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SPECIAL ARTICLE

From the *Journal* archives: Practical applicability of the epidural electrical stimulation test

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Editors' Note: Classics Revisited

Key Articles from the *Canadian Journal of Anesthesia* Archives: 1954-2013

As part of the *Journal's* 60th anniversary Diamond Jubilee Celebration, a number of seminal articles from the *Journal* archives are highlighted in the *Journal's* 61st printed volume and online at: www.springer.com/12630. The following article was selected on the basis of its novelty at the time of publication, its scientific merit, and its overall importance to clinical practice: *Tsui BCH, Gupta S, Finucane B*. Confirmation of epidural catheter placement using nerve stimulation. Can J Anaesth 1998; 45: 640-4. Drs Faraj W. Abdallah and Vincent W.C. Chan provide expert commentary on the clinical utility of the epidural electrical stimulation test in confirming accuracy of epidural catheter placement.

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Article summary
Authors: *Tsui BCH, Gupta S, Finucane B.*
Citation: Can J Anaesth 1998; 45: 640-4.
Purpose: To evaluate the clinical utility of the epidural electrical stimulation test in confirming accuracy of epidural catheter placement.
Principal findings: The epidural electrical stimulation test (EEST) developed by Tsui *et al.* can be applied to confirm proper catheter placement in the epidural space. This test is based on the delivery of an electrical current through the epidural catheter to stimulate the spinal nerve roots and elicit a motor response. The threshold current intensity required for stimulation determines whether the catheter is inside or outside the epidural space. A positive test for epidural catheter placement is indicated by a unilateral or bilateral motor response when stimulated at a current of 1-15 mA. Although catheter misplacement in the epidural vein shows a similar response, the two locations can be distinguished by the change in motor response following local anesthetic injection, i.e., diminished magnitude with the epidural location but not with the intravenous location. Other non-epidural locations have different tissue-specific electrical impedances; thus, different stimulation currents are required. A positive motor response at low current stimulation < 1 mA signals a subarachnoid, subdural, or nerve root catheter location. Positive grounded local muscle stimulation or a negative response at > 15 mA suggests a subcutaneous location.

The EEST has another important feature. Clinicians can apply the test to confirm the spinal level of the epidural catheter tip based on the site of muscle contraction observed in the body. A motor response in the upper limb, chest wall, abdominal wall, and lower limb corresponds with epidural stimulation applied to the

cervical, upper thoracic, lower thoracic, and lumbar region, respectively. Observing the changing site of muscle contraction helps guide advancement of a caudally inserted epidural catheter to the appropriate spinal level in pediatric patients.

Although the EEST is highly reliable, its application is unlikely to become routine for epidural confirmation as it has key limitations, including the need to set up special equipment, the inability to perform repetitive testing after local anesthetic administration, and the potential to misinterpret motor response. Furthermore, threshold intensity required for epidural stimulation does not predict block asymmetry, completeness, or local anesthetic consumption.

Conclusion: The epidural electrical stimulation test is a reliable test to confirm epidural catheter location and to indicate the spinal level of the epidural tip position.

Epidural anesthesia and analgesia is a potent regional anesthetic technique for the relief of surgical and obstetrical pain. The importance of epidural catheter position cannot be overstated. Not only does accurate catheter placement in the epidural space determine anesthetic effectiveness, accidental subarachnoid and intravenous catheter migration and local anesthetic administration can result in serious complications. Additionally, premature outward catheter dislodgment can also lead to sudden termination of an otherwise effective analgesic treatment. For pediatric epidural analgesia, there is still the clinical challenge of cephalad advancement of a caudally inserted catheter without guidance to a spinal level appropriate for surgery. Although uncommon, spinal cord injury has been reported following thoracic epidural anesthesia in anesthetized pediatric patients.[1] These concerns prompted a search for a practical method to facilitate quick confirmation of catheter location, inside or outside the epidural space, and to provide real-time guidance during advancement of the epidural catheter.

To address these clinical issues, Tsui *et al*. published a landmark clinical paper in 1998 on the "confirmation of epidural catheter placement using nerve stimulation", the "Tsui test", as an objective method to identify epidural catheter location.[2] To examine the sensitivity and specificity of epidural electrical stimulation as a test for accuracy in confirming the epidural catheter location, the indwelling epidural catheter in each of 40 adult surgical patients was connected to the cathode of a nerve stimulator using an adaptor. The epidural catheter was then stimulated at 1 Hz with a current intensity of 1-10 mA. Consistent unilateral or bilateral limb or truncal movement independent of the grounding anode electrode position was considered a positive test. Under these conditions, the sensitivity and specificity of this test was found to be 100% and 91.6%, respectively. As the authors acknowledged, the application of electrical current to localize peripheral nerves during regional anesthesia and to stimulate the spinal cord for chronic pain treatment was not a new concept, but electrical stimulation through an indwelling catheter in the neuraxial space to evoke a segmental motor response was indeed innovative. Muscle contractions generated by epidural stimulation presumably result from stimulation of spinal rootlets and segmental motor neurons.[3] Following a logical and orderly sequence of animal and human studies, the investigators determined the range of current threshold and stimulation criteria for epidural, subarachnoid, subdural, spinal nerve root, subcutaneous, and intravenous catheter stimulation in adult surgical[2] and obstetrical[4] patients and pediatric[5-7] patients. The investigators also validated the accuracy of this test against the lidocaine/epinephrine test dose[2] and radiographic catheter localization.[8]

In essence, this electrical stimulation test serves three important functions. Based on the current stimulation threshold, the test helps to determine: 1) whether the epidural catheter is located inside or outside the epidural space; 2) whether the epidural catheter is positioned midline or too lateral against a nerve root near the intervertebral foramen; and 3) the spinal level (myotome) at which the catheter tip is located based on the site of motor response in the body. A motor response in the upper limb, chest wall, abdominal wall, and lower limb indicates cervical,[9] upper thoracic, lower thoracic,[10] and lumbar catheter location, respectively.

The conductivity of the setup for the epidural electrical stimulation test (EEST) operates on the Ohm's law principle, V (voltage) = I (current) × R (resistance). Assuming a nerve stimulator can deliver a maximal 400 V output, there would be no difficulty in overcoming any resistance up to 40 kΩ (maximum human body resistance estimated at 6 kΩ) to generate a 10 mA current. The actual threshold current required for EEST depends on the electrophysiological (conductive) properties of the anatomical layers surrounding the spinal nerves (e.g., dura). The test also assumes a direct correlation between the stimulation threshold and the distance to the nerve root (the shorter the distance, the lower the current required), much like peripheral nerve stimulation. Although relatively simple in concept, the stimulation test requires an assembly of essential elements and a number of steps to perform in practice. These include: 1) a metal wire reinforced catheter; 2) an adapter with a metal hub (e.g., Arrow-Johans™ electrocardiogram [ECG] adapter) connected to the catheter; 3) a conductive liquid medium (e.g., normal saline) to prime the catheter; 4) a syringe for saline flushing; 5) a nerve stimulator (set at 1 Hz frequency and a 0.2 msec pulse width); 6) attaching

the anode terminal of the stimulator to a grounding surface electrode on the patient; and 7) attaching the cathode terminal to the metal hub of the adapter. One way to lessen the effort and time to assemble all equipment components is to use a commercially available kit (Epidural Positioning System using Tsui Test with the FlexTip Plus® Catheter, Arrow, Teleflex, Reading, PA, USA) or a wired catheter with a removable stylet.[11]

Once the EEST is set up, the stimulation current output is slowly increased from zero until either a muscle contraction response is detected or a maximum of 10-15 mA is reached. The Tsui test is considered positive when unilateral or bilateral muscle contraction appears upon electrical stimulation. The location and intensity of the motor response should not change regardless of the position of the anode grounding electrode. According to the original test criteria, a positive test with a current threshold of 1-10 mA indicates the epidural catheter location. A higher stimulating current is required following local anesthetic injection. A positive test is also observed at 1-10 mA when a catheter is accidentally placed in the epidural vein, but the baseline stimulation threshold does not change with local anesthetic injection.[4] A positive test at low current stimulation < 1 mA suggests subarachnoid or subdural[12,13] catheter location with the following characteristics: a bilateral localized myotomal response with subarachnoid stimulation *vs* a diffuse multi-spinal myotomal response (e.g., contraction in chest wall, back muscles, and lower limbs) with subdural stimulation. Direct nerve root stimulation also causes a unilateral response at < 1 mA stimulation, and catheter withdrawal of 1-2 cm will change the stimulation threshold from < 1 mA to > 1 mA. A positive grounded local muscle stimulation or a negative test at high current stimulation > 10 mA suggests that the catheter is outside the spinal canal (e.g., subcutaneous).

A number of technical limitations may influence the performance of the EEST. An important prerequisite for this test is low electrical impedance (resistance) to facilitate electrical conduction through the entire length of an epidural catheter to reach its tip. A catheter with spiral metal wire inside its lumen provides a low impedance baseline (usually < 10 kΩ with stylet and < 15 kΩ without). The impedance to electrical stimulation is further decreased when the catheter is primed with normal or hypertonic saline as a conductive medium. On the other hand, air (airlock in the catheter lumen or epidural air introduced during loss of resistance test), a non-conductive liquid, and a non-metal nylon catheter (impedance > 700 kΩ)[14] are all associated with high impedance, precluding effective electrical conduction. In fact, it has been reported that repeated catheter flushing with saline is required following initial priming in order to maintain electrical stimulation.[15] It has also been reported that a large variability of current is required for stimulation, likely related to variable catheter locations in the epidural space, e.g., higher current is anticipated for a catheter lying in the dorsal (sensory) aspect of the spinal column. Tsui[16] and others[15,17] suggested the need to increase the upper threshold limit to 15-20 mA for epidural stimulation, not 10 mA as originally described. Despite its utility, the stimulation threshold required for the EEST does not seem to predict block symmetry, completeness, or local anesthetic consumption in obstetrical analgesia.[18] Additionally, performing repeated catheter testing during postoperative epidural analgesia requires discontinuing the local anesthetic infusion for several hours before the stimulation threshold is restored. Interestingly, the stimulation threshold may be paradoxically lowered after epidural local anesthetic injection in some patients.[15] Finally, epidural stimulation is not recommended in patients with a pacemaker.

Several factors may interfere with the interpretation of the resultant muscle contraction response. A local muscle contraction generated by the anode terminal may be confused with a motor response elicited by epidural stimulation; thus, to avoid any misinterpretation, the ground electrode should be placed on the lower extremity for thoracic epidural catheter placement and on the upper extremity for lumbar epidural placement. Respiratory chest movement may also interfere with interpretation of intercostal muscle contraction.[15] Diaphragmatic twitches from cervical epidural stimulation can potentially be misinterpreted as chest wall twitches resulting from thoracic stimulation. Subdural catheter stimulation often produces a diffuse multi-segment motor response, e.g., in the chest, back, and legs, most likely due to widespread conduction in the plane between the arachnoid and pia mater. The laterality of a unilateral muscle contraction may indicate the predominant side of anesthesia for cervical epidural catheter placement.[19]

Tsui *et al*. report that the EEST possesses high sensitivity and specificity overall. Validation by the original group of investigators shows 100% sensitivity and 92-100% specificity with a 96% and 100% positive and negative predictive value, respectively. Nevertheless, subsequent testing showed slightly lower sensitivity. For example, Forster[15] reported 88% test accuracy when compared with epidurogram confirmation, while McAuliffe[20] reported 92% accuracy in a fluoroscopic study. de Médicis[21] reported 80% sensitivity, but this improved to 87% when both motor and sensory responses were considered with epidural stimulation. A small percentage of false positives and negatives has also been reported.[15]

Although the EEST is highly reliable, it is not routinely applied in adults for a number of reasons. The test requires some pretest planning and equipment setup. While most helpful for confirming initial catheter location before local anesthetic administration, it is not practical for repeated catheter check during epidural infusion. Other more practical and routine confirmation tests (e.g., a failure or difficulty to advance a catheter into the epidural space or an absence of sensory anesthesia after a local anesthetic bolus injection) do not require special EEST equipment. The epidural ECG test is another useful test that provides confirmation even in the presence of muscle relaxant or epidural local anesthetic (both not possible with EEST); however, it cannot differentiate epidural from subarachnoid or intravascular placement.[22] Additional simple tests can rule out subarachnoid catheter placement, e.g., aspiration for cerebrospinal fluid and examining for evidence of spinal anesthesia after a test dose. Although not completely reliable, a test dose of epinephrine is often used to rule out intravenous placement. To most clinicians, the real technical challenge associated with epidural anesthesia is more related to needle entry than to catheter entry into the epidural space. To overcome this difficulty, some studies have reported using ultrasound to localize the interspinous space.[23,24] Also, real-time ultrasound visualization of the epidural space, epidural local anesthetic expansion, and confirmation of epidural catheter placement are now possible but limited to the neonate and infant population.

In our view, the Tsui test for epidural electrical stimulation remains a useful clinical tool. Routine use of this clinical application is unlikely, rather, its use is typically reserved for initial confirmation of epidural catheter placement in selected adult patients, e.g., obesity and challenging spinal anatomy, when the accuracy of epidural needle placement is more difficult to confirm. The contribution of the EEST in guiding caudal catheter advancement and providing more consistent success in pediatric epidural analgesia is indisputable.[10] The anesthesia community truly appreciates Tsui's innovative work to advance our knowledge in epidural and peripheral nerve stimulation.

Key points

- The epidural electrical stimulation test (EEST) is an objective and reliable bedside method to confirm epidural catheter location.
- The stimulation current threshold and the pattern of segmental muscle contraction help to differentiate the epidural catheter location from the subarachnoid, subdural, nerve root, intravenous or subcutaneous location.
- The EEST provides real-time guidance of a caudally placed catheter during cephalad advancement to the appropriate spinal level in pediatric patients.
- There is some evidence to suggest that the EEST can improve the success of pediatric epidural analgesia.
- The EEST requires pre-procedure planning and an assembly of equipment, e.g., wire-reinforced catheter, metal hub connector, and nerve stimulator.

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