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Different techniques for identification of thoracic epidural space

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Abstract
The accurate placement of a thoracic epidural catheter is crucial in managing pain during surgery, especially for thoracic, abdominal, and pelvic procedures. Pressure waveform analysis serves as a dependable confirmatory method to complement the loss-of-resistance methodology for locating the epidural space throughout thoracic epidural anesthesia. M-mode ultrasound is utilised to ascertain the catheter's location, while Colour Doppler data indicate the saline flow inside the epidural space via the catheter. While the epidural catheter was not clearly visible in the ultrasonographic picture, the flow of administered saline via it was visible.

Keywords: Thoracic epidural catheter, Pressure waveform analysis, Colour Doppler, M-Mode Ultrasonography

Introduction
A thoracic epidural is recognised as an effective analgesic method for several surgical procedures, particularly thoracic, upper abdominal, and obstetric surgical procedures. The epidural may be utilised for analgesia during and after surgery. The installation of a thoracic epidural catheter needs the proficiency of an anaesthetist; difficulties might occur when targeting the upper thoracic area, among individuals with atypical neuraxial architecture, improper patient posture, or those who are morbidly obese [1].

Due to the blind nature of the technique and potential technical problems, epidural insertion might lead to consequences including postdural puncture headache, nerve injury, haematoma and abscess development, and intravascular injection [1].

Epidural waveform analysis (EWA) pertains to the assessment of the pressure waveform obtained from the epidural space using a needle or catheter. Previous research has shown that a needle or catheter is appropriately positioned in the epidural space [2].

Ultrasonography is being used as an aid for visualising the epidural region in several contexts that includes obstetric anaesthesia. Color Doppler ultrasonography has been utilised to ascertain the location of epidural catheters, relying on the injection of saline via the catheter to induce alterations in the ultrasound picture. This may indicate a mislocated catheter, such as in the intrathecal area. Nevertheless, the thoracic spine presents notoriously inadequate sonographic windows, and its use in clinical practice hasn't advanced further at this time. [3].

Thoracic Epidural Catheter
A properly placed thoracic epidural catheter is considered essential for several significant open abdominal and thoracic surgical interventions. It may provide exceptional segmental analgesics while aiding in the reduction of opioid use and minimising postoperative problems. A mispositioned epidural catheter might result in severe consequences, including insufficient postoperative pain relief, and while it stays in place, the patient might be deprived of alternate analgesic options. Furthermore, the epidural catheter might require repositioning postoperatively, which might be hindered by factors like challenges in patient placement and other possible postoperative complications like coagulopathy [4].

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Pressure Waveform Analysis (PWA)

Pressure waveform analysis is a technique used during the administration of epidural analgesia to enhance safety and efficacy of the procedure. It involves observing and interpreting the pressure patterns of the injected fluid, which can give insights into the needle tip location, thus helping to confirm the correct placement in the epidural space [5].

Identification of Needle Placement

Pressure Patterns: Different spaces (intravascular, intrathecal, and epidural) exhibit distinct pressure waveform patterns [6].

Verification: Helps in confirming that the needle is not in a blood vessel or the subarachnoid space [7].

Real-time Feedback: Offers immediate feedback during needle advancement and assisting in real-time decisions [8].

Complement to Loss of Resistance: Often utilised in combining with the loss of resistance technique to increase accuracy [9].

Role of Pressure Waveform during epidural anesthesia

In the process of transducing pressure in the epidural space, waveform analysis is a method that reveals beat-by-beat pressure waveforms that are comparable to invasive artery pressure waveforms. These waveforms are established from pulsations that are transmitted through the dura mater. In order to capture these waveforms, a transducer might be attached to either the catheter or the epidural needle using the appropriate technique. Because of its ease of use and the fact that it does not need any specialist equipment, this approach is popular [10].

Hilber et al. (2019) [11] carried out a systematic review assessing the diagnostic accuracy of epidural waveform analysis for identifying the epidural space in surgical and labour patients. They demonstrated high sensitivity varying between 0.81 and 1.00 and a specificity between 0.42 and 1.00 for the diagnostic accuracy of the epidural wave form. They also stated that a signal synchronized with arterial pulsation was obtained when the needle or the catheter was inadvertently placed intrathecally and when needle/catheter was accidentally sited in an artery.

Possible advantages

Enhanced Safety

Avoidance of Intravascular Injection: Identifies if the needle has inadvertently entered a blood vessel, reducing the risk of systemic toxicity from local anesthetics [8].

Reduction in Dural Puncture: Helps in avoiding accidental dural punctures and subsequent complications like post-dural puncture headache [12].

Efficacy

Drug Effectiveness: Ensures that the administered drugs are delivered to the intended space, thus, increasing the effectiveness of analgesia [6].

Optimal Dosage: Aids in the administration of the appropriate dosage by avoiding misdistribution of the anesthetic [5].

Disadvantages

- Pressure waveform monitoring in the context of epidural anesthesia, while providing valuable information, is not without drawbacks [13].
- One significant challenge is the subjectivity and operator dependency regarding interpreting pressure waveforms. The accuracy of the analysis heavily relies on the expertise and experience of the healthcare provider, introducing a potential source of variability in interpretation [14].
- Additionally, pressure waveforms have limited specificity, making it challenging to pinpoint the exact cause of observed changes. Factors such as catheter migration, tissue compression, or alterations in patient position may influence the waveform, complicating the interpretation process [15].
- Furthermore, pressure waveforms may not differentiate between various tissues encountered during needle advancement, such as ligaments, adipose tissue, or the epidural space itself. In cases where patients have a history of epidural procedures or surgeries, the development of epidural fibrosis can distort pressure waveforms, reducing their accuracy [10].
- The risk of misinterpretation is another concern, especially in patients with anatomical variations or obesity. Such conditions can impact pressure waveforms, leading to potential errors in analysis. Over-reliance on pressure waveform monitoring may also occur, potentially overshadowing other critical aspects of epidural anesthesia, including patient response to medication or confirmation through alternative techniques like the loss of resistance [13].
- Technological limitations, including issues of equipment reliability or calibration problems, may compromise the effectiveness of pressure waveform interpretation [15].
- Implementation of pressure waveform monitoring may also introduce additional costs and resource implications, affecting its widespread adoption in certain healthcare settings [15].

Doppler ultrasound

Ultrasound with Doppler is a medical imaging technique that use the Doppler effect to see the motion of tissues and bodily fluids, primarily blood, along with their relative velocity to the probe **[16].**

By assessing the frequency shift of a specific sample volume, such as blood flow in an artery or a jet of blood over a heart valve, one may ascertain and visualise its velocity and direction. Color Doppler or color flow Doppler represents velocity using a colour scale. Color Doppler pictures are often integrated with greyscale (B-mode) images to provide duplex ultrasound images, facilitating concurrent visualisation of the anatomical structures in the region [17].

Technique of colour Doppler-guided epidural confirmation

The colour Doppler-guided epidural confirmation technique involves the utilisation of ultrasnic technology to enhance the precision of epidural placement. During the procedure, a healthcare professional utilizes a colour Doppler ultrasound probe to observe the vertebral column and surrounding structures in real-time [18].

M-mode ultrasound has been utilized to ascertain the catheter's location. After acquiring an optimum picture of the posterior complex, the M-mode scan line was positioned perpendicularly to the posterior complex to identify changes in image features. Prior to saline injection, the picture presents as static horizontal lines. Throughout the bolus saline injection, the appearance temporarily shifts to a granular pattern at the catheter's depth [3].

Bosch et al. (2022) [19] invented color flow. Doppler ultrasonography as an expedited method for evaluating epidural catheter placement in parturient patients. Flow was seen at the injection of 1 mL of saline in 93% of individuals. In the remaining 7% of individuals, flow was seen using an air/saline combination. Saline flow was seen at the insertion interspace in 70% of individuals, at both the insertion interspace and one interspace above in 27%, and just at one interspace above in 3%. Flow was seen just in the left or right paramedian view in 51% of individuals, despite a symmetrical sensory blockade in all cases. The results underscore the potential of color flow. Doppler ultrasonography for rapid verification of catheter placement and resolution of epidural analgesia complications.

Garduño-López et al. (2024) [20] illustrated that ultrasound emerges as a recent and promising diagnostic tool for locating the epidural catheter, utilizing both the M-mode and colour Doppler mode.

The Colour Doppler technique has several limitations

1. A favourable sonographic window and high-quality pictures are essential for the effective utilization of this imaging technology. Ligamental calcification and scoliosis may have obstructed ultrasonography penetration, leading to the inability to identify the color Doppler signals [21].
2. It may be difficult to differentiate the catheter tip from the catheter shaft. If colour flow is seen inside the posterior complex or under the ligamentum flavum, the catheter tip is likely positioned within the epidural space when using a single-hole catheter [22].
3. If the catheter tip has traversed the intervertebral foramina, color Doppler signals may still be detected inside the epidural space, potentially resulting in a false-positive test [23].
4. Subdural catheter placement, however infrequent, may be difficult to distinguish from epidural implantation. Ultimately, colour Doppler readings from blood arteries may resemble saline flow via the epidural catheter. The primary differentiating characteristic is a pulsatile signal for vessels, in contrast to signals occurring just during manual saline injection [24].

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