

Localization of epidural space: A review of available technologies

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Abstract

Although epidural analgesia is widely used for pain relief, it is associated with a significant failure rate. Loss of resistance technique, tactile feedback from the needle, and surface landmarks are traditionally used to guide the epidural needle tip into the epidural space (EDS). The aim of this narrative review is to critically appraise new and emerging technologies for identification of EDS and their potential role in the future. The PubMed, Cochrane Central Register of Controlled Clinical Studies, and Web of Science databases were searched using predecided search strategies, yielding 1048 results. After careful review of abstracts and full texts, 42 articles were selected to be included. Newer techniques for localization of EDS can be broadly classified into techniques that (1) guide the needle to the EDS, (2) identify needle entry into the EDS, and (3) confirm catheter location in EDS. An ideal method should be easy to learn and perform, easily reproducible with high sensitivity and specificity, identifies inadvertent intrathecal and intravascular catheter placements with ease, feasible in perioperative setting and have a cost-benefit advantage. Though none of them in their current stages of development qualify as an ideal method, many show tremendous potential. Some techniques are useful in patients with difficult spinal anatomy and infants, and thus are complementary to traditional methods. In addition to improving the existing technology, future research should aim at proving the superiority of these techniques over traditional methods, specifically regarding successful EDS localization, better safety profile, and a favorable cost-benefit ratio.

Key words: Epidural localization, epidural space, loss of resistance, new technologies

Introduction

Epidural anesthesia is a widely used method for pain relief which is useful in various settings. Identification of needle entry into the epidural space (EDS) is performed most commonly using a loss of resistance (LOR) technique, which was described in 1921 by Sicard and Forestier,^[1] and has remained largely unchanged since.

Despite its popularity, epidural analgesia is associated with a significant failure rate.^[2] Ready reports a 27% and 32% failure rate for lumbar and thoracic epidural, respectively in a heterogeneous cohort of 2114 surgical patients.^[3] Failure was defined as need for replacement of the epidural catheter or addition of another major modality for pain control. In another cohort of 1286 patients, Kinsella reported that 24% of patients had inadequate anesthesia when using a previously placed labor epidural for cesarean section.^[4] Failure of epidural analgesia can occur due to various reasons including an inability to guide the needle through the interspinous or interlaminar gap into the EDS, false-positive identification of entry into the EDS, difficulty in advancing

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the epidural catheter into the EDS, and malposition or subsequent dislodgement of the epidural catheter.^[5-8] Apart from the failure of analgesia/anesthesia, epidural placement is also associated with complications such as postdural puncture headache, inadvertent subarachnoid, subdural,^[9] or epidural venous placement,^[10] and epidural hematoma.^[11] Postdural puncture headache following inadvertent dural puncture, during labor epidural placement, is associated with a longer hospital stay and emergency room visits following discharge.^[12]

Over the course of the last decade, newer techniques for locating and confirming entry into the EDS have been explored to circumvent these failures and complications. Anesthesiologists need to be aware of the advantages and disadvantages of these emerging technologies, to assess which techniques to adopt. Moreover, knowledge about of these newer technologies is essential to guide future research in this avenue. The aim of this narrative review is to summarize the emerging technologies for identifying the EDS and their potential role in the future.

Methods

The PubMed, Cochrane Central Register of Controlled Clinical Studies, and Web of Science databases were searched using the following search strategies. All articles, from 1995 to January 2014, were included in the search. The search was limited to articles in English language. Human as well as animal studies were included.

As our initial search strategy, we incorporated a location concept into our search criteria. We executed the search such that words such as “location” or “identify” (or its synonyms) occur within five words of “epidural space” or “ligamentum flavum.” Then, a second separate search was conducted for each of the known techniques or newer investigational techniques of epidural localization, using each of the following keywords: Ultrasound, new technology, LOR, fluoroscopy, bioimpedance, optical reflectance spectroscopy (ORS), and epidural stimulation test. The results of the first search were combined with each of the second keyword search to obtain all the possible results. This produced 54 results from Cochrane library, 694 from PubMed, and 493 from Web of Science. Of these 1241 results, 193 were duplicates and thus provided us with a final count of 1048 results. The title and abstracts of each of the search results were individually examined to shortlist 294 articles, which were related to neuraxial analgesia and anesthesia. The full text of these shortlisted articles was reviewed and 42 articles selected, which were relevant to the content of this review. In addition, the bibliography of all these

selected articles was also manually searched to identify any relevant publications, which could have been overlooked in the previous searches.

Discussion

The various methods mentioned in literature to identify EDS were categorized into three sections:

1. Guiding the needle to the EDS,
2. Identifying entry into the EDS, and
3. Confirming catheter location in the EDS [Table 1].

Guiding the needle to the epidural space

Currently, most anesthesiologists guide the epidural needle to the EDS in a blind fashion, and success is dependent on the expertise of the proceduralist. The point of needle insertion is largely identified by palpation of surface landmarks, which can be difficult in patients who are obese or who have abnormal vertebral anatomy. The subsequent angle of insertion, speed of advancement, degree of change in needle angle on encountering bone, etc., vary widely with the experience of the operator and the unanticipated variability in vertebral anatomy potentially leading to failure. This section describes techniques which would assist in guiding the needle toward the EDS.

Ultrasound guided techniques

Ultrasonography can be used either for preprocedural imaging of anatomical landmarks or for real-time ultrasound guidance of the procedure. A detailed description of the technique is beyond the scope of this review but a systematic approach to perform lumbar and thoracic ultrasound scan for aiding neuraxial blocks has been described.^[13] Prescanning can help identify the midline and the most appropriate intervertebral space. Moreover, identification of a specific intervertebral level is more accurate with ultrasonography than using surface landmarks or palpation. Palpation could result in inaccuracies of two or more intervertebral levels from the targeted level.^[14] Ultrasound also provides information on the depth of the EDS and the angle of needle insertion.^[15,16] Prescanning has been shown to decrease the number of needle passes and significantly increase the first-pass success rate^[15,17,18] and is particularly useful in patients with difficult spinal anatomy.^[15,19] Clinicians could utilize ultrasound to aid epidural placement when difficulty is anticipated or as a rescue measure in patients with unanticipated difficulty. However, ultrasonography could be particularly more challenging in patients with difficult anatomy, which could impact on its applicability in such patients.^[20] Although preprocedural ultrasound scanning is currently considered beneficial in patients with difficult anatomy, further studies are needed.

Table 1: Methods of epidural localization

Method	Type of Commercial			Comments
	study	availability		
Guiding needle to EDS				
2D ultrasonography				
Preprocedural scanning	H	Y		Helps identify midline, correct intervertebral space, depth of space, point and direction of needle entry
Real-time ultrasound guidance	H	Y		Unlike preprocedural scanning, it is not affected by change in patient position. But might require >1 operator
Newer avenues in ultrasonography				
Needle tracking	H	Y (in spinal needle)		Provide real-time visualization of needle location. Also shows a virtual image of needle trajectory and position of needle tip
Real-time 3D/4D ultrasonography	C	Y		Improves spatial orientation but poor needle visibility and resolution with current technology
Preacquired 3D images of spine	H			Complex, expensive, and time consuming. Not feasible on a routine basis
Ultrasound through needle	A			No human studies yet
Needle through ultrasound	H			Might assist in identifying vertebral interspace in patients with poor surface landmarks
Machine vision	H			Can be used to train novices in neuraxial ultrasonography
Acoustic radiation force impulse imaging	H			Might be useful in better needle visualization
Fluoroscopy	H	Y		Cumbersome in perioperative setting, radiation exposure
Identifying entry into the EDS				
Modifications of the LOR				
Membrane in syringe technique	H			These techniques replace the subjective nature of LOR by objective endpoints. But has all the limitations of identifying EDS using LOR
Epidural balloon	H	Y		
Epidrum	H	Y		
Episure autodetect	H	Y		
Auditory and visual display of pressure wave	H			
Bioimpedance	H			Might have benefit in obese individuals
ORS	A			Has ability to identify complications such as inadvertent entry into epidural vein, and intrathecal or subarachnoid position of needle tip. No human studies yet
Optical coherence tomography	A			Limited depth of imaging, 2 mm with current technology
Confirming catheter location in the EDS				
Epidural stimulation test	H	Y		Cannot be used once local anesthetic is administered or once neuromuscular blockade achieved
Electrocardiography guided system	H	Y		Though gives information on vertebral level of a catheter tip, does not confirm it epidural location
Epidurography	H	Y		Limited by requirement of fluoroscopy and associated radiation exposure
Epidural pressure waveform analysis	H			Easy to perform, but sensitivity and specificity needs to be determined by further studies
Near-infrared tracking system	C			Preliminary stages of development. Only provides information on vertebral level of catheter tip, but doesn't confirm epidural location
Ultrasonography	H	Y		Used to directly visualize epidural catheter or the expansion of EDS. Only useful in children, where visualization is facilitated by nonossified vertebrae

H = Human studies available, A = Only animal studies, C = Human cadaveric studies, Y = Yes, LOR = Loss of resistance, 2D = Two-dimensional, 3D = Three-dimensional, 4D = Four-dimensional, EDS = Epidural space, ORS = Optical reflectance spectroscopy

Unlike preprocedural scanning, real-time ultrasonography would not be affected by changes in the position of the patient and thus potentially would be more accurate. However, there is limited literature on real-time ultrasound guidance for epidural placement.^[21,22] Though two operators are considered necessary for real-time ultrasound guidance, certain investigators have reported a single operator technique with in-plane needle insertion.^[22,23] Most of the literature on ultrasound guided epidural placement comes from a small

number of centers and were performed by a few experienced proceduralists. Whether the reported advantages can be reproduced more widely is yet to be seen. From our clinical experience, real-time ultrasound guided epidural insertion is difficult technically and potentially adds the risk of introducing ultrasound gel into the EDS. Its advantage over traditional methods needs to be proven in a larger cohort. Real-time ultrasound-guided spinal anesthesia is still in its infancy and is not routinely used as a standard of practice.

Newer avenues in ultrasonography

Advances in ultrasound technology have opened up more avenues for its use in the EDS localization, some of which are described below. Whether these will complement or even replace traditional ultrasonography is unknown.

Needle tracking methods

One of the main limitations of using real-time two-dimensional (2D) ultrasound for regional anesthesia is the difficulty in visualizing the needle or its tip, and the targeted tissue plane in the same image. Needle tracking and navigation tools circumvent this limitation by improving real-time visualization of the needle. Navigation systems using electromagnetic tracking^[24] are found useful in radio frequency ablation of liver tumors,^[25] creation of transjugular intrahepatic portosystemic shunt,^[26] transbronchial biopsies,^[27] vertebroplasty, carotid stent deployment and endovascular aortic surgeries.^[28]

Guidance positioning system for regional anesthesia (SonixGPS)

A guidance positioning system uses an electromagnetic motion tracking system, consisting of a transmitter and one or more sensors. These sensors determine the position of the needle with respect to the ultrasound image. The position sensors located on the needle hub and the ultrasound transducer, track their position with respect to the transmitter, allowing the user to have a virtual image of the needle's trajectory and the anticipated position of its tip, superimposed on the ultrasound image [Figure 1]. This is particularly useful in out-of-plane needle insertions.

This device could be used for preprocedural scanning as well as for real-time ultrasound guided EDS localization. Once the tip of the needle is at the desired point of skin entry, the

GPS navigation system can be used to orient the needle such that the projected needle trajectory reaches the posterior complex. This preprocedural scan would give information on the point of entry, direction of entry and also the estimated depth, utilizing the on-screen calculation. Certain investigators have successfully used Sonix GPS (Ultrasonix, British Columbia, Canada) for peripheral nerve blocks and spinal anesthesia.^[29-31] Though promising, this technology requires a proprietary needle, which currently is not suitable for epidural insertion. There are also concerns about the accuracy of needle tip localization which further hinder its adoption into routine clinical practice.

Real-time three-dimensional/four-dimensional ultrasonography

The high computational speed of modern machines has made it possible to obtain three-dimensional (3D) ultrasound images and to display those in real-time four-dimensional (4D). In addition to the use of 3D ultrasonography in echocardiography and for fetal imaging, it has been shown to facilitate regional anesthesia.^[32,33]

Belavy *et al.*^[34] described using 3D/4D ultrasound probes for real-time visualization of needle during EDS localization. They performed 4D ultrasound guided epidural placements on cadavers and were able to visualize and successfully place epidural catheters in 11 out of the 12 attempts. As the 4D ultrasound acquires multiple planes of view simultaneously without probe repositioning, it could potentially improve the spatial orientation of the operator. However, the authors recognized the challenges associated with obtaining good quality 3D/4D ultrasound images of the spine due to the complex anatomy and strong spatially varying bony shadows and artifacts encountered. In addition, there are issues of poor

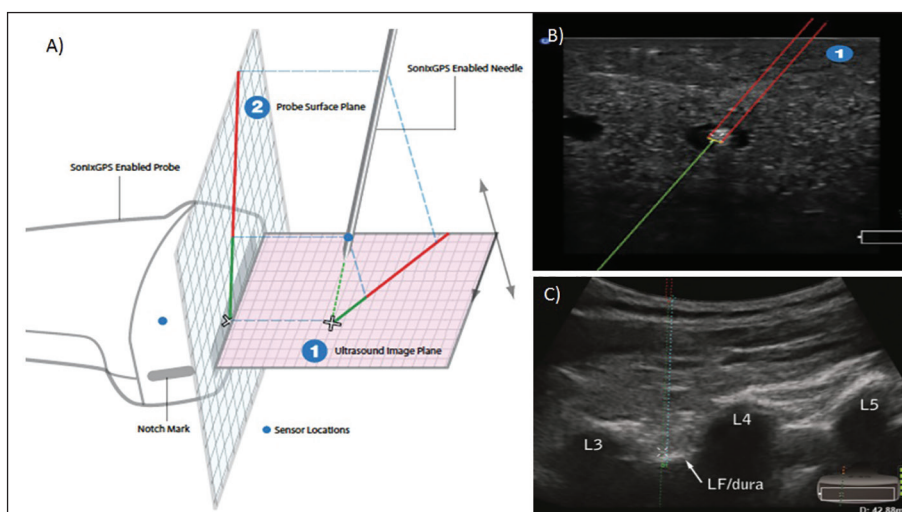


Figure 1: (a) Generation of image using SonixGPS, (b) Real-time image acquisition using SonixGPS, (c) Preprocedural scanning with GPS needle (Source: www.analogicultrasound.com)

resolution, reduced frame rate, and poor needle visibility with 4D images. Other important limitations are complexity and cost involved. Thus, the benefit of 3D/4D ultrasound guidance over traditional blind insertion is presently unclear. However, with further development of the technology, improved clarity of images, and better computational speeds, this could be a useful tool in the future.

Ultrasound imaging with preacquired three-dimensional images of spine

Due to the drawbacks of real-time 3D/4D ultrasound using current technology, investigators have tried to reconstruct the 3D vertebral anatomy of a patient. Preprocedure off-line reconstruction can produce detailed high-resolution 3D images, unlike real-time 3D ultrasonography. These can then serve as a 3D template, which can be subsequently utilized for real-time EDS localization.

Rafii-Tari *et al.*^[35] proposed a 3D panorama ultrasound guidance system, where they initially preacquired 3D image of the spine using free hand sweep with a standard 2D ultrasound probe. This image provided context for subsequent EDS localization by the proceduralist. The preacquired image was linked to the real-time 2D ultrasound image, acquired while performing the procedure, using markers on the patient skin [Figure 2]. In their initial evaluation, this technique was reported to aid in determining the point

of insertion and trajectory of the needle and the depth of EDS.^[36] Similarly, Lang *et al.*^[37] described another method which used preoperative computed tomography (CT) images of the spine to considerably enhance the accuracy of the 3D ultrasound panorama. Though this could serve as an excellent 3D context for percutaneous spinal interventions, its role in EDS localization has never been explored.

Preacquisition of these high-resolution images is however complex, expensive, and time-consuming. Changes in patient position between image acquisition and the procedure can alter the accuracy of the preacquired 3D context. Though incorporation into routine practice seems unlikely, it might have utility in patients with known difficult vertebral anatomy. Further research must evaluate cost effectiveness and benefit over conventional EDS localization techniques.

Ultrasound through needle

With advances in ultrasound technology and probe design very small ultrasound transducers have become available. Besides its established role in endoluminal ultrasonography, Chiang *et al.*^[38] reported its utility in identifying EDS. They used a 0.7 mm diameter, 40 MHz transducer placed in an 18-gauge Tuohy needle to obtain A-scan images from the tip of the needle [Figure 3]. As the needle was advanced towards the EDS of their porcine models, signals were obtained from both dura and ligamentum flavum (LF),

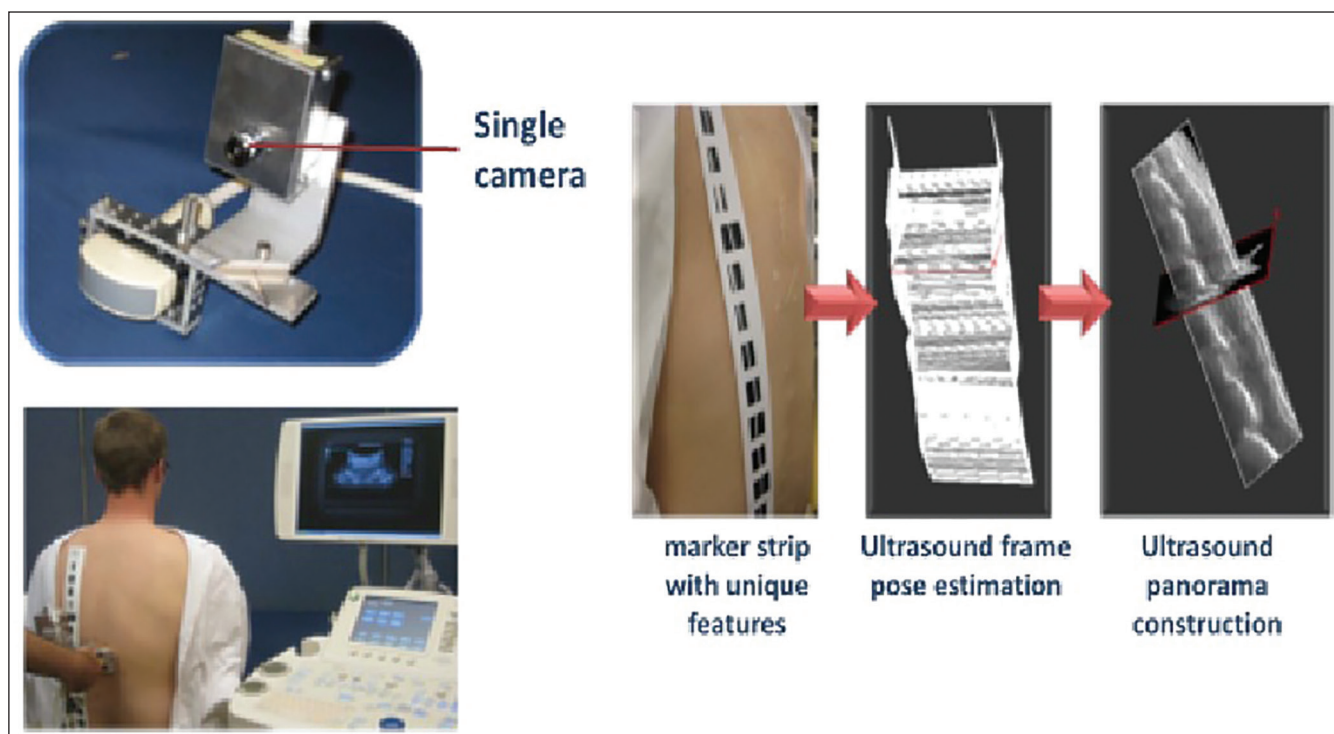


Figure 2: Ultrasound reconstruction of the spine with the camera on probe (reprinted with permission, source: Rafii-Tari H, Abolmaesumi P, Rohling R. Panorama Ultrasound for Guiding Epidural Anesthesia: A Feasibility Study. In: Taylor RH, Yang GZ, editors. Information Processing in Computer Assisted Interventions LNCS 6689, Berlin, Heidelberg: Springer science and business media; 2011. p. 179-89.

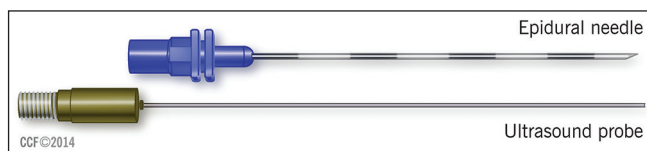


Figure 3: Ultrasound transducer and a standard 18-gauge Tuohy epidural needle

providing information on position of the needle tip. Though this method needs special equipment, it has the advantages of providing real-time guidance and can be performed by a single operator. Though promising, the absence of any human studies makes the future of this technology in EDS localization uncertain.

Needle through ultrasound

Identifying an appropriate point of entry for epidural placement can be challenging in patients with poor surface landmarks. Chen *et al.*^[39] proposed to overcome this by using real-time A-mode ultrasonography to accurately identify intervertebral spaces. They used a 10 mm small-sized cylindrical ultrasound probe with a hole in the center for insertion of the epidural needle. In their study on porcine models, they were able to accurately identify specific lumbar interspaces.

The small size of the ultrasound probe and the needle through probe design eliminates the need for an assistant to hold the probe. While this technique may have advantages over traditional surface landmark guided techniques, especially in obese individuals, it requires special equipment. This technique has not been tested in thoracic interspaces, where spatial shadowing and narrow interspace might hamper imaging. An additional limitation of this technique is that it is unlikely to provide any additional information compared to a conventional 2D ultrasound image.

Machine vision

Machine vision is a form of artificial intelligence wherein a computer is trained to recognize images. It does so by performing a standard texture analysis of the image and compares it with previously stored data using image processing and pattern recognition techniques. Once familiar structures are recognized by the software, they are pointed out in the ultrasound image by tissue-specific markings.^[40]

Among various software systems reported, some aid in correct identification of intervertebral levels,^[41,42] while others automatically identify structures such as vertebral body, lamina, articular process, and EDS.^[43,44] Unlike ultrasonography for vascular access or nerve blocks, vertebral anatomy is more complex, making pattern recognition difficult. Nevertheless, various investigators were able to identify structures automatically using parasagittal and transverse interspinous views at the lumbar level.^[41-44]

However, thoracic scans are more challenging and have not been evaluated. The ability of these systems to identify structures in the presence of uncommon or distorted anatomy is unknown.

Acoustic radiation force impulse imaging

An important drawback of ultrasound technology is difficulty in obtaining a clear image of the needle, and clear differentiation of nerves from surrounding soft tissues, which have similar acoustic impedances. Acoustic radiation force imaging differentiates tissues based on their elasticity, unlike traditional ultrasonography which differentiates tissue based on acoustic impedances.^[45] The high elastic modulus of the steel needle, compared to surrounding tissues, could aid its visualization within the complex vertebral sonoanatomy.^[46] This technology requires considerable research and development before it could be available commercially.

Fluoroscopy

Fluoroscopy has been used routinely in chronic pain practice to guide the needle and identify EDS. However, its role in the perioperative setting is less established. Certain investigators have evaluated the use of fluoroscopic guidance in localizing thoracic and lumbar EDS for preoperative placement of epidural catheters.^[47-49] Though epidural localization could be easily performed with fluoroscopic guidance, routine use would be limited by the availability of fluoroscopy in preoperative settings. There are concerns of added risk due to radiation exposure and no published studies proving its advantage.

Identifying entry into epidural space

Traditionally, LOR is used for identification of entry into EDS. However, despite identification of EDS with typical LOR, adequate analgesia was not obtained in 5-15%, as LOR, although sensitive, lacks specificity.^[50-53] LOR is a skill acquired by the proceduralist, making it subject to variations and failures. This section describes certain technologies, which try to eliminate the subjective nature of LOR, and others which utilize novel markers to identify entry into EDS.

Modifications of the loss of resistance technique

Membrane in syringe technique

Saline is favored by some anesthesiologist for obtaining LOR due to various anecdotal reports of complications occurring with an injection of air into EDS.^[54] However, air has been cited to provide better feel of compressibility and thus provide the “bounce” on the plunger while advancing the needle through the LF. However, saline being incompressible does not provide that sensation. To circumvent this issue, Lin *et al.*^[55] described a technique that preserves the compressibility of air but at the same time prevents injection of air into EDS with LOR. This “membrane in syringe” technique involves

dividing the LOR syringe into two compartments by a transversely oriented plastic membrane, one filled with saline and other with air. The saline compartment lies next to the nozzle while the air compartment is next to the plunger of the syringe. They successfully tested this device on 20 patients, proving feasibility for this syringe; however, it is not available commercially as yet.

Epidural balloon

Macintosh first described the use of an epidural balloon to identify EDS.^[56] He used a small inflated balloon attached to epidural needle hub while advancing the epidural needle. The entry of the needle tip into the EDS would result in collapse of the balloon due to relatively negative pressure in the EDS. Recently, Fyeface-Ogan and Mato^[57] tested a modification of the Macintosh balloon and found it was quicker than traditional LOR. It consists of a Y-shaped connector attached to the epidural needle with one end having a balloon and the other end attached to a syringe for charging the balloon with air. This technique provides a visual cue on entering EDS and thus provides objective evidence.

Epidrum

This device consists of a small drum with a diaphragm on one of its sides. This device is interposed between the Tuohy needle and the syringe for epidural placement and charged with air to expand its diaphragm while the needle is being advanced. The penetration of EDS results in negative pressure and sudden collapse of the diaphragm, providing visual evidence of entry into EDS. Compared with traditional LOR, use of Epidrum resulted in a shorter procedure time and fewer number of attempts.^[58,59]

Episure Autodetect

This device is an LOR syringe with an internal spring, applying constant pressure on the plunger to empty the syringe.^[60] The air or saline loaded Episure Autodetect syringe remains attached to the Tuohy needle as it is advanced through LF. Entry into EDS would be marked by forward movement of plunger with emptying of syringe contents into EDS. In comparison with traditional LOR, it has a similar learning curve and success rate, but a shorter time to epidural catheter insertion.^[61] It also allows the operator to use two hands while advancing the needle.

Auditory and visual display of pressure wave

Lechner *et al.* described an acoustic puncture assist device (APAD) which quantifies the pressure at the epidural needle tip and provides real-time auditory and visual displays of the pressure waveforms, during EDS localization.^[62,63] Once the needle tip is advanced through the skin, the APAD is connected to the needle hub, which maintains a pressurized

fluid column through the epidural needle. As the epidural needle is advanced, the pressure from the column is measured and transmitted as auditory signals and visually displayed as pressure tracings. Entry into the EDS results in a sudden drop in pressure on the visual display as well as a distinct fall in the tone of the audio output. The authors propose that simultaneous use of three senses: hearing the auditory signal, seeing the graph, and touch for needle control – makes it highly reliable and simple to perform. Lechner *et al.* demonstrated the feasibility of this method in placement of thoracic as well as lumbar epidural catheters.^[62-64] Ghelber *et al.*^[65] described a similar technique using a computer controlled injection pump to objectively measure the drop in pressure encountered on entering EDS. As the anesthesiologist advances the epidural needle, entry into EDS is identified based on visual display of the pressure waveform. A drop in pressure to <20 mmHg sustained for more than 5 s was deemed consistent with entry into EDS. The authors suggest that this method helps to identify false LOR, as the pressure drop in those instances would not be sustained over a period of time. Samhan *et al.* have used a simpler and cost effective system where a regular intravenous (IV) set with normal saline bag was connected to the Tuohy needle.^[66] The fluid bag was then pressurized to 50 mmHg using a pressure bag. The entry into EDS would be determined by result in flow of fluid into EDS, seen as fluid dripping in the fluid chamber of the IV set.

Objectively measuring LOR, as described in the above-mentioned techniques, has many advantages. In all these methods, the subjective and tactile nature of LOR is replaced by objective visual or auditory end points. Despite this, it is important to note that they share some of the same disadvantages associated with traditional LOR. For instance, the decrease in pressure might not be significant in patients with prior spine surgery and resultant scar tissue. Entry of needle into pleural or paravertebral spaces can result in false-positive LOR.

Some of these techniques such as Epidrum and epidural balloon use air as the medium for LOR. Though saline has not been proven superior to air,^[67-69] various anecdotal reports question safety of LOR to air. Injection of air into EDS has been associated with paresthesias, difficult catheter insertion, partial block, accidental dural puncture, and postdural puncture headache.^[54] Though adding objectivity to LOR seems attractive, need for special equipment, the price of the technology, and lack of demonstrable superiority to traditional LOR have limited its use in routine clinical practice.

Bioimpedance

Bioimpedance is a measure of the opposition to the flow of alternating current. This property can be used to differentiate

several tissue types including muscle and fat.^[70,71] EDS has a higher fat content than its adjoining structures such as LF and subarachnoid or intrathecal compartments, aiding in its identification using bioimpedance. The advantages of this technique are that it can be performed by a single operator and requires less expensive equipment. It could serve as a complementary tool during EDS localization when the position of the needle tip is in question. However, its role as a sole method for EDS localization needs to be further investigated.

Optical reflectance spectroscopy

When light falls on a substrate including human tissue, some portion of it is reflected and some absorbed. The intensity of light reflected or absorbed by a particular tissue varies and depends on the tissue composition. ORS uses this property to differentiate various tissues based on their optical absorption. Ting *et al.*^[72,73] and Desjardins *et al.*^[74] independently developed technology using ORS for localizing EDS in porcine models. While Ting measured the optical spectra at the needle tip using a specialized stylet introduced through the epidural needle, Desjardins *et al.* used optical fibers embedded within the needle. They found that optical spectra were significantly different between EDS and LF and thus could serve as a tool to identify epidural location of the needle tip. Ting *et al.* performed epidural placements in their porcine models using ORS with 95% success confirmed by epidurography.^[73] They also found that deliberate subarachnoid and intrathecal placements as well as inadvertent entry into epidural vein resulted in optical spectra, which were significantly different from EDS.^[75]

Most of these results were obtained by operators with sufficient expertise in interpreting ORS. To expand clinical applicability of this method, Lin *et al.*^[76] devised an intelligent recognition system (iRS) using data recorded from 90 epidural needle insertions in anesthetized pigs. During subsequent EDS localization, iRS would analyze the data obtained from optical spectra and provide real-time input to the physicians regarding position of needle tip as LF, EDS, or doubtful [Figure 4]. This could help reproduce the same accuracy among clinicians unfamiliar with ORS.

With consistent success in animal models, this technology has generated considerable interest. If these results can be reproduced in humans, it could develop into a better alternative to LOR for EDS localization. This method also has potential to identify inadvertent intravascular, subarachnoid, or intrathecal placement. Although ORS appears to be a promising technique, it has not been tried yet in humans.

Optical coherence tomography

Optical coherence tomography (OCT) is the optical analog of B-mode ultrasonography, but measures time delay and

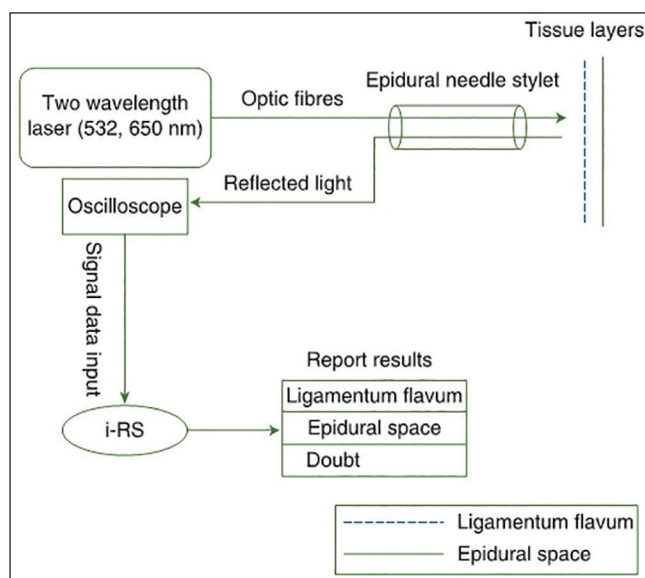


Figure 4: Intelligent recognition system (reprinted with permission, source)^[76]

magnitude of light, in lieu of sound. The light reflected back from tissue is used to determine the depth of penetration and then to create 2D and 3D images of the imaged tissue. Though the depth of imaging is limited to approximately 2 mm, it is adequate for identification of structures immediately at the tip of the needle.^[77] Newer developments in OCT technology could potentially increase depth of imaging to 7 mm.^[78] The ability of this imaging technique to prevent inadvertent intraneural injection while performing transforaminal nerve root injections has been investigated in animal studies.^[79] Though its use in EDS localization has been speculated, it has never been explored.

Confirm catheter location in epidural space

In spite of accurate localization of EDS, there is no guarantee that the catheter threaded through that needle would remain in the EDS. Secondary failure rates as high as 7% have been reported in literature.^[80] Failure could result from migration of the epidural catheter out through an intervertebral foramen or from the catheter being pulled out of the EDS.^[5,8]

The position of the epidural catheter tip is an important factor in determining whether satisfactory epidural analgesia will be achieved. An epidural catheter has been shown to move from its initial position with patient movement.^[7] The following section describes various techniques for identifying location of the epidural catheter tip during epidural placement or subsequently to investigate the secondary failure.

Epidural stimulation test

Tsui *et al.* first described the use of nerve stimulation to ascertain the correct position of epidural catheter tip.^[81] The epidural stimulation test involves electrical stimulation of nerves passing through the EDS using a saline column

in the epidural catheter. Motor or sensory response to a stimulation of 1-10 mA indicates epidural location of the catheter tip. Reported sensitivity in literature ranges from 80% to 100%.^[82-85] EST can also be useful in detecting inadvertent subarachnoid,^[86] subdural,^[87] or intravascular^[86] placement of the epidural catheter. Bilateral stimulation with stimulating current <1 mA has been associated with subarachnoid position, subdural space, or is seen if the catheter is in close proximity to a nerve root. This can also be used to estimate the vertebral location of epidural catheter tip.^[82,88,89] This is especially helpful in determining the extent of cephalad migration in a caudally threaded epidural catheter in infants.^[88] Epidural stimulation test has been criticized for being technically difficult and cumbersome to perform in a perioperative setting.^[90] Electrical stimulation is ineffective once local anesthetics are administered through the epidural catheter or after the patient receives neuromuscular blocking agents. Furthermore, the test cannot be relied upon in patients with preexisting neuromuscular disease. In spite of its advantage for caudal epidural placement in infants, EST has not been adopted widely due to these drawbacks.

Electrocardiography guided system

Electrocardiograph (EKG) guided positioning of epidural catheter was first described by Tsui *et al.* in 2002 for determining the dermatomal location of the epidural catheter tip.^[91] This technique uses a specially designed epidural catheter, which enables its tip to be one of the EKG leads. Moreover, EKG with another surface electrode positioned at the desired dermatomal level is displayed simultaneously. Once the tip of the catheter reaches the desired segment, both the EKG tracings would be identical. In their initial study, Tsui *et al.* successfully positioned caudally threaded epidural catheters at the targeted spinal level, in 20 children. Unlike EST, this technique can also be used after administration of neuromuscular blockade or after injecting local anesthetic through the epidural catheter. However, it has only found use in pediatric population and requires special equipment. Though this technique reveals the vertebral level of an epidural catheter tip, it does not confirm the presence of the catheter in EDS.

Epidurography

Epidurography involves fluoroscopy after injection of contrast dye through the epidural catheter. Accurate location of the catheter is indicated by typical epidural spread of the dye as seen in the fluoroscopic image. Though routinely used in chronic pain practice, nonavailability of equipment and added radiation risk have prevented routine use perioperatively. To circumvent these concerns, Uchino *et al.* performed epidurography concurrently with postoperative abdominal or spine X-rays, which were obtained as part of routine postoperative care.^[92] Though this technique confirms epidural

location and level of the catheter, this information would only be available postoperatively. Epidurography could serve as a tool to determine correct epidural placement postoperatively, before manipulating an inadequately functioning catheter.

Epidural pressure waveform analysis

Transducing and plotting the pressure measured in the EDS produces a unique and reproducible waveform, which reflects heart rate and peripheral pulse waves [Figure 5]. These waveforms are thought to be originating from the spinal cord and are transmitted through the dura to the EDS. Thus, the presence of these pulsatile waveforms in synchrony with heart rate, obtained on transducing the epidural catheter, would imply epidural location of the catheter.^[54] Among patients with inadequate postoperative analgesia, Ghia *et al.* found that presence of a typical waveform strongly correlated with epidural location of the catheter, as confirmed by CT cathetergram.^[93] Ability of epidural pressure waveform to accurately determine catheter location has been reported in two other studies.^[85,94] Easy availability of pressure transducers, in perioperative setting, makes this an attractive method to confirm epidural location of a catheter immediately after placement or later on.

Near-infrared tracking system

The near-infrared tracking system consists of a fiberoptic wire, placed in an epidural catheter, which emits infrared signal allowing its visualization with an infrared camera. Chiu *et al.* used an infrared light emitting guidewire to facilitate threading of an epidural catheter to a desired vertebral level, in cadavers.^[95] The potential advantage is the ability to guide placement of epidural catheters distantly from the needle tip, to the desired dermatomal level. However, the signal was diminished in obese patients, and when the catheter passed under-lamina or diverged from midline. Its role in confirming epidural position of a catheter is also uncertain.

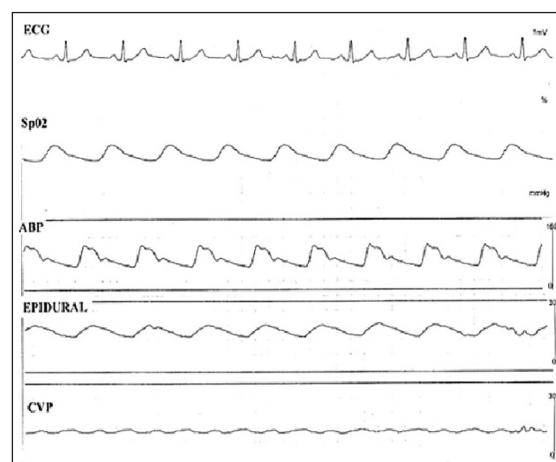


Figure 5: Typical epidural pressure waveform transduced through an epidural catheter shown along with other standard monitors (reprinted with permission, source)^[94]

Ultrasound

Certain investigators have used ultrasonography to accurately locate epidural catheter position within the EDS, especially among infants. Willschke *et al.*^[96] used ultrasonography to locate the position of the catheter tip by identifying the movement of dura, from expansion of EDS, during local anesthetic injection through the epidural catheter. On the other hand, Ueda *et al.*^[97] evaluated the images of EDS obtained using a transesophageal echocardiography probe to guide a caudally inserted epidural catheter to a desired thoracic vertebral level.

The use of these methods in adults has not been reported, but would likely be hampered by poor image quality from ossified vertebrae. However, the authors suggest that the transesophageal echocardiography probe might be able to obtain images through the intervertebral spaces, and thus avoid vertebral shadowing. However, its utility is limited to patients requiring intraoperative echocardiography such as for cardiac surgeries.

Conclusion

An ideal method to identify EDS should be easy to learn and perform, easily reproducible with high sensitivity and specificity, and identify inadvertent intrathecal and intravascular catheter placements with ease. It is also important to consider the availability of resources, clinical feasibility, and cost-benefit advantage before adopting any new technology. Though none of the newer techniques have currently replaced traditional LOR, some have found use in special scenarios and thus could be complimentary to LOR. Ultrasound is increasingly being used as a rescue method when a patient with difficult anatomy is encountered. Others such as EST and EKG guided techniques are used in certain institutions to guide a caudally threaded epidural catheter in infants. Nevertheless, several of these technologies need further characterization of safety profile and proof of a favorable cost-benefit profile. Demonstration of a lower complication rate would require larger studies, especially since traditional technique itself is associated with a low complication rate. As several of these technologies are in early stages of development, it is difficult to have an accurate insight into its potential. With newer advances in technology and innovation, some of these techniques might eventually prove to be superior to traditional methods and thus decrease the failure rate associated with epidural placements.

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Conflicts of interest

There are no conflicts of interest.

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