Brazilian Journal of ANESTHESIOLOGY

R e v i s t a   B r a s i l e i r a   d e   A n e s t e s i o l o g i a

CLINICAL RESEARCH

Correlation of the epidural space measured intraoperatively and estimated by MRI or US: an observational study

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Abstract

Background and objectives: To assess the agreement between the epidural depth measured from the surgical site with the epidural depths estimated with magnetic resonance imaging (MRI) and ultrasound scanning.

Methods: Fifty patients of either sex, scheduled for L4−5 lumbar disc surgery under general anesthesia were enrolled in this prospective observational study, and the results of 49 patients were analyzed. The actual epidural depth was measured from the surgical site with a sterile surgical scale. The MRI-derived epidural depth was measured from the MRI scan. The ultrasound estimated epidural depth was measured from the ultrasound image obtained just before surgery.

Results: The mean epidural depth measured from the surgical site was 53.80 ± 7.67 mm, the mean MRI-derived epidural depth was 54.06 ± 7.36 mm, and the ultrasound-estimated epidural depth was 53.77 ± 7.94 mm. The correlation between the epidural depth measured from the surgical site and MRI-derived epidural depth was 0.989 ($r^2 = 0.979$, $p < 0.001$), and the corresponding correlation with the ultrasound-estimated epidural depth was 0.990 ($r^2 = 0.980$, $p < 0.001$).

Conclusions: Both ultrasound-estimated epidural depth and MRI-derived epidural depth have a strong correlation with the epidural depth measured from the surgical site. Preprocedural MRI-derived estimates of epidural depth are slightly deeper than the epidural depth measured from the surgical site, and the ultrasound estimated epidural depths are somewhat shallower. Although both radiologic imaging techniques provided reliable preprocedural estimates of the actual epidural depth, the loss of resistance technique cannot be discarded while inserting epidural needles.

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Correlação entre a profundidade do espaço peridural medida no intraoperatório e a estimada por RM ou US: estudo observacional

Resumo

Justificativa e objetivos: Avaliar a concordância entre a profundidade peridural medida no campo cirúrgico com a profundidade peridural estimada pela Ressonância Magnética (RM) e ultrassonografia.

Métodos: Cinquenta pacientes de ambos os sexos, agendados para cirurgia de disco lombar L4–5 sob anestesia geral, foram incluídos neste estudo observacional prospectivo, e os resultados de 49 pacientes foram analisados. A profundidade peridural real foi medida no campo cirúrgico com uma régua cirúrgica estéril. A profundidade peridural obtida pela Ressonância Magnética (RM) foi medida a partir das imagens do exame de RM. A profundidade peridural estimada pelo ultrassom foi medida a partir da imagem do ultrassom obtida imediatamente antes da cirurgia.

Resultados: A profundidade peridural média medida no campo cirúrgico foi de $53,80 \pm 7,67$ mm; a profundidade peridural média da RM foi de $54,06 \pm 7,36$ mm; e a profundidade peridural estimada por ultrassom foi de $53,77 \pm 7,94$ mm. A correlação entre a profundidade peridural medida no campo cirúrgico e a profundidade peridural derivada da RM foi de 0,989 ($r^2 = 0,979$; $p < 0,001$); e a correlação correspondente com a profundidade peridural estimada por ultrassom foi de 0,990 ($r^2 = 0,980$; $p < 0,001$).

Conclusões: Tanto a profundidade peridural estimada por ultrassom quanto à profundidade peridural derivada da RM mostram forte correlação com a profundidade peridural medida no campo cirúrgico. As estimativas pré-operatórias da profundidade peridural derivadas da RM são um pouco mais profundas do que a profundidade peridural medida no campo cirúrgico, e as profundidades peridurais estimadas por ultrassom são um pouco mais rasas. Embora ambas as técnicas de imagem radiológica tenham fornecido estimativas pré-operatórias confiáveis da profundidade peridural real, a técnica de perda de resistência não pode ser descartada durante a inserção da agulha peridural.

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Introduction

Neuraxial anesthesia is technically challenging but has well established intraoperative and postoperative benefits.[1,2]

Neuraxial procedures necessitate due diligence since they are routinely performed with a so-called ''blind technique''. The success rate of precisely identifying the epidural space depends on the accuracy of the clinican sensing the loss of resistance. The inaccurate identification of epidural depth is not trivial among novices and may result in failed regional anesthesia, inadvertent dural puncture, paresthesia, and epidural hematoma.[3–7]

Preprocedural information of epidural depth may facilitate epidural insertion and increase the safety of the procedure. Previous studies assessed the agreement between the actual epidural depth and radiologic estimates of epidural depth measured with computed tomography, Magnetic Resonance Imaging (ED/MRI), and Ultrasonography (ED/US) in a variety of patient populations with varying age groups to provide a reliable estimate of the epidural depth.[8–13]

Former studies assessing the correlation between the actual epidural depth with those measured with ED/US and ED/MRI were retrospective in nature, and the ''actual epidural depth'' was defined as the epidural needle depth.[8,12,13] To the best of our knowledge, our study is unique in that we identified the ''actual epidural depth'' as the ''Epidural Depth measured from the surgical site'' (ED/AC), and the study is prospectively designed.

The primary outcomes of the present study were determining the ED/US. The secondary outcomes of the study were to determine ED/MRI and ED/AC.

In the present study, ED/AC was assessed for its agreement with ED/US and ED/MRI. We hypothesized that both ED/US and ED/MRI are in strong agreement with ED/AC.

Methods

This prospective observational study on patients scheduled for lumbar herniated disc surgery at the L4–5 level with general anesthesia was conducted from 31 May 2018 to 31 August 2018 to assess the agreement among ED/AC, ED/US and ED/MRI. Written informed consent was obtained from all patients. The study was prepared following the Declaration of Helsinki and Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines (Fig. 1).

After obtaining approval from the ethical committee (2017-20/244, 26/12/2017) and institutional review board (13389610/449, 19/01/2018), the study was prospectively registered in the Australian New Zealand Clinical Trials Registry (ACTRN12618000552280, 13/04/2018).

Patients with American Society of Anesthesiologists physical status (ASA-PS) I –III who were aged 18–75 years and scheduled for lumbar herniated disc surgery at the

L4–5 level with general anesthesia were included in the study. Patients with neurological diseases, vertebral column anomalies, history of previous spine or spinal canal surgeries, and ASA-PS > III, patients aged younger than 18 years or older than 75 years, and patients pregnant or lactating were excluded.

The majority of herniated lumbar discs occur at the L4–5 and L5–S1 levels.[14] One of the treatment modalities for lumbar herniated disc to improve the functional status of the patient is surgical treatment.[15] In the present study, we included patients who underwent surgery for a herniated lumbar disc at the L4–5 level.

The rationale for choosing a study group composed of patients scheduled for herniated disc surgery was that they readily had lumbar MRI scans, and surgical site ED/AC measurements were possible during the operation.

Ultrasound measurements

The patients received electrocardiogram, pulse oximeter, and noninvasive blood pressure monitoring on arrival to the operating room. General anesthesia was induced with intravenous 2–2.5 mg.kg^{-1} propofol and 2 mcg.kg^{-1} fentanyl. Muscle relaxation was achieved with intravenous rocuronium 1.5 mg.kg^{-1}. Maintenance of anesthesia was achieved with 2% Sevoflurane in a 50% air/oxygen mixture with 4 L.min^{-1} fresh gas flow. After securing the airway, the patients were placed in a prone position.

The ultrasound examination was performed in the paramedian sagittal oblique plane with a 2–5 MHz curved array probe (Esaote Mylab30, Florence, Italy) before surgical draping was performed in the prone position. The paramedian sagittal oblique plane was formerly reported to provide

STROBE Statement – checklist of items that should be included in reports of observational studies			
	Item nº	Recommendation	Page nº
Title and abstract	1	(a) Indicate the study's design with a commonly used term in the title or the abstract	1
		(b) Provide in the abstract an informative and balanced summary of what was done and what was found	1–2
Introduction			
Background/ Rationale	2	Explain the scientific background and rationale for the investigation being reported	3
Objectives	3	State specific objectives, including any prespecified hypotheses	3
Methods			
Study design	4	Present key elements of study design early in the paper	4
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	4–6
Participants	6	(a) Cohort study – Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up Case-control study – Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls Cross-sectional study – Give the eligibility criteria, and the sources and methods of selection of participants	4
		(b) Cohort study – For matched studies, give matching criteria and number of exposed and unexposed Case-control study – For matched studies, give matching criteria and the number of controls per case	
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	3
Data sources/ measurement	8^a	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability	4–6

Figure 1 STROBE Checklist.
^{a} Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

		of assessment methods if there is more than one group	
Bias	9	Describe any efforts to address potential sources of bias	6
Study size	10	Explain how the study size was arrived at	7
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	6
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding	6
		(b) Describe any methods used to examine subgroups and interactions	6
		(c) Explain how missing data were addressed	8
		(d) Cohort study – If applicable, explain how loss to follow-up was addressed Case-control study – If applicable, explain how matching of cases and controls was addressed Cross-sectional study – If applicable, describe analytical methods taking account of sampling strategy	6
		(e) Describe any sensitivity analyses	6
Results			
Participants	13ᵃ	(a) Report numbers of individuals at each stage of study – eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	8
		(b) Give reasons for non-participation at each stage	8
		(c) Consider use of a flow diagram	
Descriptive data	14ᵃ	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	
		(b) Indicate number of participants with missing data for each variable of interest	8
		(c) Cohort study – Summarise follow-up time (eg, average and total amount)	

Figure 1 (*Continued*)

Outcome data	15[a]	Cohort study – Report numbers of outcome events or summary measures over time	
		Case-control study – Report numbers in each exposure category, or summary measures of exposure	
		Cross-sectional study – Report numbers of outcome events or summary measures	8
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	8
		(b) Report category boundaries when continuous variables were categorized	
		(c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	
Other analyses	17	Report other analyses done – eg analyses of subgroups and interactions, and sensitivity analyses	8
Discussion			
Key results	18	Summarise key results with reference to study objectives	9–11
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	10
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	10
Generalisability	21	Discuss the generalisability (external validity) of the study results	11
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	11

[a] Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Figure 1   (*Continued*)

optimal window for ultrasound scanning.[16] All ultrasound scanning was performed by the same investigator (MC) with more than five years of experience in vertebral sonoanatomy who was blinded to the ED/MRI measurements. First, the hyperechoic continuous line of the sacrum was identified in the midline. The probe was placed 2–3 cm lateral to the midline in sagittal axis and tilted to provide the paramedian sagittal oblique view of the vertebral canal. After achieving visualization of the saw-tooth-like appearance, the L4–5 interspace was located in the center of the probe. The screen was frozen to measure the ED/US. The distance from the skin to the posterior border of the ligamentum flavum was accepted as the ED/US and measured in millimeters with the built-in caliper of the ultrasound device.

MRI measurements

All patients underwent MRI scanning of the lumbar vertebra within 30 days before the surgery, following the standard protocol of the neurosurgery clinics in our institution. MRI scanning was performed in the supine position. All MRI measurements were acquired by the same investigator (NK,

trained for lumbar epidural depth measurements by a neuroradiologist) at the L4–5 level. NK was blinded for the ED/US measurements. MRI scans were selected from the T2–weighted sagittal images stored in the picture achieving and communication system (PACS, GE Healthcare Co.) of the hospital to measure the ED/MRI. The distance from the skin to the posterior border of the ligamentum flavum, measured in the horizontal plane was accepted as the ED/MRI and was recorded for further statistical analysis. Measurements were acquired in millimeters with the built-in caliper of the PACS system.

Surgical site epidural depth measurements

After positioning the patient for surgery, the patients back was prepared aseptically and covered with surgical drapes. Following the skin incision and surgical dissection, ligamentum flavum was exposed. The position of the patient was then turned to supine in the horizontal plane. The actual epidural depth was measured in the horizontal prone position, rather than in the surgical flexed position, which could affect the distance from the skin to the ligamentum flavum.

The surgeon used a sterile surgical scale to measure the distance from the skin to the posterior border of the ligamentum flavum in millimeters. This distance was accepted as the actual Epidural Depth (ED/AC).

Statistical analysis

The data were analyzed for normality with the Shapiro-Wilk test. The normally distributed data were expressed as the mean ± Standard Deviation (SD). Categorical variables are presented as percentages. Pearson's correlation and Lin's concordance correlation[17,18] were used to analyze the agreement among ED/AC, ED/US, and ED/MRI. A Bland-Altman plot was used to analyze the accuracy among the measurements. One-sample t-test was used to compare mean differences. The mean differences among measurements were calculated by subtracting ED/US or ED/MRI from ED/AC and dividing by two. The mean values of the measurements were calculated by summing of ED/US or ED/MRI with ED/AC and dividing by two. The mean differences in measurements were graphically plotted against the mean sums of measurements on a Bland-Altman diagram[19,20] that presented the 95% limits of agreement among ED/AC, ED/US, and ED/MRI.

The sample size of the study was calculated by using data obtained from the preliminary results of the study with G*Power 3.1.9.2. Minimum required sample size (n) was 50 to detect a desired statistical power level of 0.80 and p-value = 0.05.
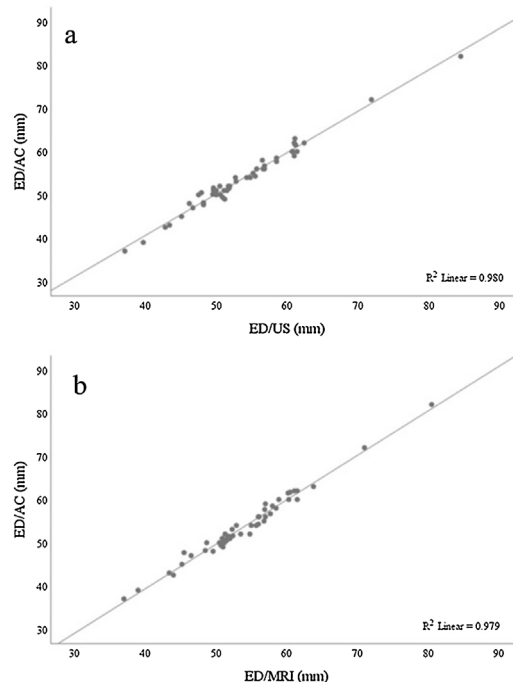
Results

We enrolled fifty patients in this prospective observational study. One patient withdrew his consent to participate in the study, and the results of 49 patients were considered for analysis. Mean age of the patients was 47.61 ± 13.92 years, and the mean height was 167.27 ± 8.67 cm. Mean patient weight was 82.11 ± 12.58 kg. The mean Body Mass Index (BMI) was 29.51 ± 5.18 kg.m^{-2}. The distribution of patients according to ASA-PS was as follows: 19 patients with ASA-OS I, 22 patients with ASA-PS II, and eight patients with ASA-PS III. Twenty-five patients were female, and 24 were male. The mean ED/AC was 53.80 ± 7.67 mm, the mean ED/US was 53.77 ± 7.94 mm, and the mean ED/MRI was 54.06 ± 7.36 mm (Table 1).

The Pearson correlation coefficient between ED/AC and ED/US was 0.990 (r^2 = 0.980, p < 0.001). The concordance correlation coefficient between ED/AC and ED/US was 0.990 (95% CI 0.982–0.994). The Pearson correlation coefficient between ED/AC and ED/MRI was 0.989 (r^2 = 0.979, p < 0.001). The concordance correlation coefficient between ED/AC and ED/MRI was 0.975 (95% CI 0.958–0.985). Pearson correlation and Lin's concordance correlation plots are presented in Figs. 2 and 3 respectively.

The mean difference between ED/US and ED/AC was -0.36 ± 1.13 mm (95% limits of agreement: -2.52–1.91). The mean difference between ED/MRI and ED/AC was 0.26 ± 1.14 mm (95 limits of agreement: -1.97–2.49). The mean difference in the epidural depth was plotted against the mean sum of epidural depth measurements on a Bland-Altman diagram representing the upper and lower 95% limits of agreement of the ED/AC with ED/US and ED/MRI (Fig. 4).
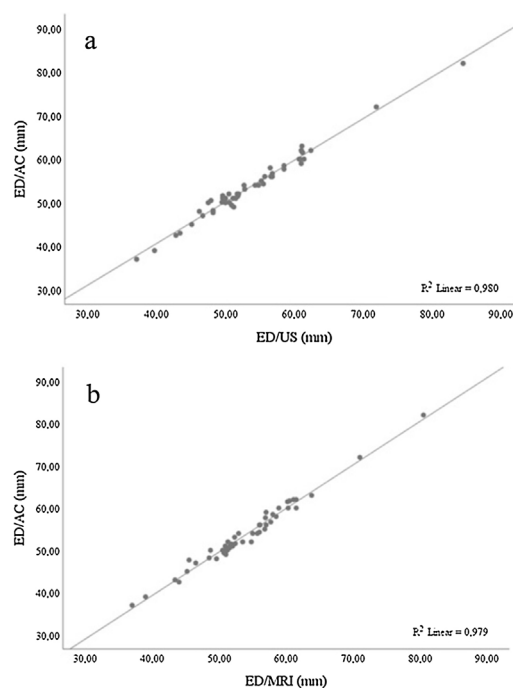
Figure 2 Pearson's correlation plots. (a) The correlation between the actual Epidural Depth (ED/AC) and the Eltrasound estimated Epidural Depth (ED/US); r^2, coefficient of determination. (b) The correlation between the Actual Epidural Depth (ED/AC) and the Magnetic Resonance Imaging derived Epidural Depth (ED/MRI); r^2, coefficient of determination.

Figure 3 Lin's concordance correlation plots. (a) The correlation between the actual Epidural Depth (ED/AC) and the Ultrasond estimated Epidural Depth (ED/US); r^2, coefficient of determination. (b) The correlation between the actual Epidural Depth (ED/AC) and the Magnetic Resonance Imaging derived Epidural Depth (ED/MRI); r^2, coefficient of determination.

Table 1 Patient characteristics.

Patient characteristics	Results
ASA-PS I/II/III (n)	19/22/8
Gender M/F (n)	24/25
Age (y)	47.61 ± 13.92
Weight (kg)	82.11 ± 12.58
Height (cm)	167.27 ± 8.67
BMI (kg.m^{-2})	29.51 ± 5.18
ED/US (mm)	53.77 ± 7.94
ED/MRI (mm)	54.06 ± 7.36
ED/AC (mm)	53.80 ± 7.67

ASA-OS, American Society of Anesthesiologist physical status; M, Male; F, Female; BMI, Body Mass Index; ED/US, Ultrasound Estimated Skin to Epidural Space Depth; ED/MRI, Magnetic Resonance Imaging-Derived Skin to Epidural Space Depth; ED/AC, Real Epidural Depth Measured from the Surgical Site. Values are expressed as mean ± standard deviation except for ASA and gender.
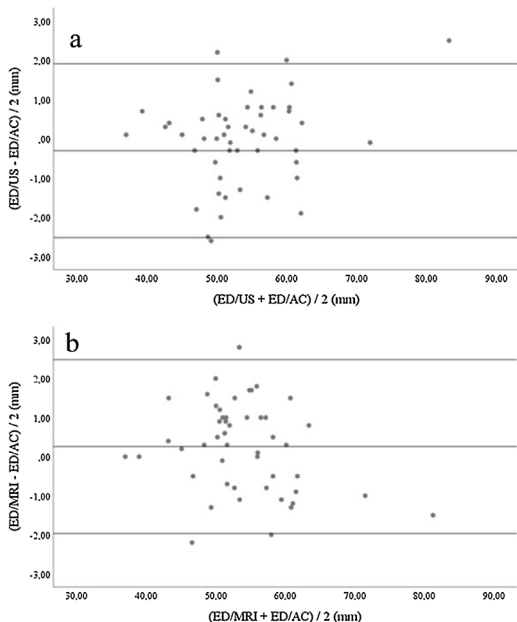
Figure 4 Bland-Altman plots. (a) The Bland-Altman plot representing the agreement between the actual epidural depth and the ultrasound estimated epidural depth (ED/US, Ultrasound Estimated Skin to Epidural Depth; ED/AC, Actual Epidural Depth measured from the surgical site. (b) The Bland-Altman plot representing the agreement between the actual epidural depth and the magnetic resonance imaging derived epidural depth (ED/MRI, Magnetic Resonance Imaging derived skin to Epidural Depth; ED/AC, Actual Epidural Depth Measured from the surgical site.

Discussion

We assessed the correlation of ED/AC with ED/US and ED/MRI in patients scheduled for lumbar disc surgery under general anesthesia. We demonstrated a strong correlation between ED/AC and ED/US, which was also consistent between ED/AC and ED/MRI.

The precise identification of the epidural space determines if the procedure will be a success or failure. The identification of the epidural space with the loss of resistance technique depends mainly on the clinician performing the epidural. Preprocedural knowledge of the depth of the ligamentum flavum may facilitate the precise location of the epidural space, providing the safe distance for epidural needle advancement.

The correlations between epidural space depth and patient characteristics were analyzed in previous studies. A mathematical formula was derived to predict epidural depth.[8,9,11,13] These earlier works were undertaken to facilitate the epidural insertion as well as to prevent the inadvertent complications of the procedure. The agreement between the actual epidural depth and radiologic measurements was assessed to predict the epidural depth.[9–12,21–23]

Daniel et al.[24] reported that there were variations in the deposition of epidural fat along the vertebral column that alter the anterior-posterior diameter of the epidural space. Other than the study published by Jones et al.,[12] other previous studies defined the epidural depth as the distance from the skin to the anterior border of the ligamentum flavum-posterior dura complex.[11,25] In the present study, we described the epidural depth as the distance from the skin to the posterior border of the ligamentum flavum.

To the best of our knowledge, all previous investigators accepted the epidural needle depth as the gold standard. Our study is unique because the ''gold standard epidural depth'' was measured from the surgical site (ED/AC) by the surgeon, and defined as the distance from the skin to the ligamentum flavum.

Although there was a strong agreement between ED/AC and ED/US, ED/US was shorter than ED/AC in our study, which was in agreement with previous studies.[9,21,22] Both ED/AC and ED/US measurements were acquired in the prone position. The compression applied to the probe can explain the difference between ED/US and ED/AC. The pressure applied to the ultrasound probe squeezes the soft tissue underneath the skin, leading to a shorter epidural depth measurement. However, ED/AC was measured from the skin to the ligamentum flavum without soft tissue compression.

ED/AC was also in strong agreement with ED/MRI; however, the ED/MRI measurements were deeper than the ED/AC measurements in our study. Patients lie in the supine position during MRI scan, and the skin to epidural depth distance is compressed by the patient's body weight. Therefore it is expected that the ED/MRI measurements would be shallower than the ED/AC measurements. Previous investigators have reported similar differences in epidural depth measurements between ED/MRI and ED/AC.[8,12] It is difficult to explain the deeper epidural depth measurements with MRI. However, the spinal curvature contributr to the extended epidural depth with MRI.

We demonstrated a strong positive correlation between ED/AC and ED/US, showing that when there is an increase in the actual epidural depth the ultrasound estimated epidural depth also increases. This is also consistent between ED/AC and ED/MRI.

The limits of agreement between ED/AC and ED/US were clinically very close to the limits of agreement between ED/AC and ED/MRI. Therefore both epidural depth measurement techniques can be used interchangeably while

inserting epidural needles. Although ED/MRI and ED/US are in strong agreement when predicting ED/AC, we recommend that ED/US is more reliable and easy to acquire for novices. Moreover, we suggest that sensing the loss of resistance cannot be ruled out even with preprocedural knowledge of the epidural depth.

A critical limitation of the present study was that the supine position of the patient during the MRI scan was different from the position of the patient at the time of ED/AC and ED/US measurements. Further studies with larger sample sizes are warranted to validate our results.

Summary

Although ED/MRI and ED/US have a strong correlation and are in agreement with ED/AC, the loss of resistance technique should not be excluded while performing epidurals. Estimating the epidural depth with ultrasound is more appropriate in operating rooms with today's technology. The developments in radiologic monitoring systems may provide more precise and accurate measurements of epidural depth.

Funding

The authors declare no funding sources for the present study.

Conflicts of interest

The authors declare no conflicts of interest.

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