▼ Review Article

Needle Visualization in Ultrasound-Guided Regional Anesthesia: Challenges and Solutions

Ki Jinn Chin, M.B.B.S., F.A.N.Z.C.A., M. Med., F.R.C.P.C.,
Anahi Perlas, M.D., F.R.C.P.C., Vincent W. S. Chan, M.D., F.R.C.P.C., and
Richard Brull, M.D., F.R.C.P.C.

Needle visualization is important for safe and successful ultrasound-guided peripheral nerve block. However, accurate and consistent visualization of the needle tip can be difficult to achieve. This review article describes many of the challenges affecting needle visualization, summarizes the relevant literature on ultrasound imaging of needles, and offers practical strategies for improving needle tip visibility. Finally, future directions for research and development are suggested. *Reg Anesth Pain Med 2008;33:532-544.*

Key Words: Needle visualization, Peripheral nerve block, Regional anesthesia, Ultrasound.

The foremost advantage of ultrasound (US)-guided peripheral nerve block (PNB) is the ability to visualize both anatomical structures of interest as well as the advancing block needle. Ideally, US guidance should translate into greater efficacy, by ensuring accurate deposition and spread of local anesthetic around the target nerve; and improved safety, by avoiding unintentional intraneural and intravascular puncture and injection. While the identification of relevant anatomical structures can become relatively easy with practice and development of a trained eye, keeping the needle tip in view as the needle is advanced toward the target is much more difficult.[1] Failing to do so was the most common error observed in residents learning to perform US-guided PNB.[2] Persistent failure to visualize the needle tip was documented even after performing more than 100 US-guided PNB, suggesting that experienced practitioners can also face difficulty.[2] Needle advancement and/or local anesthetic injection without adequate needle tip visualization may result in unintentional vascular, neural, or visceral injury.

This review article describes many of the challenges in needle visualization, summarizes the relevant literature on ultrasound imaging of needles, and offers practical strategies for improving needle tip visibility.

Methods

We performed a literature search of the MEDLINE database from January 1960 to January 2008 using the search terms “ultrasound” and “needle” and limited the search by excluding terms related to anatomical structures or techniques that we considered irrelevant to peripheral nerve block. These included “endoscopic,” “endobronchial,” “brain,” “lung,” “pancreas,” “kidney,” “ovary,” “prostate,” and “fetus.” The search was limited to articles in the English language. This search strategy captured 4,427 articles, of which we eliminated 4,358 based on their titles. We reviewed the remaining abstracts and eliminated a further 29 articles due to lack of relevance. We reviewed the full text of the remaining 40 articles for relevance to our topic. We identified another 11 articles of interest from the reference lists of the reviewed articles. The selected articles were graded according to their level of evidence as recommended by the Centre for Evidence-Based Medicine (Appendix 1).

Results and Discussion

We identified 34 articles of direct relevance, including letters and case reports. These are summarized in Table 1 and discussed below. Where appro-

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From the Department of Anesthesia and Pain Management, Toronto Western Hospital, University Health Network, Toronto, Ontario, Canada.

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Reprint requests: Richard Brull, M.D., F.R.C.P.C., Department of Anesthesia, Toronto Western Hospital, University Health Network, 399 Bathurst Street, Toronto M5T 2S8, Ontario, Canada. E-mail: richard.brull@uhn.on.ca

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Table 1. Summary of Needle Visualization Strategies in Ultrasound-Guided Peripheral Nerve Block

Reference	Level of Evidence	Study Design/Subject(s)	Study Interventions	Outcomes	Key Results
Needle guides					
Hatada et al.[3]	3b	Retrospective case-control study. Patients undergoing ultrasound-guided fine needle aspiration biopsy of the breast.	Mechanical fixed needle guide vs. freehand technique.	Accuracy of pathological diagnosis.	1. Greater sensitivity of freehand technique for tumors <3 cm in diameter.
Phal et al.[4]	5	Comparative laboratory study. Gelatin liver phantom.	Mechanical fixed needle guide vs. freehand technique.	1. Procedure time. 2. Sample quality of biopsy specimen.	1. Shorter time to perform biopsy using a needle guide, especially for less experienced operators. 2. No difference in quality of biopsies.
Tsui[5]	5	Descriptive feasibility study. Water bath model.	Optical needle guide (laser-sighting apparatus for in plane needle-beam alignment).	Not applicable.	1. Feasible in the laboratory model. 2. No data on clinical use.
Echogenic needle design					
Perrella et al.[6]	1b	Controlled clinical trial (both interventions in each patient). Patients undergoing tissue biopsies or aspiration of fluid collections or percutaneous nephrostomy.	Biosponder 20G to 22G needles vs. standard Turner 20G biopsy needle.	Subjective assessment of NTV.	1. Poor NTV with standard biopsy needle in all patients. 2. Excellent NTV of Biosponder needle in 16 patients. There was technical equipment failure in the other 4 patients.
Bergin et al.[7]	1b	Randomized controlled trial. Patients undergoing tissue biopsy.	Polymer coated needle vs. uncoated 20G needle.	Subjective assessment of NTV and NSV.	1. NSV moderate to good in 79% coated vs. 28% uncoated. 2. NTV moderate to good in 100% coated vs. 84% uncoated. 3. No correlation between lesion depth and NTV.
Jandzinski et al.[8]	1b	Randomized controlled trial. Patients undergoing thyroid or liver biopsy	Polymer coated vs. Teflon coated vs. etched tip vs. untreated 22G needle.	Subjective assessment of NTV.	1. Best NTV with polymer coated needle for both thyroid and liver biopsy. 2. Superior NTV with untreated needle vs. Teflon coated and etched tip needles for liver biopsy, but not thyroid biopsy.
Gottlieb et al.[9]	5	Comparative laboratory study. Rabbits undergoing kidney biopsy.	Polymer coated vs. uncoated 22G spinal needles.	Subjective assessment of NSV.	1. Superior NSV with coated vs. uncoated needle. 2. Deterioration in visibility of coated needle with repeated use.
Culp et al.[10]	5	Comparative laboratory study. Gelatin liver phantom.	Polymer coated needle vs. dimpled distal shaft vs. uncoated 21G needle.	Objective and subjective assessments of NV.	1. Superior NV with coated and/or dimpled needles. 2. NV decreases with increasing needle-beam angle. Threshold for good visibility is 10° (coated and/or dimpled needles) vs. 40° (standard needle).
Hopkins and Bradley[11]	5	Comparative laboratory study. Sponge-based liver phantom.	Teflon coated and/or echogenic tip vs. untreated 18G and 22G needles.	Subjective assessment of NV.	1. Superior NV with echogenic 20G needles vs. untreated needles at 10° needle-beam angle. 2. No difference in NV at 60° needle-beam angle or for 18G needles.

Table 1. (Continued)

Reference	Level of Evidence	Study Design/Subject(s)	Study Interventions	Outcomes	Key Results
Nichols et al.[12]	5	Comparative laboratory study. Liquid-based liver phantom.	Polymer coated vs. dimpled distal shaft vs. prototype dimpled needle vs. roughened tip vs. nonenhanced plastic coated needle.	Objective assessment of NV.	1. All needles highly visible at 90° needle-beam angle. 2. Nonenhanced and roughened tip needles poorly visible at needle-beam angle $<60°$. 3. Good NV with polymer coated needle at needle-beam angles $\geq 45°$. 4. Best NV with dimpled distal shaft needles at all needle-beam angles $\geq 15°$.
Deam et al.[13]	5	Comparative laboratory study. Synthetic gel phantom.	Textured tip vs. standard 22G spinal needle vs. 18G Tuohy needle vs. 22G insulated needle.	Subjective assessment of NV.	1. Superior NV with textured needle vs. all others 2. NV of textured needle unaffected by angle of insertion.
Needle manipulation					
Bondestam and Kreula[14]	5	Descriptive laboratory study. Water bath model.	Needles of varying diameter 10G to 25G, and bevel angles 10° to 70°. Various insertion angles and bevel orientations used.	Objective assessment of NTV.	1. Superior NTV at larger needle-beam angles. 2. Superior NTV with larger needle diameter. 3. Superior NTV with bevel opening oriented 0° or 180° to beam vs. 90° or 270°. 4. No difference in NTV with bevel angle.
Bisceglia et al.[15]	5	Comparative laboratory study. Blood agar phantom.	The “pump maneuver” – pumping the stylet up and down in the needle 7 times – applied to a 21G styletted biopsy needle.	Subjective assessment of NTV.	1. NTV consistently increased by pump maneuver. 2. Increase in NTV was transient, lasting 5 to 10 minutes, and attributed to microbubble formation.
Bradley[16]	5	Descriptive laboratory study. Sponge-based liver phantom.	18G biopsy needle inserted at various insertion angles and needle-transducer distances.	Subjective assessment of NV.	1. Needle-transducer distance of 2 cm to 3 cm and a needle-beam angle of 55° to 60° recommended to achieve good NV and a short needle track length.
Schafhalter-Zoppoth et al.[17]	5	Descriptive laboratory study. Gelatin liver phantom.	Nonechogenic needles of varying tip bevel designs and diameters (18G-22G).	Objective and subjective assessments of NTV.	1. Best NTV with Hustead tip, followed by Quincke and Tuohy tip. 2. Superior NTV with 17G to 18G vs. 20G to 22G needles. 3. Superior NTV at needle-beam angle $>60°$ with in plane approach. 4. Superior NTV at needle-beam angle $<30°$ with out of plane approach.
Maecken et al.[18]	5	Descriptive laboratory study. Water bath model and pork tissue phantom.	Nonechogenic block needles with varying diameters (19G-22G).	Subjective assessment of NTV.	1. Acceptable NTV for all needles at 0° to 45° needle-beam angle in the water bath model. 2. Acceptable NTV using the in plane approach for all needles in tissue phantom at 0° needle-beam angle but only for 3 needles at 45° needle-beam angle. 3. Acceptable NTV using the out of plane approach in 11 out of 12 needles in tissue phantom at 45° needle-beam angle.

Table 1. (Continued)

Reference	Level of Evidence	Study Design/Subject(s)	Study Interventions	Outcomes	Key Results
Ultrasound imaging technology					
Mesurolle et al.[19]	1b	Controlled clinical trial. Patients undergoing breast biopsy.	Tissue harmonic imaging vs. frequency compound imaging vs. conventional B-mode imaging.	Subjective assessment of NV.	1. Inferior NV with tissue harmonic imaging vs. conventional imaging. 2. Equivalent NV with frequency compound imaging vs. conventional imaging.
Cohnen et al.[20]	2b	Comparative laboratory and clinical trial. Cadaveric liver phantom and 10 cirrhotic patients undergoing transjugular intrahepatic portosystemic stent-shunt insertion.	Spatial compound imaging vs. conventional B-mode imaging.	Objective and subjective assessments of NV.	1. Superior NV with spatial compound imaging at smaller needle-beam angles $<60°$.
Saleh et al.[21]	5	Comparative laboratory study. Cadaveric muscle phantom.	Spatial compound imaging vs. conventional B-mode imaging.	Objective assessment of NV.	1. Good NV with all imaging modes at large needle-beam angles (78°-90°). 2. Reduced NV at smaller needle-beam angles (65°-72°), but NV is improved by spatial compound imaging.
Karstrup et al.[22]	5	Comparative laboratory study. Gel liver phantom.	Automatic tissue optimizing vs. coded excitation vs. coded harmonic imaging vs. conventional B-mode imaging.	Subjective assessment of NTV.	1. Best NTV with automatic tissue optimizing and coded excitation settings. 2. Superior NTV with conventional imaging than coded harmonic imaging.
Baker et al.[23]	2b	Controlled clinical trial. Patients undergoing breast biopsy.	Active beam steering to increase needle-beam angle toward 90° vs. no beam steering.	Subjective assessment of NSV and NTV.	1. Excellent NTV with beam steering in all cases (needle-beam angle of incidence increased by 18° on average). 2. NTV and NSV improved by beam steering in 6 out of 8 cases from “not identified/barely perceptible” to “excellent perceptibility.”
Color Doppler					
Feld et al.[24]	1b	Controlled clinical trial (both interventions in each patient). Patients undergoing tissue biopsy.	ColorMark vibrating needle system vs. conventional B-mode ultrasound.	Subjective assessment of NTV.	1. Needle tip visualized in 92% of procedures with ColorMark system vs. 77% of procedures with conventional imaging. 2. Superior NTV with ColorMark system.
Jones et al.[25]	1b	Controlled clinical trial (both interventions in each patient). Patients undergoing tissue biopsy.	ColorMark vibrating needle system vs. conventional B-mode ultrasound.	Subjective assessment of NTV and NSV.	1. NTV and NSV improved by ColorMark system in 58% of superficial (<3 cm depth) biopsies, but only in 13% of deep biopsies.
Armstrong et al.[26]	1b	Descriptive laboratory and clinical study. Urethane phantom and patients undergoing elective pericardiocentesis.	ColorMark vibrating needle system.	Accuracy of localization of needle tip in the phantom. Successful visualization of needle tip in patients.	1. ColorMark system permitted accurate localization of needle tip in the phantom. 2. The needle tip was visualized in 72% of patients.

NOTE: ColorMark manufactured by EchoCath Inc., Princeton, NJ; and Biosponder manufactured by Advanced Technology Laboratories, Bothell, WA.
Abbreviations: G, gauge; NSV, needle shaft visibility; NTV, needle tip visibility; NV, needle visibility in general (tip/shaft not specified).

priate, we have supplemented the available evidence from the literature with recommendations based on our experience with US-guided PNB at the Toronto Western Hospital using conventional 2-dimensional US and standard (nonechogenic) block needles.

Needle-Beam Alignment: In Plane Needle Approach

Challenges/Background

There are 2 methods of orienting the needle relative to the US beam in US-guided PNB: the in plane and out of plane approaches.[27] In the in plane needle approach, the needle is inserted in the same plane as the US beam and is visible as a bright hyperechoic line. Needle-beam alignment is critical to visualize the shaft (i.e., profile) of the needle in the in plane approach. The freehand technique requires bimanual coordination in 3 dimensions whilst looking away at a 2-dimensional image on the US screen. This, coupled with the narrow width of the US beam (as little as 1 mm at the focal zone of high frequency transducers), can make it difficult to maintain needle-beam alignment as the needle is advanced.[2]

Strategies

Mechanical needle guides. Needle-beam alignment can be facilitated by the use of a mechanical needle guide attached to the transducer. While there are no published descriptions of mechanical needle guides in US-guided PNB, they have been compared with the freehand technique in 2 studies of US-guided needle biopsy.[3,4] Mechanical guides significantly reduced biopsy procedure time compared with a freehand technique, especially for less experienced operators.[4] However the mean difference was only 20 seconds and this may not be clinically significant. Interestingly, the use of needle guides did not improve biopsy quality;[4] in fact diagnostic accuracy was better with the freehand technique for biopsy of smaller targets (<3 cm in diameter).[3] This suggests that the precision of needle tip placement afforded by mechanical needle guides may be inadequate for US-guided PNB, as target nerves are often 1 cm or less in diameter.

Optical needle guides. Tsui[5] described a laser-sighting apparatus that facilitates in plane needle-beam alignment and that can be assembled from inexpensive off-the-shelf components. This optical guide provides a clear visual indication of precise needle-beam alignment, and may prove useful in teaching and developing bimanual coordination in novices. However, a portion of the needle shaft has to protrude from the skin surface at all times to allow alignment with the laser. This may require the use of longer block needles that can be more difficult to manipulate. As the author pointed out, the method is also unsuitable for continuous catheter techniques that require the probe (and laser) to be encased in a sterile sleeve.

Recommendations

The utility of mechanical needle guides in interventional ultrasound is controversial.[28-30] While needle guides may minimize challenges with needle-beam-alignment in the in plane approach and therefore be helpful for the less experienced operator,[4,28,30] they also restrict needle redirection.[29] Adjustable guides have been described in order to overcome this limitation,[31-33] but redirection still requires complete withdrawal and reinsertion of the needle. The demands of US-guided PNB are also different from that of US-guided biopsy. Given that fine adjustments in needle trajectory and depth are often required to achieve adequate local anesthetic spread around the target nerve, our preference is for a freehand technique. Nevertheless, the use of mechanical needle guides in US-guided PNB should be investigated.

It is our experience that in plane needle-beam alignment can be achieved by careful manipulation of transducer and needle using the freehand technique. Resting the medial edge and/or fingers of the operator's transducer hand on the patient and applying firm pressure downwards with the transducer will minimize slipping on gel-covered skin (Fig 1). Firm pressure has the added advantage of compressing adjacent veins and reducing distance to the target. Operator fatigue also contributes to unintentional transducer movement and may be

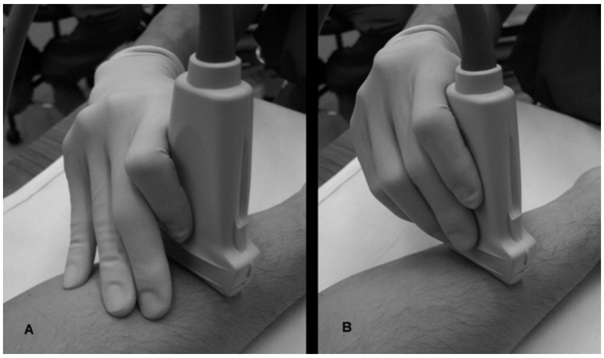

Fig 1. The operator's transducer hand should be resting on the patient for support as shown in (A), to prevent unintentional slipping of the transducer. The other hand position illustrated in (B) will predispose to fatigue and unintentional transducer movement.

reduced by careful attention to ergonomics, such as raising the bed to an appropriate height to allow an erect posture during performance of the block. If the needle tip becomes poorly visible at any time, it should not be advanced further. The first step to troubleshooting a "disappearing" needle is to visually inspect needle and transducer position and exclude gross misalignment. The transducer should then be moved in a slow and controlled manner, using the 3 basic (sliding, tilting, and rotating) movements described by Marhofer and Chan,[34] until the needle shaft and tip have been brought back into view. We do not recommend moving the transducer and needle at the same time when trying to align them, as this makes the task more difficult and increases the risk of unintentional needle trauma.

Needle-Beam Alignment: Out of Plane Needle Approach

Challenges/Background

In the out of plane needle approach, the longitudinal axis of the needle is inserted in a plane perpendicular to that of the US beam.[27] Visualizing the needle tip in this approach can be difficult, as only a cross-sectional area of the needle is imaged. In a gel phantom, the tip appears as a bright hyperechoic dot, often with an anechoic acoustic shadow immediately below it (Figs 2A and 2B). It is more difficult to identify the needle tip in clinical practice due to the lack of contrast between it and the surrounding echogenic tissue. The needle shaft may also be mistaken for the tip as both have a similar appearance in cross-section.

Strategies

A "walkdown" technique has been suggested to aid out of plane needle tip visualization.[35] This consists of inserting the needle at a distance from the transducer equivalent to the depth of the target, such that the tip will eventually intersect the US beam and target at a trajectory angle of approximately 45°. The initial insertion angle should, however, be shallow so as to facilitate detection of the needle tip. The needle is then incrementally angled, with the tip visualized at progressively greater depths until the target is reached. Potential disadvantages of this technique include the need for multiple needle passes and a long needle track to reach deeper targets, both of which may increase patient discomfort.

Recommendations

There are no clinical data to support any particular technique of out of plane needle insertion. It is our preference to insert the needle close to the transducer (within 1 cm), irrespective of target depth, and at a steeper (approximately 75°) angle to

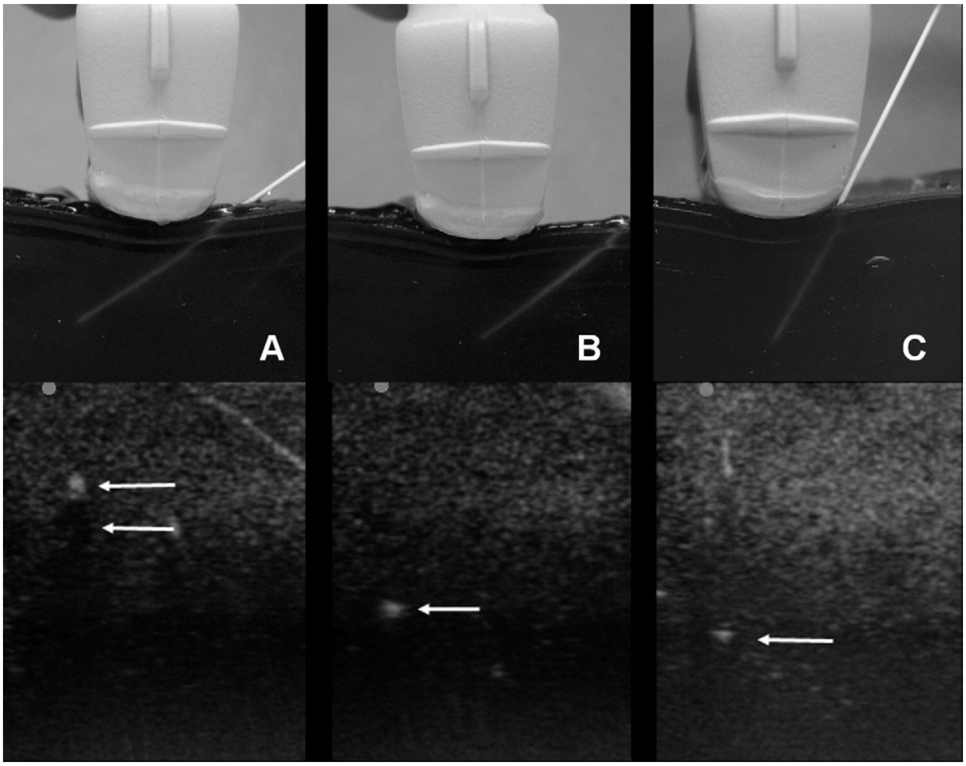

Fig 2. With the needle inserted at a 45° angle in the out of plane approach, it is relatively easy to confuse the shaft, indicated by the upper arrow in (A), for the tip, indicated by the arrow in (B), as the 2 images are similar; both being echogenic dots. (A) The acoustic shadow (lower arrow) cast by the shaft is more prominent, and may be a clue to distinguish it from the tip. (C) Inserting the needle at a steeper angle and closer to the transducer (tip indicated by arrow) reduces the length of needle shaft that can be imaged, and makes this error less likely.

the skin (Fig 2C). Visibility of the needle tip has been shown to be better at smaller rather than larger needle-beam angles in the out of plane approach.[17,18] We also rely heavily on surrogate markers to confirm needle tip location (see below).

Echogenic Needle Design

Challenges/Background

The echogenicity of commonly used block needles under clinical conditions was investigated by Maecken and colleagues.[18] The authors found the visibility of 9 of 12 needles to be unacceptable when inserted at a 45° angle in an animal tissue phantom.[18] In contrast, all needles had excellent visibility scores in a water bath regardless of insertion angle.[18]

These findings can be explained in terms of acoustic impedance, which is a measure of the degree to which sound waves are transmitted through a particular medium. At the interface between media with different acoustic impedances, some of the sound waves are reflected whilst the others are transmitted. The amount of reflection that occurs is proportional to the difference in acoustic impedance between the media. Hence, metal needles (high impedance) are clearly visible as bright objects against the dark uniform background provided by gel phantoms and water baths (low impedance). This often leads novices who are training on gel phantoms to erroneously conclude that needle visualization is easily achieved. Soft tissue, however, is a heterogeneous mix of fluid, fat, muscle, and connective tissue, each with different acoustic impedances. Reflection of sound waves occurs at each of these tissue interfaces, giving soft tissue a speckled echogenic appearance. The reduced visual contrast between needle and the background of soft tissue makes it difficult to distinguish between the two. The multiple acoustic interfaces also cause refraction (scatter) and attenuation of returning echoes,[36] further reducing needle visibility.

Strategies

Physical enhancement of needle echogenicity. The problem of poor needle visibility has been addressed by the development of echogenic needles. Echogenic needles are engineered to increase the reflection of US waves back towards the transducer. The most echogenic needle designs include a polymer coating that traps microbubbles (Echo-Coat, STS Biopolymers, Henrietta, NY), and a dimpled distal shaft (Echotip, Cook, Bloomington, IN). Their superior needle tip and shaft visibility has been demonstrated in both laboratory[9-13] and clinical settings,[7,8] and is especially significant at small needle-beam angles.[9-13] However only 1 study to date involved needles designed for regional anesthesia;[13] all others involved needles designed for ultrasound-guided tissue biopsy.

Electronic enhancement of needle echogenicity. A unique innovation in needle design is the Biosponder biopsy needle (Advanced Technology Laboratories, Bothell, WA), which has a stylet with a piezoelectric polymer sensor at the tip. US waves striking the sensor generate electrical impulses that are transmitted along the stylet and cable attached to the US machine. The needle tip is then displayed as a bright flashing marker on the US image. In a small study of 20 patients undergoing biopsy or fluid drainage, the Biosponder system greatly improved needle tip visibility compared with a standard biopsy needle.[6] The authors concluded that the tip of the Biosponder needle could be consistently identified regardless of body habitus, tissue echogenicity, and depth or size of the target. However, despite the obvious potential, no other reports on the use of the Biosponder system have been published.

Recommendations

Echogenic block needles are likely to become more widely available in the future, but it is clear from the radiological literature that some designs perform better than others. Clinical trials will be needed to establish the individual efficacy of these needles before they can be recommended for use.

Needle Manipulation

Challenges/Background

The visibility of nonechogenic needles may be enhanced by manipulating the needle in several ways, including altering the needle-beam angle, orienting the needle bevel appropriately, and priming the shaft.[14-18]

Strategies

Needle-beam angle. The angle at which the needle shaft and US beam intersect (needle-beam angle) greatly affects needle visibility (Fig 3). The smooth metallic surface of a standard needle is a specular (mirror-like) reflector of US waves, hence a greater number of echoes will return to the transducer as the needle-beam angle approaches 90°.[36] As a result, in plane needle tip and shaft visibility is better at larger needle-beam angles;[10,13,14,16,17] the optimal angle appears to be $>55°$.[10,16,17] Interestingly, out of plane needle tip visibility is better at

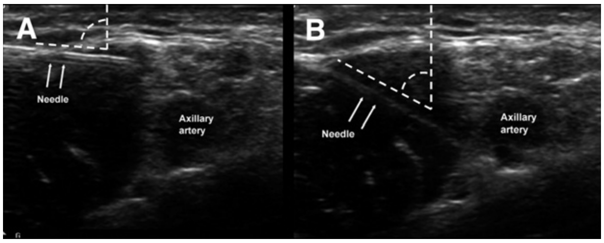

Fig 3. (A) A 22-gauge needle is initially inserted in a shallow trajectory toward the axillary brachial plexus, and both the shaft and tip are clearly visible. The needle-beam angle (indicated by dashed lines) is almost 90° and reflection back to the transducer is maximal. (B) As the needle trajectory increases, and the needle-beam angle becomes smaller, the shaft becomes less echogenic, and the tip is no longer clearly visible.

smaller needle-beam angles ($\leq 30°$); however, the reason for this is not clear.[17,18]

Needle bevel orientation. Needle tip visibility is better when the bevel opening is oriented either to directly face the US beam (0°) or to face 180° away from the beam.[11,14]

Priming the needle. There appears to be little difference in visibility between needles primed with either water or air.[17] Inserting a guidewire will significantly increase needle shaft visibility.[17] However, this effect is lost if very tightly-fitting guidewires are used, as there is no longer an acoustic interface between the shaft and guidewire.[17] For the same reason, stylet and hollow needles have similar visibility.[17] However if a stylet needle is used, pumping the stylet up and down several times within the shaft may transiently increase needle echogenicity.[15] The effect of this "pump maneuver" is attributed to the formation of microbubbles about the needle tip and shaft.

Using needles of larger diameter. Better needle tip visibility can be obtained with larger diameter needles,[14,17] but at the expense of increased tissue trauma and patient discomfort.

Recommendations

A needle-beam angle close to 90° offers the best needle visibility when using an in plane needle approach (Fig 3).[10,13,14,17] However maintaining a large needle-beam angle is not always feasible, especially when targeting deeper nerves, e.g., the infraclavicular brachial plexus. In these situations, a "heel-in" maneuver may be helpful. This involves pressing one end (the "heel") of the transducer more deeply into the patient than the other end (the "toe), thus increasing the needle-beam angle (Fig 4). It is our routine practice to prime needles with fluid (local anesthetic or dextrose 5%) to avoid obscuration of the image by the echogenic artifact that occurs with injection of air. We continue to use 22-gauge block needles for single shot PNB as we find in most cases the increase in visibility afforded by larger needles does not warrant the corresponding increase in patient discomfort.

Ultrasound Imaging Technology

Challenges/Background

As ultrasound technology has advanced, new imaging modes have been developed; these include spatial compound imaging, frequency compound imaging, tissue harmonic imaging, beam steering, and 3-dimensional US. These modes are designed to improve image quality and increase the amount of information that can be obtained from an US examination; however, their effect on needle visibility varies.

Strategies

Compound and harmonic imaging. Compound imaging involves acquiring multiple images of the same object and combining them into a single image; the images may be acquired from different angles in the same plane (spatial compound imaging) or acquired at different frequencies (frequency compound imaging). Tissue harmonic imaging forms an image using echoes at twice the emitted frequency; this higher frequency harmonic signal is spontaneously generated by propagation through tissues.

When compared with conventional B-mode imaging, spatial compound imaging consistently improves needle visibility[20,21] while tissue harmonic imaging worsens it.[19,22] Frequency compound imaging does not appear to have a significant effect on needle visibility.[19]

Electronic beam steering. Electronic beam steering is a technology that allows the US beam to be tilted relative to the transducer, thus increasing the needle-beam angle of incidence toward 90°. This greatly improved needle tip and shaft visibility in a small study of 7 patients undergoing breast biopsy.[23]

Three-dimensional ultrasound. Preliminary case reports on the use of 3-dimensional US to guide PNB suggest that a third dimension (i.e., plane view) may be able to give additional information about needle and catheter location.[37,38] However, the present technology does not appear to enhance needle visibility per se, and all of the challenges associated with poor needle echogenicity likely still apply. Additional limitations of 3-dimensional US currently include a slower frame rate and

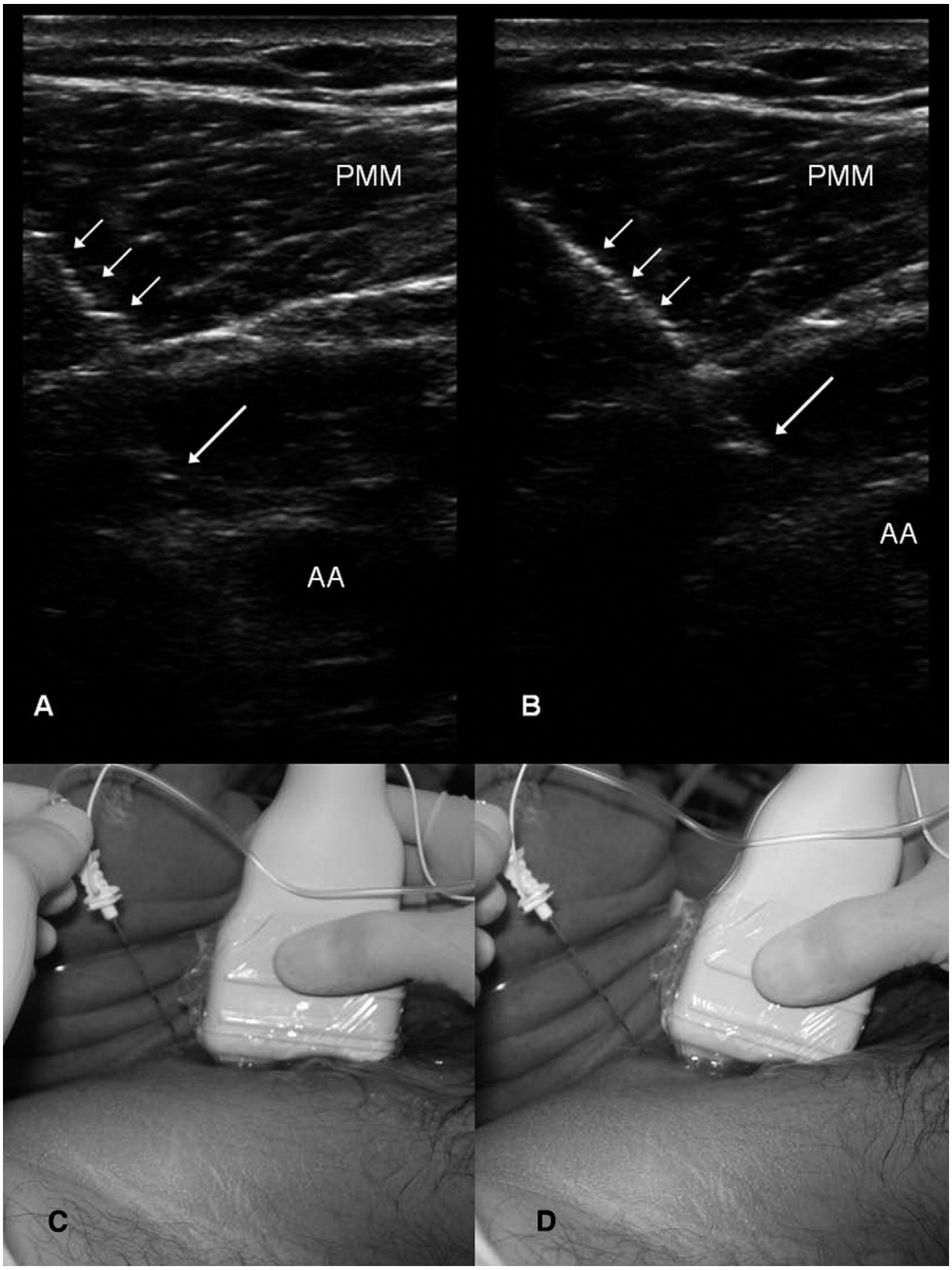

Fig 4. A 22-gauge needle is inserted in a steep trajectory (small needle-beam angle) toward the infraclavicular brachial plexus. (A) The needle shaft (small arrows) and tip (large arrow) are poorly visible. (B) The needle-beam angle is effectively increased by applying a "heel-in" maneuver to the position illustrated in (C), and pressing the caudad end of the transducer more deeply into the patient as shown in (D), thus increasing the echogenicity of the needle shaft (small arrows), and tip (large arrow), as shown in (B). AA, axillary artery; PMM, pectoralis major muscle.

a bulkier transducer,[38] both of which can make needle-beam alignment more difficult.

Color Doppler detection of the needle tip. Movement of an object within an US beam produces a Doppler shift in the frequency of the reflected echoes.[39] The color Doppler function available on most modern US machines modulates this frequency shift into a color signal, and is commonly used to detect blood flow. It may also be used to localize a moving needle tip against a stationary background. The ColorMark device (EchoCath Inc, Princeton, NJ) clips onto the needle shaft and induces minute vibrations at the needle tip (maximum amplitude 15 μm, which is imperceptible to touch), which are sufficient to generate a signal with color Doppler. The ColorMark device significantly improved needle tip visibility in patients undergoing tissue biopsy and pericardiocentesis.[24-26] A prototype device based on similar principles has recently been described for regional anesthesia using an 18-gauge Tuohy block needle and 20-gauge stylet catheter in a cadaver model.[40] Other methods to generate movement at the needle tip have been described, including an oscillating air column,[41] manual motion of the needle,[42,43] and vibration induced by rotation of a bent stylet within the needle;[44] however, there is no evidence from comparative studies to support the efficacy of these methods in improving needle visibility.

Recommendations

Spatial compound imaging is available on most of the newer compact US machines and should be used whenever possible.[20,21] Harmonic imaging may improve the visibility of hypoechoic targets but cannot be recommended for improving needle visibility.[19,22] Electronic beam steering is potentially useful, especially when performing deeper in plane blocks at small needle-beam angles, e.g., infraclavicular. Early limitations of this technology included deterioration of image quality, and vulnerability to noise and distortion;[45] hence it has not been a standard feature on most machines. This is likely to change; for example, the LOGIQe (GE Healthcare, Wauwatosa, WI) compact US unit now offers a beam steering function (B-Steer) designed to improve needle visibility. One concern is whether nerve visibility may be compromised with the change in beam angle given that many nerves are anisotropic (i.e., their echogenicity varies depending on the angle at which they are insonated).

The use of color Doppler combined with a moving needle tip is promising,[24-26] and worthy of further investigation. Although manually-induced needle motion has been described,[42,43] our own limited experience suggests that this generates too much color artifact along the needle shaft to allow accurate localization of the tip. Adjusting the color Doppler gain (usually the only means of adjusting color Doppler imaging parameters on compact US machines) can help reduce artifact but also reduces the signal intensity at the needle tip. Mechanically induced, high frequency vibratory motion of the needle tip, such as that generated by the ColorMark device, appears to be the most practical technique, although it still requires optimization of color Doppler settings for successful use.[24,26] The ColorMark device could be used with existing block needles, although this has not been reported to date. Its application in PNB may be limited by its bulk, which caused bending of the shaft when used with 22-gauge needles.[25] In addition, it performed less well at depths >3 cm, due to attenuation of the needle tip vibration.[25,41] Finally, we have observed deterioration in image quality within the color Doppler target area in some US machines that can render nerves nearly invisible. It would be counterproductive to increase needle tip visibility at the expense of target visibility and this issue will need to be addressed if the technique is to become useful.

Surrogate Markers of Needle Tip Location

Challenges/Background

Despite the strategies discussed above, the operator may still encounter difficulty in achieving good needle tip visibility. However, needle tip location may be inferred using other methods described in the literature.

Strategies and Recommendations

Tissue movement. Jiggling the needle in small, controlled, in-out movements creates corresponding visible tissue movement at the needle tip and is recommended when advancing the needle.[29] One should be aware that tissue motion may be transmitted beyond the needle tip as well as along the needle shaft, making it difficult to precisely locate the tip, especially when using the out of plane needle approach. We recommend the use of short-beveled needles because in our experience, they minimize the risk of piercing nerves and arteries in the event of unintentional needle contact. Such needle contact may in fact provide further visual cues to tip location (Fig 5). Short-beveled needles also provide tactile feedback when "popping" through fascial layers; this is a useful adjunct to visible tissue movement.

Hydrolocation. Hydrolocation involves rapid injection of a small amount of fluid (0.5-1 mL) to confirm needle-tip position by both tissue movement and the appearance of a small anechoic "pocket" (Fig 5).[46] Further injection of fluid also aids in opening up the space between anatomical structures (hydrodissection), thus creating an obstacle-free path for further needle repositioning. The needle tip is often accentuated as a bright echogenic structure within the dark anechoic pocket of fluid. Either local anesthetic or 5% dextrose may be used as the injectate. The advantage of using 5% dextrose is that it preserves the motor response to subsequent electrical stimulation.[47,48] There is also less "waste" of local anesthetic by deposition distant from the target nerve.

Microbubble injection. A variation on the technique of hydrolocation is the injection of microbubbles, which are highly echogenic and serve as an US contrast agent. Microbubble injection has been used to confirm catheter tip location in continuous PNB.[49,50] However, the potential disadvantage of any technique involving injection of air into soft tissue is deterioration of image quality. Microbubbles cause acoustic shadowing that obscures the target area, and can persist for up to 2 minutes or more.[51] We consider this deterioration to be a sig-

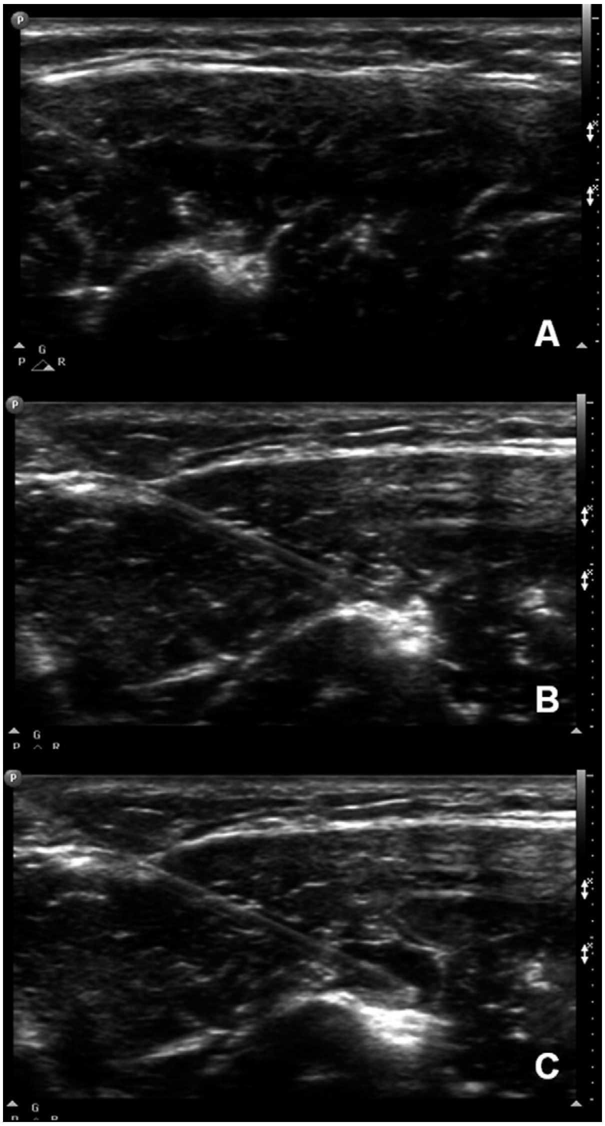

Fig 5. (A) A 22-gauge needle is inserted toward the musculocutaneous nerve, but the tip is not clearly visible. (B) Indentation of the fascia surrounding the musculocutaneous nerve indicates the location of the needle tip. (C) Injection of a small amount of fluid confirms the location of the needle tip next to the musculocutaneous nerve (hydrolocation). The needle tip is also highlighted by the contrast between it and the anechoic pocket of fluid.

nificant disadvantage in single shot PNB, where repositioning of the needle is often required after initial injection to achieve optimal local anesthetic spread around the target.

Conclusion

Needle visualization during US-guided regional anesthesia is likely essential for safety and efficacy. However, accurate and consistent needle tip visualization is hampered by several factors, including the difficulty of needle-beam alignment, and the poor echogenicity of commonly available block needles in the clinical setting. In our experience, systematic manipulation of the needle and transducer to ensure needle-beam alignment, maintaining a large needle-beam angle where possible, and utilizing surrogate markers of tip location such as tissue movement and hydrolocation are most helpful. Future avenues for improving visualization include the development of more echogenic needles, and advances in ultrasound imaging technology, such as 3-dimensional US, and the use of color Doppler to identify a moving needle tip.

Appendix

Selected articles for this review were graded according to their level of evidence as recommended by the Centre for Evidence-Based Medicine.

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Appendix 1. Levels of Evidence as Defined by the Oxford Centre for Evidence-Based Medicine (May 2001)

Level	Therapy/Prevention, Etiology/Harm
1a	Systematic review (with homogeneity) of RCTs
1b	Individual RCT (with narrow confidence interval)
1c	All or none
2a	Systematic review (with homogeneity) of cohort studies
2b	Individual cohort study (including low quality RCT; e.g., <80% follow-up)
2c	"Outcomes" research; ecological studies
3a	Systematic review (with homogeneity) of case-control studies
3b	Individual case-control study
4	Case series (and poor quality cohort and case-control studies)
5	Expert opinion without explicit critical appraisal, or based on physiology, bench research or "first principles"

Abbreviation: RCT, randomized controlled trial.
Adapted from the Centre for Evidence-Based Medicine.[52]