Piezoelectric Vibrating Needle and Catheter for Enhancing Ultrasound-Guided Peripheral Nerve Blocks

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Ultrasound imaging has been used for performing single-injection peripheral nerve blocks and continuous catheters. One limitation with current technology is the inability to confirm the location of the needle or catheter tip. We describe a new needle and catheter design that permits distal tip visualization using color flow Doppler. An 18-gauge 100-mm insulated Tuohy needle and a 20-gauge 50-mm polyamide catheter (open tip) with a Teflon-coated steel stylet (B. Braun, Bethlehem, PA) were customized by adhering in place two piezoelectric actuators. These created 1–8 kHz vibrations when coupled to a function generator (FG502, Tektronix, Richardson, TX) and a 100 W audio amplifier (R3000, KLH, Sun Valley, CA). Mimicking a lateral popliteal fossa block, the needle and catheter were inserted into the leg of an unembalmed cadaver. When activated, the tip of each was highlighted in color when scanned in the short axis using the color Doppler mode of a two-dimensional ultrasound and a 12 MHz L38 probe (MicroMaxx, Sonosite, Bothell, WA). Vibration technology may be a useful adjunct while performing ultrasound-guided regional anesthesia. Further study evaluating its usefulness and safety in live tissue is warranted.

(Anesth Analg 2007;105:1858–60)

Ultrasound imaging has been shown to be a useful adjunct and primary technique for performing single-injection peripheral nerve blocks and continuous catheters (1). One limitation with the currently available technology is the narrow plane of the ultrasound beam and subsequent image. Maintaining the entire needle within the visual field requires practice, and determining the exact location of the needle tip is not often possible (2). When inserting a small diameter catheter, this issue may be compounded if the tip leaves the plane of the needle. Often the location of the catheter tip can only be determined by local anesthetic spread (3). Injecting small quantities of air may be beneficial but is limited in precision and duration (1). Having a method to confirm the location of the needle or catheter tip would be helpful. We describe a piezoelectric needle and catheter design that permits distal tip visualization using color flow Doppler. *In situ* images of a lateral popliteal fossa block and continuous catheter after insertion in the leg of a cadaver are presented.

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Accepted for publication July 31, 2007.

Two of the authors, S. W. Smith and M. P. Fronheiser, hold intellectual property rights to some of the content outlined in the report. The details are provided in the cover letter.

Reprints will not be available from the author.

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DOI: 10.1213/01.ane.0000286814.79988.0a

METHODS

Needle Design

An 18-gauge, 100-mm insulated Tuohy needle (Contiplex, B. Braun, Bethlehem, PA) was customized by removing the proximal insulation and soldering in place a piezoelectric actuator (Fig. 1). Similarly, a 20-gauge, 50-mm polyamide catheter (open tip) with a Teflon-coated steel stylet (B. Braun, Bethlehem, PA) was modified. The catheter was shortened so that 4 cm of exposed stylet protruded from the proximal end of the catheter and another piezoelectric actuator was epoxied to the exposed metal (Fig. 2). The actuators create 1–8 kHz vibrations when coupled to a function generator (FG502, Tektronix, Richardson, TX) and a 100 W audio amplifier (R3000, KLH, Sun Valley, CA).

Ex Vivo Evaluation

The use of a left knee joint and proximal 15 cm of leg of a 77-yr-old, 177 cm, 82 kg unembalmed (fresh) male cadaver was approved and provided for by the Duke University Human Fresh Tissue Laboratory. The leg was placed in the prone position. The sciatic nerve was imaged and identified by scanning in the short axis using a two-dimensional ultrasound and a 12 MHz L38 probe (MicroMaxx, Sonosite, Bothell, WA). The piezoelectric needle was then inserted perpendicularly between the vastus lateralis and biceps femoris muscles at a point immediately proximal to the bifurcation of the tibial and peroneal components.

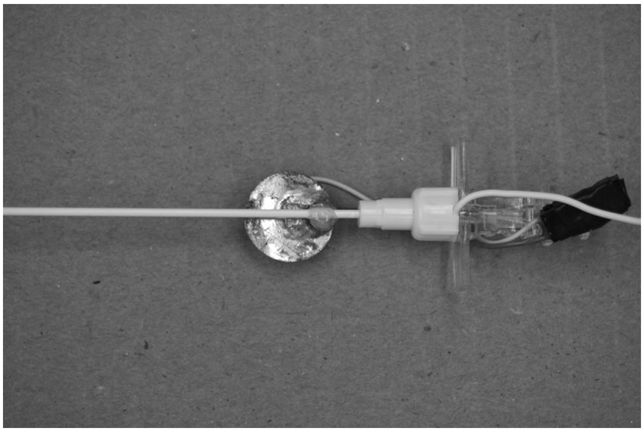

Figure 1. The proximal end of an 18-gauge, 100-mm insulated Tuohy needle (Contiplex, B. Braun) customized by removing the insulation and soldering in place a piezoelectric actuator.

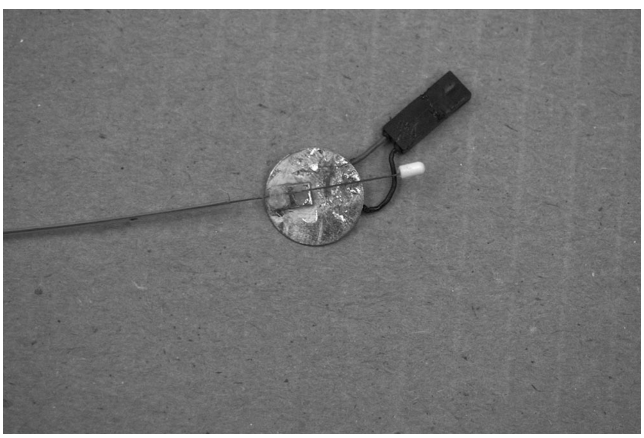

Figure 2. The proximal end of a 20-gauge, 50-mm polyamide catheter (open tip) with a Teflon-coated steel stylet (B. Braun, Bethlehem, PA). A piezoelectric actuator is epoxied to the exposed stylet.

With the probe in the same position, the needle was imaged in its long axis as it approached the nerve. Next, when the needle was thought to be in contact with the nerve, the signal generator was turned on and the ultrasound scanner was switched to its color Doppler mode to highlight the needle tip below the skin. The catheter was then advanced through the needle toward the nerve and the needle removed. The signal generator was switched to the catheter and the distal tip was imaged in color Doppler mode. To confirm that the identified structure was the sciatic nerve, 3 mL of methylene blue dye was injected via the catheter. The area was then dissected to identify the catheter location with respect to the sciatic nerve.

RESULTS

An image of the needle in its long axis as it approaches the nerve (in the short axis) is presented in Figure 3. The nerve was located approximately 4 cm beneath the probe. The needle contacted the nerve at a needle depth of 6.0 cm and an angle of approximately 30° from the skin entry point. A color Doppler mode image of the needle with the signal generator turned on is presented in Figure 4. Images were successfully obtained on five consecutive attempts. The amount of needle highlighted in the color Doppler mode could be adjusted by varying the degree of signal intensity. High signal intensity corresponded to approximately 2 cm of highlighted needle shaft, whereas a lower intensity only accentuated the needle tip (Fig. 4). A color Doppler mode image of the catheter with the distal tip highlighted in color Doppler mode is presented in Figure 5. Subsequent dissection of the area demonstrated methylene blue dye spread 4 cm along the lateral aspect of the peroneal division of the sciatic nerve.

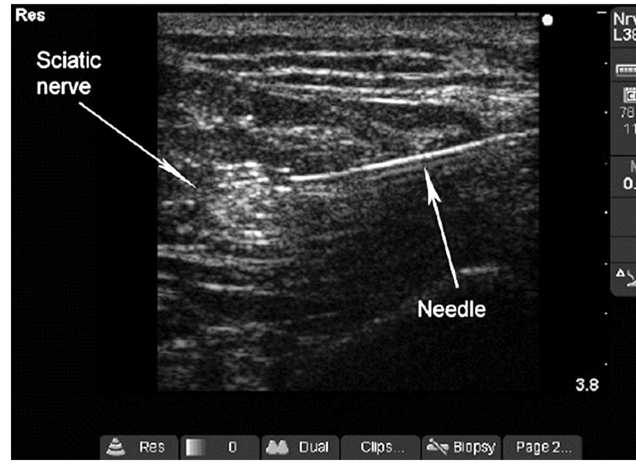

Figure 3. Posterior to anterior, short axis ultrasound image of the sciatic nerve using a 12 MHz L38 probe (MicroMaxx, Sonosite). The piezoelectric modified Tuohy needle (Contiplex, B. Braun) is approaching the sciatic nerve from lateral to medial.

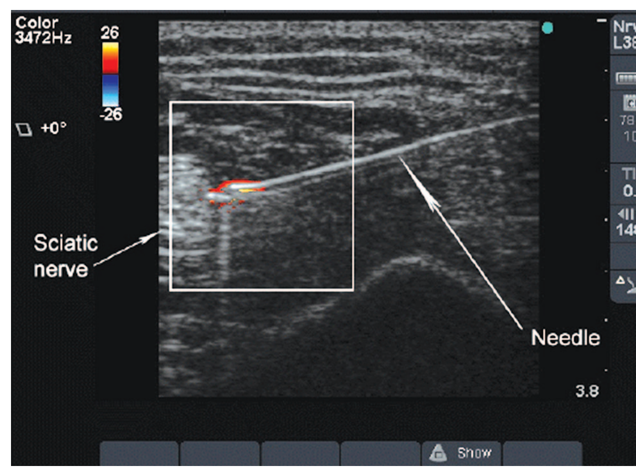

Figure 4. Posterior to anterior, short axis, color Doppler mode ultrasound image of the sciatic nerve using a 12 MHz L38 probe (MicroMaxx, Sonosite). The piezoelectric modified Tuohy needle (Contiplex, B. Braun) is approaching the sciatic nerve from lateral to medial. The function generator (FG502, Tektronix) coupled to a 100 W audio amplifier (R3000, KLH) is turned on. The red colored area surrounds the needle tip.

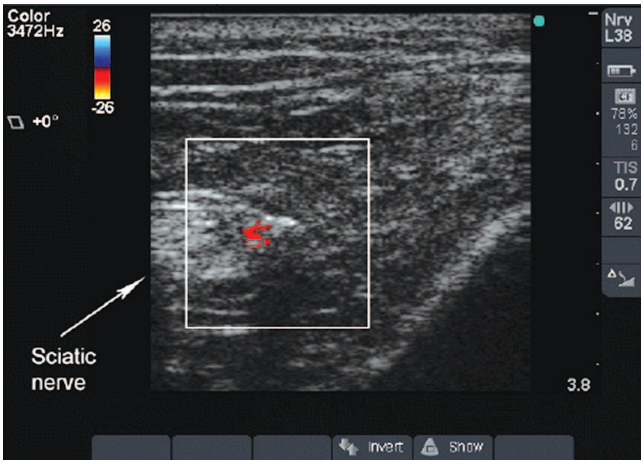

Figure 5. Posterior to anterior, short axis, color Doppler mode ultrasound image of the sciatic nerve and the piezoelectric modified 20-gauge catheter and stylet (B. Braun, Bethlehem, PA), using a 12 MHz L38 probe (MicroMaxx, Sonosite). The function generator (FG502, Tektronix) coupled to a 100 W audio amplifier (R3000, KLH) is turned on. The red colored area surrounds the catheter tip.

DISCUSSION

The ability to visualize or confirm the tip of a needle or identify the location of a small translucent catheter tip is an important but challenging aspect of ultrasound-guided regional anesthesia. In this case, both the needle and catheter tip were easily identified and outlined during the placement of a continuous nerve block in a clinically relevant tissue model using the normal color Doppler mode of an ultrasound machine. Another important concern is the cost of new technology. Compared with the cost of the needle and ultrasound machine, this technology is inexpensive. The piezoelectric actuator costs approximately $0.75 US, and with this design would be disposable. Ultimately, for widespread application, the laboratory-grade function generator and amplifier would have to be miniaturized, adding an undetermined cost.

Color Doppler ultrasound uses autocorrelation methods to provide the mean velocity and directional information of flow for a particular region. This information is then used to generate a color overlay, which is placed on top of the B-mode ultrasound image. Typically, shades of red are used for flow towards the transducer, whereas shades of blue are used for flow away from the transducer. By modifying the needle and catheter with an attached piezoelectric generator, both vibrate at a preset 1–8 kHz frequency. The vibrations are transmitted down the shaft of the needle or via the metal stylet where the tips are at a vibration antinode with motion $x = A\sin(2\pi ft)$ and tip velocity $v = dx/dt = 2\pi fA\cos(2\pi ft)$, where A is the amplitude for the vibration frequency (f). The result is that the distal most vibrations have a typical peak amplitude of 15 μm and velocity range of 9–28 cm/s. This range of values is detected with the color Doppler and displayed as a strong velocity source using shades of color, emanating from the needle and catheter tips.

Explained another way, similar to cracking a whip, a small motion at the proximal end is transformed to a large motion at the distal end. In this case, the entire needle is vibrating, but the magnitudes of the vibrations are greatest at the tip and are the only ones within the detection range of the Doppler.

To our knowledge, this is the first description using vibration-facilitated imaging to enhance needle and catheter placement in regional anesthesia. This was successful despite the dense musculature and multiple fascial planes in this area of the leg, which have the potential to dampen vibration, particularly of the small flexible catheter. In contrast, previous uses of this technology demonstrated with an aspiration needle (4), cardiac pacing lead (5), Brockenbrough atrial puncture needle (5), and radio frequency ablation probes (5), all surrounded by echogenic material-like fluid (blood) or a soft homogeneous medium, such as the liver.

The ability to confirm needle and catheter tip location could be a useful adjunct while performing ultrasound-guided regional anesthesia. The efficacy of this technology in a cadaver leg will need to be replicated using a human model that could be susceptible to nerve injury and may introduce different tissue densities as well as a potential for motion artifacts created by the operator and nearby blood vessels. Nevertheless, given the results of this model, further study seems warranted.

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