

# Eyes to the Needle

## To Assist Identification of the Epidural Space

### Clinical Assessment

Ting *et al.*<sup>1</sup> report a novel technique to identify the ligamentum flavum (LF) and epidural space (ES) by using the magnitudes and the ratio of two reflected optical (light) signals obtained from tiny optical fibers incorporated into the stylet of the epidural needle. By using xenon single wavelength scanning onto *ex vivo* porcine intervertebral tissues, the authors first identified two wavelengths, which show specific reflective optical characteristics to the LF and dura. Then with anesthetized pigs, they attached a light source to provide these two wavelengths of light at the proximal end of the optical stylet in the epidural needle. As the distal end of the needle is advanced through LF into ES in the lumbar intervertebral space of anesthetized pigs, the light reflected from the tissue reveals unique changes in optical characteristics to allow differentiation between LF and ES. The authors further verify the ES with ultrasound and contrast radiography. Their method is fundamentally different from all the epidural techniques that we are currently accustomed to. It provides a "surrogate eye" or an optical signal indicator to signify when the distal end of the epidural needle is in the LF or ES during the epidural procedure.<sup>1</sup>

Ting *et al.*<sup>1</sup> provide a new tool toward improving the identification of and the differentiation between LF and ES. Their technique may perhaps be able to reduce inadvertent dural puncture by more definitive identification and differentiation between LF and ES. With the loss of resistance technique (LORT), there are times when the change or loss of resistance is inconclusive. In such cases, inserting the fiberoptic stylet used in the technique by Ting *et al.* would provide valuable optical information to confirm whether the distal end of the needle is in the ES. However, inadvertent dural puncture may also be due to abnormal LF or narrow and adhered ES. Further research is needed to demonstrate whether the optical technique used by Ting *et al.* would be able to differentiate accurately between abnormal LF and ES and the normal LF and ES. Even in identifying normal ES, it is not known without further research whether the sensitivity and specificity of their technique would be any better than that of the LORT. The study by Ting *et al.* shows as good a differentiation between LF and ES with one optical wave-

length as with two wavelengths or their ratio.<sup>1</sup> However, they do not show whether the reflected optical signals obtained with their dual wavelength technique would be able to reliably differentiate LF and ES against other tissues or potential spaces between the tissues along the path of the epidural needle, such as the interspinous ligament, supraspinous ligament, and adipose tissue, and even muscles, cartilages, bones, or blood. Furthermore, the tissue-specific characteristic of the optical signal and the ability to differentiate between LF and ES are lost if more than one pass of the needle is attempted with their technique.<sup>1</sup> In its current form, their technique may have limited clinical acceptance because of limited advantages over the simple manual LORT. Much research, refinement, and validation of their technique are needed to explore the full potential of this new technique. Feasibility of using multiple wavelengths should be assessed to provide additional information to identify multiple tissues along the path of the epidural needle. As the smaller submillimeter optical fiber becomes available, its incorporation into the epidural catheter may be possible. Perhaps then the technique used by Ting *et al.* can be applied to guide more accurately not only the epidural needle placement but also the epidural catheter placement to improve the success of epidural anesthesia and to avoid epidural venous structures and false ESs.

The technique used by Ting *et al.* provides good differentiation between ES and LF, but it does not provide guidance to the desired trajectory path for the epidural needle placement. Neuraxial ultrasonography represents one of the few applications aiming to solve the problem of difficult initial placement by directionally guiding the epidural needle placement.<sup>2-5</sup> The recent reports have shown successful ultrasound applications in some patients with difficult spinal anatomy when LORT may be difficult and less consistent. There are also reports suggesting improved outcomes of reduced inadvertent dural punctures, procedural attempts, and improved patient satisfaction.<sup>2-5</sup> Recent advances in incorporating submillimeter magnetic and ultrasonic transducers in the needle and the availability of compact electromagnetic

Accepted for publication December 2, 2009. The authors are not supported by, nor maintain any financial interest in, any commercial activity that may be associated with the topic of this article.

◆ This Editorial View accompanies the following article: Ting CK, Tsou M-Y, Chen P-T, Chang K-Y, Mandell MS, Chan K-H, Chang Y: A new technique to assist epidural needle placement: Fiberoptic-guided insertion using two wavelengths. ANESTHESIOLOGY 2010; 112:1128-35.

field generators may in the near future allow real-time triangulation and visualization of the epidural needle placement and its projected trajectory path.<sup>6</sup> Exploring the technique used by Ting *et al.* in conjunction with these advance ultrasound techniques may in the future add another dimension to the accuracy and safety in the placement of epidural needle and catheter to significantly improve the success and reliability of epidural anesthesia and reduce its complications.

LORT has been the most common technique used to identify the ES since Dogliotti<sup>7,8</sup> first described the technique in his textbook in 1939. Several alternative techniques, mostly involving an adapted or automated mechanical or pneumatic feedback to detect a change of resistance or pressure, have been proposed.<sup>9–16</sup> These alternatives have thus far gained very limited acceptance or practical use because of their marginal advantages, if any, over the manual LORT. Given the apparent efficacy and simplicity of the LORT, any new proposed epidural technique must clear some hurdles that the LORT does not by providing a solution to overcome one or more causes of epidural failures without adding undue risks or inconveniences.<sup>17–20</sup>

## Technologic Assessment

Technologic enhancement to aid placement of epidural needles has included mechanical force detection, ultrasound imaging, and various optical methods.<sup>21–25</sup> Commonly, mechanical feedback from the insertion needle to the operator's hand is sufficient for localization, as entry into the ES is associated with a significant drop in mechanical pressure or resistance. Devices have been constructed that assist in the detection of the change in mechanical pressure or resistance for identifying the ES. However, one of the more generally accepted technology-assisted methods is ultrasonic guidance because it provides important sonoanatomical information that can be very helpful, especially in patients with difficult anatomy.<sup>22</sup> An external transducer allows visualization of the needle, ES, LF, and dural structures. This method may require two clinicians to work together and is often impractical in a clinical environment given the marginal benefit in routine patients. New technology using ultrasound in conjunction with electromagnetic triangularization has extended the accuracy and simplicity of placing needles with ultrasound.

Various optical techniques similar to the method used by Ting *et al.* have been investigated, including laser (optical) spectroscopy, optical coherence tomography, and tiny fiber-optic camera systems.<sup>1,21</sup> Optical methods show great promise for needle localization because of their compact nature, allowing real-time tissue characterization in small needles or even microcatheters. Simple optical technology can be mass produced at a low cost to allow the devices to be discarded after use. Optical technologies that are not camera based are similar to ultrasound as emitted signals are back scattered to a detection probe. Instead of sound, they use the variation in light scattering properties inherent in tissue. Optical coherence tomography is used to reconstruct images with high

axial resolution, whereas spectroscopy, similar to the technique used in the study of Ting *et al.*, is used to form a characteristic signal. Both methods are limited by the difficulty in deciphering the optical properties of different tissues and poor light penetration limiting the range of localization.

Ting *et al.*<sup>1</sup> present an interesting study in optical spectrometry showing statistically significant differences in the optical properties between ES and LF. They introduce an *ex vivo* porcine model for studying the optical properties of the ES at varying wavelengths. An *ex vivo* model of this nature could be very useful for optimizing a new optical method. However, recreating *in vivo* conditions, especially blood and fluid perfusion, is very difficult. These conditions can have a large influence on the results and may account for the notable differences seen in the *ex vivo* and *in vivo* studies. Namely, the wavelength that seems most optimal in the *ex vivo* study failed to satisfy the receiver operating characteristic curve requirements *in vivo* in the current study by Ting *et al.*<sup>1</sup> (see fig. 6 of Ref. 1). Furthermore, the optical properties are very different during retraction of the needle with no significant differences in tissue properties, suggesting large effects from either hollow retraction path or fluid leaking into the corridor.

Ting *et al.* explore a limited number of wavelengths due to the desire to use off the shelf optical components. However, this provides a narrow picture of the potential for this optical method as other wavelengths could prove to be more robust in identifying the ES. There is also the question of using multiple wavelengths together to characterize different tissues. Could this improve the sensitivity and specificity of the method? How do the limitations of directional emission and detection combined with poor light penetration affect the usefulness of this technology? Clearly, work such as that of Ting *et al.* raises many important questions about the many possibilities of optical technologies for this application.

Accurate localization of the needle placement for epidural puncture and many other procedures presents a great frontier in biomedical research. Tiny optical spectrometers could allow micrometer precision in placing extremely small catheters. Although the optical fibers reveal the nature of the immediate space, tiny ultrasonic transducers fit into an epidural needle could provide a more penetrating spectroscopic view of the tissue ahead. Moreover, the relatively small size of the fibers used in optical localization could allow the use of both in tandem. Finally, mechanical (sound) and optical waves are two small pieces of a much larger array of tools available for research. Studies should not be limited to these modalities. As it stands, much work is still needed to advance this technology to achieve highly reliable results worthy of widespread adoption.

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