrasound equipment would be possible within a reasonable time frame. Initial results by Sandhu *et al.* (12) are promising.

Perfect working central blocks following large surgery in children will be the basis for early extubation and shorter ICU stays, further reducing costs. Future multicenter trials have to be conducted to support these theoretical considerations.

Closely associated with costs is the avoidance of complications following regional blocks. We should be aware that most of the complications in this field go unreported. Nevertheless, it is clear that direct ultrasonographic visualization is an important factor in the avoidance of complications.

The most fundamental concern lies with the need for appropriate education and practical training in order for the anesthesiologist to perform effective and safe ultrasound-guided blocks. Extensive anatomical knowledge is also a basis for these techniques. Ultrasonography does not replace anatomical knowledge. A basic understanding of the physics involved in ultrasound should be considered mandatory. A graduated scheme of education will be discussed later in this article.

## *Ultrasound equipment*

A crucial requirement allowing these techniques to be routinely used has been met by the introduction of portable ultrasound equipment (Figure 3) offering almost the same level of image resolution as larger (and more expensive) systems. Special operating systems have proven useful in daily practice because they offer excellent stability and short start-up times. Today's portable designs offer resolutions high enough to visualize nerve structures.

For most of the blocks we use linear ultrasound probes with a 25 mm active surface area (Figure 4). In older children, probes with a 38 mm active surface area can be used for an increased overview. Sector probes are usually not necessary in pediatric ultrasound-guided regional anesthesia.

While high sound frequencies are needed for high-resolution imaging, there is an inverse relationship

 

**Figure 3**
Transportable ultrasonographic high-end system.

**Figure 4**
Linear ultrasonographic probe with a 25 mm active surface area (6–13 MHz).

between frequency and penetration depth. Most nerve block applications require frequencies in the range of 10–14 MHz. Broadband transducers covering a bandwidth of 5–10 MHz or 8–14 MHz offer an excellent resolution of superficial structures in the upper limbs and good penetration depths in the lower limbs.

### *Needle equipment*

In principle, common needle equipment can be used for all ultrasonographic techniques. Preliminary results suggest that differences in ultrasonographic needle visualization depend on the diameter of the needle and the angle of penetration (13), but our daily clinical practice illustrates only minimal differences between needles. Different manufacturers have been trying to improve the needle visibility in ultrasound by modifying the surface material, and future studies will show if an appropriate balance between needle visibility and artifacts could be found. In our daily clinical practice, we perform most peripheral nerve blocks with 22G needles with a facette tip. The facette tip allows an exact movement of the needle with minimal pain during the placement of the needle.

## Performance of blocks

### *Planning*

Usually the surgical procedure dictates the level of the block and is independent of the method of nerve identification. The main advantage of ultrasonography is the possibility to block nerve structures at the optimal level of ultrasonographic imaging. Thus, two factors influence the site of injection of local anesthetic for central and peripheral regional techniques: the surgical procedure and the area of optimal ultrasonographic visualization of neural structures.

Another important part is the appropriate plan to perform the ultrasound-guided block itself. First, the optimal ultrasound probe should be selected. As described above, the majority of techniques in children require a linear probe with a 25 mm active surface and high frequencies (>10–12 MHz). Following exact ultrasonographic investigation of the area of puncture, the particular needle guidance technique is an important factor for a successful and safe block, and will be described later in this article. There is still no consensus about needle guidance techniques for each block, but our study group performs most of the blocks in a transverse technique.

 

## Disinfection

For single-shot punctures under ultrasound guidance, a surface disinfectant is applied to the probe in accordance with the manufacturer's recommendations. Then, the puncture site is disinfected and covered with a sterile ultrasound gel. We prefer urinary catheter gels. All subsequent steps follow a no-touch strategy. Skillful manipulation is required to avoid all contact of the needle with the probe or any other surfaces.

A different method is used for catheter techniques under ultrasonographic guidance. The skin is disinfected and we use a sterile covering. The ultrasound probe is inserted in a sterile glove filled with ultrasound gel, and then sterile gel is applied to the outside of the glove.

For both ultrasound-guided methods, single-shot and catheter techniques, we have never observed any infections with this sterile approach to regional anesthesia.

## Needle guidance techniques

Ultrasound techniques for regional anesthesia fall into two major categories depending on the needle position relative to the probe. The first method relies on a transversal needle orientation and is known as the cross-sectional technique (Figure 5). The needle can be identified by the tissue it displaces and by an acoustic shadow emerging dorsally at its tip. Only the needle tip can be visualized with this approach and therefore it must be precisely advanced to the depth of the target structure by selecting an appropriate puncture angle. The ultrasound image will reveal both the target structure and the needle position. Cross-sectional imaging allows us to maintain well-established puncture techniques in developing sonographic block techniques. In addition, the needle has to be advanced significantly less until it reaches the target structures, which reduces the degree of puncture-related trauma and pain compared with other needle guidance techniques.

The second option is to advance the needle longitudinally to the ultrasound probe and is known as the in-line technique (Figure 6). This will ideally allow the shaft of the needle to be visualized in addition to its tip if the needle is strictly located within the range of the emitted ultrasound signals. Hence, the relative orientation of the probe is crucial. Slight transversal deviations as small as 1–2 mm will remove the needle from the image, and it requires deft hand coordination for the optimal ultrasonographic visualization of the shaft and tip of the needle. Another problem associated with this technique is the dorsal reverberation artifact caused by the shaft of the needle. The spectrum of clinical indications for the in-line technique is narrow.

No matter which needle guidance technique is used, the direct imaging of local anesthetic spread during injection is a prerequisite for a safe block.

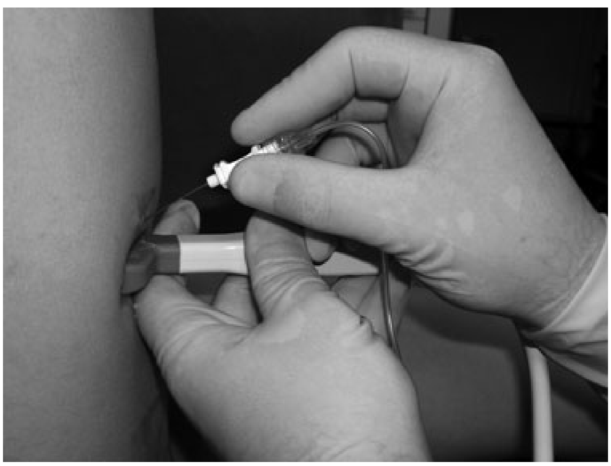

**Figure 5**
Cross-sectional technique for blockade of the sciatic nerve at the infragluteal level.

**Figure 6**
In-line technique for blockade of the sciatic nerve at the popliteal level.

## Education

As described above, appropriate education in ultrasonographically guided regional anesthetic techniques is one of the major limitations of the method. Currently, there is a severe lack of specialists in the field, and only a very few centers worldwide have introduced the technique into their daily clinical practice. No learning curves are available, but it is an observation that those who are experienced in regional anesthesia and able to understand the basic principles of ultrasonography will show a steeper learning curve.

The first step in education should be an intensive theoretical training in anatomy and in the physics underlying ultrasonography. Prior experience in adult regional anesthesia is an advantage. Most anesthesia congresses include ultrasonography in regional anesthesia in their programmes, and therefore an initial 'contact' with the topic is possible.

The second step is intensive ultrasonographic training. Wherever an ultrasound machine is available, this training can be performed. Specialized workshops including theory, practical needle guidance techniques, and intensive discussion of all topics in the field are useful during the initial education process. Finally, the acquired knowledge and skills should be implemented in the clinical practice following a step-by-step approach from 'peripheral to central'. It is clear that ultrasound-guided epidurals in babies should only be performed by someone thoroughly familiar with peripheral blocks.

## Ethics in science

The current standard of science in this field is directly correlated with the level of appropriate education and knowledge dissemination. At present, only a very few publications of appropriate scientific standard on ultrasound-guided regional anesthesia techniques in children are available. Prerequisites for these studies are a prospective, blinded and randomized design with an adequate number of cases in order to achieve sufficient power. Studies should only be performed and published by authors with extensive prior clinical experience with the technique. The future of ultrasonography and regional anesthesia (not only in children) will be dependent on large and well-designed studies investigating the observations in daily clinical practice. Case reports (14) are the first step of the scientific ladder, and should be followed by controlled studies.

But we should also be aware that not all questions can readily be answered using studies alone. The rate of complications of different regional anesthetic techniques is largely unknown, and therefore studies with extremely large case numbers would be necessary to prove that one technique is superior to another. Until then, a logical intellect and critical reflection and observations will be necessary to quantify the value of a new technique.

## Development of standards

As long as scientific publications are only available in low numbers, it is difficult to define standards in ultrasound-guided regional anesthesia. Once again, therefore, the 'expert opinion' serves as the basis for standards. Currently, a number of experts are developing standards under the patronage of the American Society of Regional Anesthesia, which will include basic requirements for equipment, a clear description of optimal views for the appropriate imaging of nerve structures for different regional anesthesia techniques and other closely related topics.

## Future perspectives

A lot has already been done, yet we must be aware that we are only at the beginning of a singularly important development in pediatric regional anesthesia. Ultrasonography for pediatric regional anesthesia is not a technique associated with extremely high costs. Affordable portable ultrasonographic equipment is available and can be used in circumstances in which general anesthesia is very risky and the demands on regional blocks are extremely high. In experienced hands, almost 100% success rate can be achieved, which is an important cost factor. Without disregarding the increasingly important discussion of costs, patient satisfaction and safety should be foremost in the mind of the anesthesiologist.

A staff anesthesiologist from our department has been involved in the use of ultrasound in regional anesthesia in children scheduled for orthopedic surgery in project in a remote location in India (http://www.johar.de). Regional anesthesia techniques can safely enable sophisticated surgical procedures in marginal settings. At present, and more so in the near future, a huge number of children could profit from these ultrasound-guided regional anesthesia techniques.

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