

The All-seeing Eye?

Ultrasound Technologies for Neuraxial Techniques

The only thing worse than being blind is having sight but no vision.—*Helen Keller*

IN 1885, when the neurologist J. Leonard Corning coined the term “spinal anesthesia,” his supporting investigations were most likely being conducted within the epidural space.¹ Corning’s success in finding the epidural space, albeit inadvertently, is a task that can elude novice and experienced anesthesiologists. Among the more difficult regional blocks to learn,² the epidural technique typically is performed “blindly” without direct or indirect visualization.

In an attempt to improve the efficiency, efficacy, and safety of neuraxial techniques, particularly within the epidural space, innovators have investigated the use of optical technologies. In this issue of *ANESTHESIOLOGY*, Chiang *et al.*³ introduce a novel, potentially significant, “needle” ultrasound transducer that can be advanced within an epidural needle. The value of this and future neuraxial technique guidance devices can be observed through the lens of current procedures and their associated limitations.

Blind. An anatomic location full of fatty tissue, lymphatics, spinal nerve roots, small arteries, and a valveless plexus of thin-walled veins, the epidural space would seem an unlikely destination for the provision of anesthesia or analgesia. Making this space even less desirable is the troublesome voyage to the ligamentum flavum, which can be obscured by frequent, sometimes subtle, but often misleading changes in resistance as structures and tissue planes are breached.

Yet the promise of a relatively predictable, prolongable block that can provide the dynamic range of analgesia to anesthesia results in thousands of epidural techniques being performed globally each year for obstetric, orthopedic, thoracic, cardiac, and pain medicine indications. Enthusiasm for the epidural technique is tempered by complications,⁴ which occur even when the technique is performed by experienced hands. The impact of postdural puncture headaches makes it a common topic for the medical and lay press, although other more frequent (*e.g.*, incomplete block, need for repeated or alternative anesthetic techniques, pain at the insertion site) or potentially devastating (*e.g.*, epidural hematoma, neurologic injury) issues warrant continued attention.

These consequences have generated interest in confirming the position of needles, catheters, or drugs placed within the epidural space; although methods to detect changes in mechanical pressure or electrical conductivity have been promoted, optical technologies have generated the greatest in-

terest. We appear to trust most of those things that we can confirm visually.

Sight. Interestingly, the presence of sight, even with refreshing clarity, may not assist in the placement of neuraxial techniques. A decade ago, Igarashi *et al.* threaded a fiberoptic scope through a 17-gauge Tuohy needle for the purposes of visualizing, but not navigating, the epidural space. They identified a venous network that engorges with pregnancy⁵ but also recognized that the fiberoptic view was limited to the pneumatic space created immediately adjacent to the scope’s tip. As such, the trajectory of the needle and the contents lying behind tissue or connective tissue planes (*e.g.*, ligamentum flavum, dura) could not be evaluated.

Therein lies the seduction of ultrasound technologies, particularly given the accumulating evidence supporting its use in the conduct of peripheral nerve blockade.⁶ Although the available data on ultrasound guidance of neuraxial techniques is more limited, the American Society of Regional Anesthesia⁶ and others⁷ recently have classified the findings according to the United States Agency for Health Care Policy and Research Scale for Evidence Statements. In a number of trials, the blinding of participants was difficult or compromised, few employed a randomized controlled design, and highly experienced operators were responsible for performing the ultrasound guidance, thereby impairing external validity.

Acknowledging these issues, the data suggest that bedside ultrasound can identify the lumbar interspace more accurately than surface landmark palpation (IIa) and the depth to the epidural space with a high degree of accuracy (Ib), resulting in experienced anesthesiologists using fewer attempts, interspaces (Ib) and time (in children; Ib) with less “bony contact” (in children; Ib) to achieve the block. With trainees, the success rate for epidural insertions may be improved (Ib).⁶ Nonetheless, the overall analgesia success rates were similar (Ib) for ultrasound and standard techniques. Moreover, only anecdotal evidence was available to indicate a benefit of ultrasound guidance for neuraxial techniques in patients with high body mass index, abnormal spinal anatomy, or previous spinal surgery.⁷

The research illuminates inherent limitations in the guidance of neuraxial techniques with current ultrasound technologies. The epidural and spinal spaces are ensconced in a complex bony structure that limit ultrasound beam access

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and scatter the resulting image, particularly in adults, where the bones are fully calcified. Thus, glimpses of the structures of interest (*e.g.*, ligamentum flavum, epidural space, and dura) must rely on the interspinous and intralaminar windows, which require separate transverse midline and longitudinal paramedian ultrasound approaches, respectively. Additional reductions in the size of these skin-puncture and needle-passage windows and greater skin-to-epidural-space distances are witnessed during pregnancy.⁸ Moreover, current ultrasound fidelity cannot identify nerves and other structures within the epidural space well (the space appears dark or hypoechoic); thus, only *assistance* in landmark identification and occasional identification of needle tip and medication placement can be provided (*e.g.*, rectus sheath, transverse abdominis plane, intercostal, paravertebral, and lumbar plexus blocks). Future optical technologies may allow true, real-time *guidance*, which implies direct visualization of the target nerve structures and the ability to continuously observe needle, catheter, and medication placement (*e.g.*, ilioinguinal/iliohypogastric, femoral, sciatic, and brachial plexus). Finally, the simultaneous manipulation of an ultrasound probe in one hand and an epidural or spinal needle in the other represents a practical burden; a paramedian epidural needle approach within the ultrasound plane combined with the simultaneous use of a spring-loaded syringe may partially alleviate this limitation.⁹

The custom-designed, single-crystal, nonfocused, needle ultrasound transducer reported by Chiang *et al.*³ can overcome some of these limitations. With an outside diameter of 0.7 mm, the transducer was introduced through an 18-G epidural needle into anesthetized pigs and could reliably identify the ligamentum flavum. The dura mater provided an even stronger signal that could be observed at a distance of approximately 3.5 mm to as far as 7.5 mm. The center frequency of the transducer was approximately 42 MHz, with a -6 dB fractional bandwidth of 50% and a resolution of 0.15 mm. By contrast, current ultrasound probes for neuraxial techniques are curvilinear and have a lower frequency (2–5 MHz) to allow better tissue penetration (5–16 cm) and resolution (2 mm axial; 3 mm lateral).¹⁰

Vision. The research prototype produced by Chiang *et al.*³ offers a novel advance that may someday offer real-time, ultrasound guidance of neuraxial techniques. An ultrasound transducer “eye” that moves with the tip of the needle allows a preview of coming tissue planes and structures and, as importantly, what lies distal to them, before they are traversed. Such a probe essentially eliminates the issues associated with the greater skin-to-epidural-space depth witnessed during pregnancy or in patients with high body mass index and potentially could assist in negotiating the needle around bone or other obstructions. A reduction in needle-related mischief and trauma would be expected. An “ultrasound (transducer) needle within (epidural) needle” approach would also enable the easy advancement of both needles as a coordinated unit, instead of the cumbersome manipulations

currently required to control the physically separate external ultrasound probe and epidural needle.

Several alterations remain on the clinician’s wish list for neuraxial technique guidance. Would an ultrasound needle with a side port, similar to the ultrasound probe used for oocyte retrieval, allow “real time” observation of the epidural catheter introduction and drug deposition? Would a flexible needle or conduit allow a malleable ultrasound probe to more deftly navigate the journey to the epidural space? Would broader, multiplane views be preferable? The current transesophageal ultrasound transducers for cardiac imaging offer evolutionary insights. These transducers offer multiplane views with rapid acquisition of two-dimensional images, which can be stitched together to provide three-dimensional images. With spatiotemporal image correlation, such probes offer real-time or “live” three-dimensional (also known as four-dimensional) images. To date, these cardiac ultrasound transducers lack the ability to provide rapid, real-time calculations of cardiac volumes as well as continuous pulse wave Doppler signals to assess blood flow, but these elements may be unnecessary for neuraxial technique guidance. Additional insight may be gained by modifying intravascular ultrasound probes, which are linear, flexible transducers that can produce high-resolution, albeit cross-sectional, images of coronary lumens and vessel walls.

Our vision for ultrasound guidance of neuraxial techniques should not be limited to accomplishments within hardware and software. Future advances may rely on returning to broader questions. Can other imaging technologies offer better resolution and a similar absence from radiation risks (*e.g.*, optical coherence tomography, which uses light instead of sound)? Does imaging guidance promote or further prevent practicing clinicians’ eagerness to employ regional anesthesia? Can requirements for imaging guidance possibly alter trainee (at all levels) education and learning in unfavorable ways? How far can imaging technologies prompt advances in needle, catheter, or drug development? Can imaging advance to the point where selective nerve or plexus blockade within the neuraxial space is offered? Finally, can imaging guidance play a verifiable role in optimizing patient safety? The current literature is silent with regard to patient- or situation-specific safety outcomes where ultrasound guidance has proven to be particularly useful⁶; limited data suggest that complication rates with ultrasound guidance are similar to the historical norms observed with the use of traditional nerve localization tools and that rare complications may not be further reduced.^{6,11}

Although these questions may remain unanswered for some time, current investigations should attempt to determine whether ultrasound guidance of neuraxial techniques can achieve reliable, measurable improvements in analgesia and anesthesia success rates, procedure times, block onset times, block reliability and duration with lesser anesthetic doses, safety profiles, and cost/benefit analyses. The key efficacy outcomes identified by the United Kingdom’s National

Institute for Health and Clinical Excellence for ultrasound guidance of epidural techniques should also be assessed, including patient comfort during catheter insertion, success rate for entering the epidural space on the first attempt, and success in patients in whom the conventional technique has failed.¹² Finally, the ability to provide successful neuraxial techniques in patients with distorted anatomy (*e.g.*, scoliosis, disc pathology, Harrington rods) should be evaluated.

The practice of regional anesthesia, including neuraxial techniques, has been advanced with ultrasound guidance. Continued progress will depend on clinicians and investigators prompting product designers and innovators, such as Chiang and colleagues, to produce devices with measurable clinical utility. We have intruded on the epidural space for more than a century; perhaps this next century will witness how the gift of sight has allowed our vision for imaging-guided regional anesthesia to come into focus.

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