International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 4, 2025
https://www.theaspd.com/ijes.php

Comparison Of Skin To Epidural Space Distance Using BMI-Derived Predictive Equation Versus Ultrasound Guidance In Elective Surgery Patients: A Prospective Randomized Study

Dr. S. Ganapathy[1], Dr. Bhagyavaradhan Botta[2], Dr. Vinai Theerthaan M[3]
[1,2,3]Sree Balaji Medical College and Hospital, Chennai, Tamil Nadu – 600044, India
Corresponding author: Dr. Vinai THEERTHAAN.M, Senior resident, Sree Balaji Medical College and Hospital, Chennai, Tamil Nadu 600044, vinai0710@gmail.com

Abstract
Background: *Accurate identification of the epidural space is essential to the safety and efficacy of neuraxial anaesthesia. Conventionally, the depth of the epidural space is identified using the loss of resistance technique, which is highly operator-dependent. Ultrasound (USG) provides a more reliable, real-time estimation of epidural depth. In resource-limited settings, a predictive equation based on body mass index (BMI) may serve as an alternative. This study aimed to compare the skin-to-epidural space distance obtained using a BMI-based predictive formula with the distance measured by ultrasound in patients undergoing elective surgery.*
Materials and Methods: *Prospective, cross-sectional study conducted at a tertiary care hospital. Sixty adult patients (ASA I–III) scheduled for elective lower abdominal or lower limb surgery were enrolled. The depth of the epidural space at the L3–L4 interspace was measured using ultrasound guidance. A BMI-based predictive equation—Depth (mm) = 17.7966 + (0.9777 × BMI)—was also applied. Mean values from both methods were compared.*
Results: *The mean skin-to-epidural space distance measured by USG was 4.7 ± 0.4 cm, while the mean predicted depth using the BMI equation was 4.3 ± 0.3 cm. The difference was statistically significant ($p < 0.0001$).*
Conclusion: *The BMI-based predictive equation underestimates the actual epidural depth measured by ultrasound. While useful as an approximate guide in settings where USG is unavailable, ultrasound remains the superior tool for accurate epidural space localization.*
Keywords: *Epidural anaesthesia, Ultrasound guidance, Body mass index, Epidural space depth, Predictive equation, Regional anaesthesia*

1. INTRODUCTION

Epidural anaesthesia remains a cornerstone technique in regional anaesthesia, extensively employed across a wide range of surgical procedures.[1] Its versatility and effectiveness make it particularly valuable in surgeries involving the lower abdomen, pelvis, and lower limbs, as well as in providing analgesia during labour and delivery.[2] It offers several advantages over general anaesthesia, including preservation of consciousness, reduced systemic medication exposure, improved postoperative pain control, and a lower incidence of certain complications such as nausea, vomiting, and thromboembolism.[3] Owing to these benefits, epidural anaesthesia is widely used in both elective and emergency surgical settings, as well as in chronic pain management.

The efficacy and safety of the epidural block are critically dependent on the accurate identification of the epidural space.[4] Precise localization ensures that the anaesthetic agent is deposited correctly, facilitating the desired sensory and motor blockade while minimizing the risk of inadvertent complications. Failure to accurately locate the epidural space can lead to inadequate analgesia, failed blocks, repeated attempts, and patient discomfort.[5] Moreover, erroneous needle advancement may result in dural puncture, leading to post-dural puncture headache, or even intrathecal or intravascular injection, with potentially serious consequences. [6]

Traditionally, the epidural space is identified using the loss of resistance (LOR) technique.[7] This involves advancing a Tuohy needle into the intervertebral space while applying gentle pressure to a syringe filled with

International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 4, 2025
https://www.theaspd.com/ijes.php

air or saline. The tactile feedback perceived when the needle enters the epidural space results in a sudden loss of resistance, signalling correct placement. While this method is simple and does not require specialised equipment, it is inherently a blind technique, highly reliant on the experience, judgment, and manual dexterity of the anaesthesiologist. In skilled hands, LOR can be highly effective; however, it is subject to variability and may become unreliable in patients with atypical or difficult spinal anatomy.[8]

Several patient-related factors can complicate the use of LOR. Obesity, for instance, introduces significant challenges in identifying surface landmarks due to the accumulation of adipose tissue and poor visibility of bony structures.[9,10] Similarly, patients with spinal deformities such as scoliosis or those with degenerative changes due to aging or previous spinal surgeries may present altered anatomy that obscures the usual path to the epidural space.[11] In such cases, the practitioner may require multiple attempts, each increasing the risk of patient discomfort, complications, and procedural failure.

In light of these limitations, accurate preprocedural estimation of the depth to the epidural space becomes essential. Knowing the likely depth in advance can guide the selection of appropriate needle length, anticipate technical difficulties, and improve the overall efficiency of the procedure.[12] More importantly, it can help to reduce the number of needle redirections and thereby lower the risk of traumatic complications such as vascular puncture or nerve injury.[13]

Recent advancements in regional anaesthesia have introduced ultrasonography (USG) as a valuable adjunct to traditional landmark-based techniques. Preprocedural ultrasound imaging offers real-time visualisation of the underlying spinal structures, including the spinous processes, laminae, ligamentum flavum, and dura mater.[14] It allows the anaesthesiologist to determine the midline, assess interspinous spaces, and measure the depth from the skin to the epidural space with high precision. By using either the transverse median or paramedian sagittal oblique views, clinicians can identify the posterior complex, which serves as a reliable sonographic marker of the epidural space.[15]

Numerous studies have demonstrated that ultrasound-guided epidural placement improves the accuracy of needle insertion, reduces the number of attempts, increases first-pass success rates, and minimises the incidence of complications.[16,17,18] It is particularly beneficial in patients with high BMI[19], difficult anatomical landmarks,[20] or a history of failed neuraxial blocks.[21] Moreover, ultrasound can also assist in detecting anatomical abnormalities such as calcified ligaments or narrowed interspinous spaces, allowing for better procedural planning.[22]

Despite these advantages, the widespread implementation of ultrasound guidance in epidural anaesthesia faces practical challenges. The availability of high-frequency ultrasound machines, especially in resource-limited settings such as primary health centres and rural hospitals, may be limited.[23] Additionally, the technique requires adequate training and familiarity with spinal sonoanatomy, which may not be universally available among anaesthesiology trainees or general practitioners. As such, while USG is considered the gold standard for accurate depth estimation, alternative approaches remain relevant, particularly in low-resource environments.

To address this gap, several attempts have been made to develop predictive models for estimating the depth to the epidural space using simple anthropometric measurements. Parameters such as height, weight, and BMI have been explored as potential indicators of epidural depth. BMI, in particular, has demonstrated a consistent positive correlation with skin-to-epidural space distance across various populations. This relationship has led to the development of multiple linear regression-based formulas that use BMI as a predictive factor for estimating epidural depth.

One such widely studied formula is:

$$\text{Depth (mm)} = 17.7966 + (0.9777 \times \text{BMI})$$

This equation, derived from prior clinical studies, allows for the estimation of the epidural depth based solely on a patient's BMI, offering a cost-effective, non-invasive, and easily applicable method.[24] The predicted depth can be used to preselect the appropriate length of the Tuohy needle, thereby aiding procedural preparation.

International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 4, 2025
https://www.theaspd.com/ijes.php

Such formulas are especially useful in busy operating theatres or rural setups where time, equipment, and trained personnel may be limited.

However, the utility of BMI-based predictive equations is not without limitations.[25] While these formulas provide a general estimate, they do not account for individual variations in spinal curvature, intervertebral space narrowing, or differences in fat distribution, all of which can influence the actual depth to the epidural space. Additionally, most of these equations are derived from specific population cohorts and may not be universally applicable. For instance, body composition, lifestyle, and genetic predispositions can vary significantly across ethnic groups, affecting the relationship between BMI and spinal anatomy.

In the Indian context, such predictive models have been less extensively validated. Given the unique demographic, nutritional, and lifestyle patterns of the Indian population, it becomes necessary to test the accuracy and reliability of these equations within a local clinical setting. Moreover, the Indian healthcare system encompasses a wide range of facilities, from technologically advanced urban centres to resource-constrained rural clinics. Thus, establishing a practical and accurate method of epidural depth estimation that is both affordable and feasible across these diverse settings is of significant clinical importance.

The present study was therefore designed to evaluate the performance of the BMI-based predictive formula for estimating skin-to-epidural space distance and to compare it with ultrasound-guided measurements in patients undergoing elective surgery. By comparing these two techniques, the study aims to determine whether BMI-based estimations can serve as a reliable alternative in environments where ultrasound is either unavailable or impractical. Therefore, this study was designed to evaluate the accuracy of a BMI-based predictive equation for estimating the depth to the epidural space and to compare it with preprocedural ultrasound-guided measurements in patients undergoing elective surgeries. The goal is to assess whether such a formula can serve as a reliable alternative in settings where ultrasound is unavailable and to better inform clinical decision-making in diverse practice environments.

2. MATERIALS AND METHODS

This prospective, cross-sectional study was conducted in the Department of Anaesthesiology at Sree Balaji Medical College & Hospital, Chennai, following approval from the Institutional Ethics Committee (IEC ref. no. 002/SBMC/IHEC/2020/1451). The study spanned a period of one year and aimed to compare the skin-to-epidural space distance estimated using a BMI-based predictive equation with that obtained through ultrasound guidance in adult patients undergoing elective surgeries under epidural anaesthesia.

A total of 60 adult patients were enrolled in the study after obtaining informed written consent. Each patient underwent a detailed pre-anaesthetic evaluation, including history taking, physical examination, and measurement of anthropometric parameters. Body mass index (BMI) was calculated using the formula: weight in kilograms divided by height in metres squared. This value was used to estimate the predicted depth to the epidural space using the equation: Depth (mm) = 17.7966 + (0.9777 × BMI), which was later converted to centimetres for comparison.

Patients aged between 15 and 80 years, with an American Society of Anesthesiologists (ASA) physical status of I to III, scheduled for elective lower abdominal or lower limb surgeries requiring epidural anaesthesia, were included in the study. Patients requiring emergency surgery, those with ASA physical status IV or above, and individuals with a history of spinal deformities, prior spinal surgery, coagulopathies, local site infection, or bleeding disorders were excluded. Additionally, pregnant women and paediatric patients were not considered for inclusion in this study.

All procedures were conducted with patients in the left lateral decubitus position. The L3–L4 interspace was selected as the site for epidural placement. Ultrasound-guided measurement was used to measure the skin-to-epidural space distance by utilizing a 2–5 MHz curvilinear probe. The transverse median view was used to identify the posterior complex, and the distance from the skin to this point was recorded in centimetres. Ultrasound assessments were performed by a single experienced anaesthesiologist to eliminate inter-observer variation.

In parallel, the predicted depth from the skin to the epidural space was calculated using the BMI-based formula. This calculated depth was also expressed in centimetres, ensuring direct comparability with the ultrasound measurements.
All collected data were analysed using IBM SPSS Statistics version 23.0. The mean ± standard deviation (SD) was used to express continuous variables. The comparison between the ultrasound-measured depth and BMI-predicted depth was performed using a paired t-test. A p-value of less than 0.05 was considered statistically significant.

3. RESULTS

A total of 60 patients who fulfilled the inclusion criteria were enrolled in the study and included in the final analysis. All participants completed the preprocedural assessments and epidural depth evaluations as per the study protocol, with no dropouts or exclusions after enrollment. The primary aim of this investigation was to compare the skin-to-epidural space distance as measured by ultrasound with that estimated using a BMI-based predictive equation. The secondary objective was to assess the correlation between BMI and the ultrasound-measured depth.
The demographic distribution of the study population reflected a diverse adult surgical cohort. The mean age of the patients was 47.2 ± 13.6 years, with the youngest participant being 18 years and the oldest 78 years. This broad age range allowed the inclusion of both younger adults and elderly patients, providing a representative sample of the adult population undergoing elective surgeries (**Table 1, Figure 1**). Gender distribution was relatively balanced, with 32 males (53.3%) and 28 females (46.7%), minimising sex-related confounding in epidural depth variability (**Table 2. Figure 2**).

Table 1. Age wise distribution of study participants

AGE (years)	NUMBER	PERCENTAGE
≤ 39	6	10
40 – 59	36	60
≥ 60	18	30
TOTAL	60	100
MEAN ± SD	**54.0 ± 9.3**	

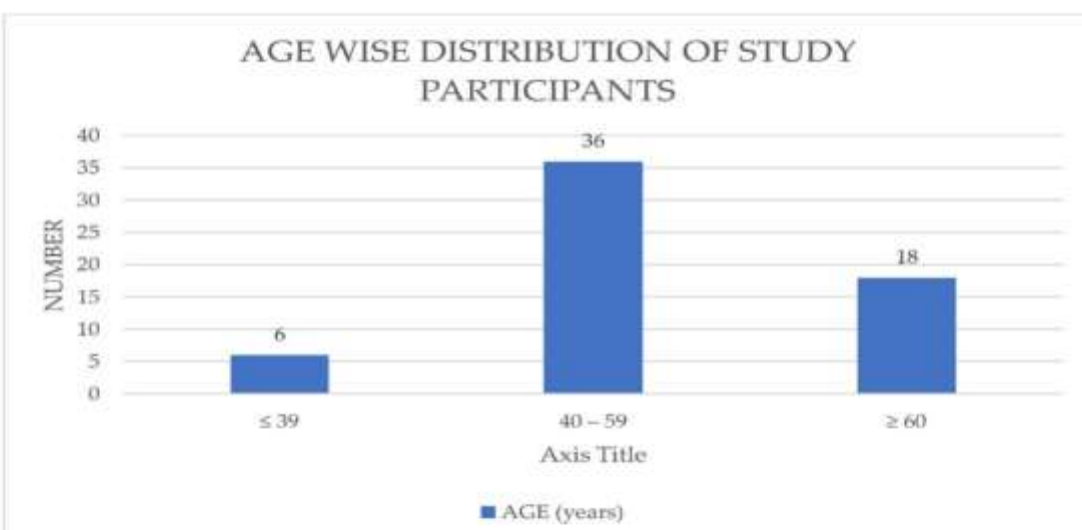

Figure 1. Age wise distribution of study participants

International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 4, 2025
https://www.theaspd.com/ijes.php

Table 2. Gender distribution of study participants

SEX	NUMBER	PERCENTAGE
MALE	45	75
FEMALE	15	25
TOTAL	60	100

Figure 2. Gender distribution of study participants

Patients were classified according to the American Society of Anesthesiologists (ASA) physical status classification system. The majority were in ASA class II (n = 34; 56.7%), followed by ASA class I (n = 18; 30%), and ASA class III (n = 8; 13.3%). No patients with ASA IV or above were included as per the exclusion criteria (**Table 3, Figure 3**).

Table 3. ASA grading among study participants

ASA	Frequency	Percentage
I	49	82
II	6	10
III	5	8
Total	60	100

Figure 3. ASA grading among study participants

Anthropometric measurements were recorded for all participants. The mean body mass index (BMI) was 26.1 ± 2.8 kg/m², with individual values ranging from 20.5 to 32.8 kg/m². The BMI data indicated that a substantial proportion of the study population fell into the overweight category, and a few patients were mildly obese (**Table 4, Figure 4**). This distribution allowed for an adequate evaluation of the BMI-based prediction model across a realistic clinical range.

Table 4. BMI among study participants

BMI	NUMBER	PERCENTAGE
18.5-24.99	20	33.34
25.0-29.99	36	60
30-34.99	4	6.66
TOTAL	60	100
MEAN ± SD	**25.7 ± 3.1**	

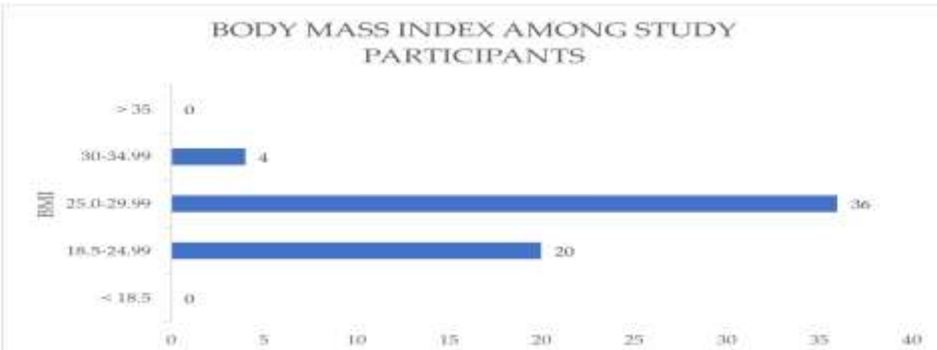

Figure 4. Body Mass Index among study participants

The primary analysis focused on comparing the skin-to-epidural space distance (SED) measured using preprocedural ultrasound and that estimated using the BMI-based formula:

Depth (mm) = 17.7966 + (0.9777 × BMI)

When applied to the BMI values of the participants, the predictive equation yielded an estimated epidural depth ranging from 3.9 cm to 5.0 cm, with a mean value of 4.3 ± 0.3 cm. In contrast, ultrasound-guided measurements of the same distance demonstrated a slightly broader range, from 4.3 cm to 5.2 cm, with a mean of 4.7 ± 0.4 cm. These results revealed a consistent pattern where the BMI-based estimation was lower than the corresponding ultrasound measurement **(Table 5, Figure 5)**.

Table 5. Comparison of mean skin to epidural space distance by BMI and USG guided measurement

Method	Mean distance	SD	P value
USG guided measurement	4.7 cm	0.4	< 0.0001
BMI equation	4.3 cm	0.3	

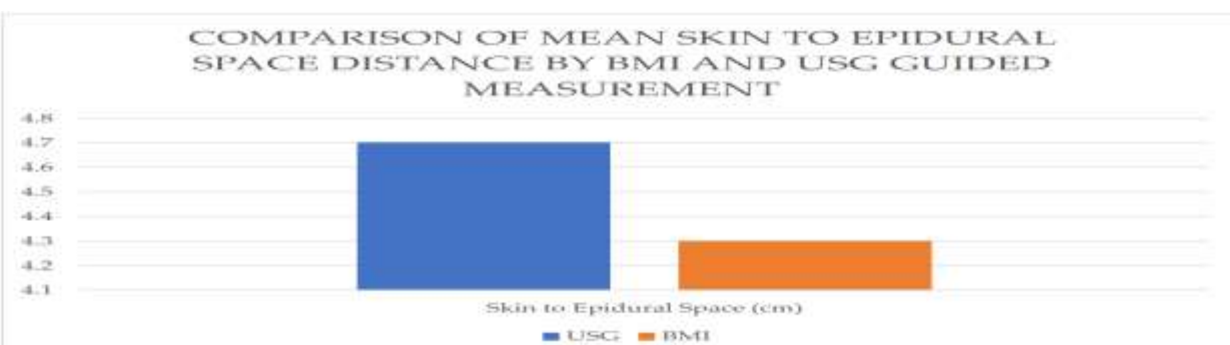

Figure 5. Comparison of mean skin to epidural space distance by BMI and USG guided measurement

To determine the statistical significance of this difference, a paired t-test was conducted between the two sets of measurements. The test yielded a p-value of <0.0001, indicating a highly significant difference between the predictive formula and ultrasound methods. This statistical outcome reinforces that the BMI-based formula consistently underestimated the actual distance to the epidural space when compared with the more accurate ultrasound technique.

Further analysis was conducted to evaluate the relationship between BMI and the ultrasound-measured epidural depth. A positive linear correlation was observed, with increasing BMI associated with an increased depth to the epidural space. This trend confirms the biological plausibility and rationale behind using BMI in predictive models. Higher BMI typically reflects increased adipose tissue, particularly in the lumbar and subcutaneous regions, which logically contributes to an increased needle path length before reaching the epidural space.

A Pearson correlation coefficient was calculated to quantify the strength of this relationship. The coefficient (r) was found to be 0.68, indicating a moderate to strong positive correlation between BMI and actual epidural depth. Although the correlation was statistically significant ($p < 0.01$), it was not perfect, which suggests that other factors—such as individual anatomical variation, fat distribution, vertebral alignment, and posture—may also influence epidural depth.

A subgroup analysis was performed based on BMI categories, dividing patients into normal weight (BMI <25), overweight (BMI 25–29.9), and obese (BMI ≥30). It was observed that the discrepancy between predicted and actual epidural depth widened with increasing BMI. Among normal-weight individuals, the average difference between the two measurements was minimal (~0.2 cm), whereas in the obese group, the underestimation reached up to 0.6 cm in some cases. This trend suggests that the BMI-based formula, although derived to include a range of BMI values, may not perform optimally in individuals at the upper end of the BMI spectrum. All 60 patients underwent ultrasound scanning without any complications. The ultrasound probe was well tolerated, and the imaging was successfully obtained in all patients without the need for rescanning or repositioning. Following the measurement, epidural catheter placement was performed at the same interspace (L3–L4) using standard technique. None of the patients experienced adverse events related to the epidural procedure such as dural puncture, failed block, nerve injury, or local site infection. All catheters were successfully placed, and postoperative analgesia was deemed effective in all cases, although these procedural outcomes were not the focus of this study.

4. DISCUSSION

Epidural anaesthesia is a widely utilised regional technique for both intraoperative and postoperative analgesia in a variety of surgical procedures.[1] Its success hinges on accurate identification of the epidural space. Traditionally, the loss of resistance (LOR) technique has been employed to locate this space.[7] However, LOR is a blind technique and may lead to multiple attempts, failed procedures, or complications, particularly in patients with altered spinal anatomy or increased adiposity. These limitations have driven the search for more reliable, objective, and reproducible methods for estimating the skin-to-epidural space distance (SED).

This study sought to evaluate whether a BMI-based predictive equation could serve as a useful alternative to ultrasound guidance in estimating the SED. The findings demonstrate that although there is a statistically significant correlation between BMI and epidural depth, the predictive equation consistently underestimated the actual depth as measured by ultrasound. The mean SED measured by ultrasound was 4.7 ± 0.4 cm, compared to 4.3 ± 0.3 cm by the BMI formula, with the difference being statistically significant ($p < 0.0001$). These results suggest that while the BMI-based formula offers a general estimate, it lacks the precision of ultrasound and may not be suitable as a standalone method in clinical decision-making.

Several studies have attempted to derive and validate predictive equations to estimate epidural depth using anthropometric variables. Hirabayashi et al. reported a significant correlation between BMI and epidural depth, providing early support for the use of body habitus in predicting needle insertion depth.[26] Similarly, Shiroyama et al.[27] and Kim et al.[28] showed a progressive increase in epidural depth with increasing BMI and weight. The present study aligns with these findings, confirming that BMI positively correlates with SED. However, the use of this correlation in clinical practice must be approached cautiously, as reliance solely on predicted values may result in underestimation, especially in obese patients where even small miscalculations can lead to multiple attempts or inadvertent dural puncture.

Ultrasound imaging offers a solution to the limitations of blind techniques. In this study, ultrasound was used to visualize the L3–L4 interspace and measure the depth to the posterior complex. The benefits of ultrasound-guided neuraxial procedures are well documented, including improved first-pass success rates, fewer needle passes, reduced complications, and enhanced patient satisfaction. Ultrasound allows real-time visualization of spinal structures, aiding in the identification of landmarks that may be impalpable, particularly in obese or elderly individuals.

Despite these advantages, the widespread use of ultrasound is limited in many settings, particularly in resource-constrained environments where equipment may not be available or operators may not be trained. In such situations, a reliable predictive model could serve as a valuable adjunct to clinical judgment. However, the findings of this study suggest that while the BMI-based formula may provide a rough estimate, it cannot replace the accuracy and clinical utility of ultrasound. A key concern is the underestimation of depth, which may lead to the use of shorter-than-required epidural needles or misplacement of the catheter.

One of the notable strengths of this study is its prospective design and standardisation of ultrasound measurements, all of which were performed by a single experienced anaesthesiologist, thereby minimising inter-observer variability. The use of the same spinal interspace (L3–L4) in all patients further adds to the methodological consistency. Moreover, the exclusion of patients with spinal deformities, emergencies, and other confounding conditions allows for a cleaner comparison between the two measurements techniques.

However, this study also has limitations that warrant consideration. The sample size of 60 patients, while adequate for initial comparison, may not capture the full spectrum of variability across different BMI ranges, especially at the extremes. Inclusion of morbidly obese patients or those with very low BMI could have tested the predictive limits of the formula further. Additionally, the study was conducted at a single tertiary care centre, which may limit the generalisability of the findings to broader patient populations or rural healthcare settings where demographic profiles and clinical practices may differ.

Another limitation is that only the preprocedural depth was measured and compared; the actual clinical endpoint—successful epidural catheter placement—was not evaluated. Future studies could assess whether BMI-based predictions correlate with procedural success or complication rates in clinical practice. The study also did not account for variables such as intervertebral space narrowing due to age or degenerative spinal changes, which could independently affect epidural depth.

Despite these limitations, the present study adds to the growing body of evidence supporting the role of preprocedural imaging in neuraxial anaesthesia. It reaffirms that while BMI can be used as a rough indicator of epidural depth, ultrasound remains the superior modality for accurate estimation. In institutions where ultrasound is available, it should be the method of choice, particularly in high-risk or anatomically difficult patients. Where ultrasound is unavailable, BMI-based estimations may serve as a helpful adjunct, but clinicians should remain cautious and use clinical judgement, especially in patients with higher BMI or altered anatomy. In conclusion, the study highlights the importance of individualised patient assessment and the need for ongoing training and resource allocation to expand the use of ultrasound in regional anaesthesia. The integration of both objective predictive models and imaging modalities may offer the best outcomes in terms of safety, efficacy, and patient satisfaction.

5. CONCLUSION

This prospective study involving 60 adult patients undergoing elective surgeries demonstrated that while a BMI-based predictive equation can provide a general approximation of the skin-to-epidural space distance, it significantly underestimates the actual depth when compared to ultrasound-guided measurements. The mean epidural depth measured by ultrasound was 4.7 ± 0.4 cm, compared to 4.3 ± 0.3 cm estimated using the BMI-based formula, with a statistically significant difference ($p < 0.0001$). A moderate to strong positive correlation ($r = 0.68$, $p < 0.01$) between BMI and ultrasound-measured depth confirms the biological plausibility of BMI as a predictor, yet the accuracy of the formula declined in overweight and obese individuals. Importantly, no complications were reported during ultrasound scanning or epidural catheter placement, affirming the procedural safety of both methods. These findings reinforce that ultrasound offers a more accurate, reliable, and reproducible method for estimating epidural depth and should be the preferred modality for preprocedural planning, especially in patients with complex or difficult anatomy. While the BMI-based formula may serve as a useful tool in resource-limited settings where ultrasound is unavailable, it cannot substitute for the precision of ultrasound guidance. Routine use of ultrasound can improve first-attempt success, minimize the number of needle passes, and reduce the risk of complications. We recommend wider adoption of ultrasound in epidural anaesthesia wherever feasible and encourage further research involving larger, more diverse populations to refine anthropometric predictive models for use in settings lacking advanced imaging resources.

7. Source of Funding: None.

8. Conflict of Interest: None.

REFERENCES

1. Gohad R, Jain S. Regional Anaesthesia, Contemporary Techniques, and Associated Advancements: A Narrative Review. Cureus. 2024;16(7).
2. Sultan P, Sultan E, Carvalho B. Regional anaesthesia for labour, operative vaginal delivery and caesarean delivery: a narrative review. Anaesthesia.;76:136-47.
3. Wu Q, Zhi XJ. Intravenous patient-controlled analgesia versus epidural anesthesia in the treatment of patients undergoing total hip arthroplasty: a retrospective comparative study. BMC anesthesiology. 2025;25(1):89.
4. Elsharkawy H, Sonny A, Chin KJ. Localization of epidural space: A review of available technologies. Journal of Anaesthesiology Clinical Pharmacology. 2017;33(1):16-27.
5. Carvalho LP, Agarwal A, Kashiwagi FT, Correa I, Pereira JE, El Dib R. Commonly-used versus less commonly-used methods in the loss of resistance technique for identification of the epidural space: A systematic review and meta-analysis of randomized controlled trials. Journal of Clinical Anesthesia. 2017 May 1;38:41-51.
6. Patel R, Urits I, Orhurhu V, Orhurhu MS, Peck J, Ohuabunwa E, Sikorski A, Mehrabani A, Manchikanti L, Kaye AD, Kaye RJ. A comprehensive update on the treatment and management of postdural puncture headache. Current pain and headache reports. 2020 Jun;24:1-9.
7. Tran DQ, González AP, Bernucci F, Finlayson RJ. Confirmation of loss-of-resistance for epidural analgesia. Regional Anesthesia & Pain Medicine. 2015 Mar 1;40(2):166-73.
8. Carvalho LP, Agarwal A, Kashiwagi FT, Correa I, Pereira JE, El Dib R. Commonly-used versus less commonly-used methods in the loss of resistance technique for identification of the epidural space: A systematic review and meta-analysis of randomized controlled trials. Journal of Clinical Anesthesia. 2017 May 1;38:41-51.
9. Lee JY, Lee SM, Sim WS, Ahn HJ, Park MH, Lim HY, Lee SH, Kim YR, Kim YI, Bang YJ. False loss of resistance in cervical epidural injection: the loss of resistance technique compared with the epidrum guidance in locating epidural space. Pain physician. 2016;19(3):131.
10. Arici T. An operator's experience of the loss-of-resistance technique in epidural injections: an observational study. The Eurasian Journal of Medicine. 2021 Feb;53(1):48.
11. Fehlings MG, Kato S, Lenke LG, Nakashima H, Nagoshi N, Shaffrey CI, Cheung KM, Carreon L, Dekutoski MB, Schwab FJ, Boachie-Adjei O. Incidence and risk factors of postoperative neurologic decline after complex adult spinal deformity surgery: results of the Scoli-RISK-1 study. The Spine Journal. 2018 Oct 1;18(10):1733-40.
12. Nada E. Predictors of Epidural Depth and the Role of Technology. Current Anesthesiology Reports. 2024 Dec;14(4):616-27.
13. Elsharkawy H, Sonny A, Chin KJ. Localization of epidural space: A review of available technologies. Journal of Anaesthesiology Clinical Pharmacology. 2017 Jan 1;33(1):16-27.
14. Barrett NM, Arzola C, Krings T, Downey K, Carvalho JC. Lumbar spine anatomy in women sustaining unintentional dural puncture during labor epidural placement: a descriptive study using magnetic resonance imaging and ultrasound. Regional Anesthesia & Pain Medicine. 2018 Jan 1;43(1):92-6.
15. Choi YS, Jang J, Kim HY, Lee B, Kim EJ, Yoon HJ, Lee J, Kim HJ. Ultrasound estimates of the epidural depth in the paramedian sagittal oblique and transverse median planes: the correlation between estimated and actual depth to the epidural space in children with scoliosis. Regional Anesthesia & Pain Medicine. 2024 Dec 1;49(12):883-8.
16. Tao B, Liu K, Ding M, Xue H, Li X, Zhao P. Ultrasound increases the success rate of spinal needle placement through the epidural needle during combined spinal-epidural anaesthesia: A randomised controlled study. European Journal of Anaesthesiology| EJA. 2021 Mar 1;38(3):251-8.

17. Tawfik MM, Atallah MM, Elkharboutly WS, Allakkany NS, Abdelkhalek M. Does preprocedural ultrasound increase the first-pass success rate of epidural catheterization before cesarean delivery? A randomized controlled trial. Anesthesia & Analgesia. 2017 Mar 1;124(3):851-6.
18. Zhang Y, Peng M, Wei J, Huang J, Ma W, Li Y. Comparison of ultrasound-guided and traditional localisation in intraspinal anesthesia: a systematic review and network meta-analysis. BMJ open. 2023 Nov 1;13(11):e071253.
19. Zhou Y, Chen W, Zhou S, Tao Y, Xu Z, Liu Z. Comparison of different approaches to combined spinal epidural anesthesia (CSEA) under the guidance of ultrasound in cesarean delivery of obese patients: a randomized controlled trial. European Journal of Medical Research. 2021 Dec;26:1-8.
20. Pakpirom J, Thatsanapornsathit K, Kovitwanawong N, Petsakul S, Benjhawaleemas P, Narunart K, Boonchuduang S, Karmakar MK. Real-time ultrasound-guided versus anatomic landmark-based thoracic epidural placement: a prospective, randomized, superiority trial. BMC anesthesiology. 2022 Jun 25;22(1):198.
21. Perlas A, Chaparro LE, Chin KJ. Lumbar neuraxial ultrasound for spinal and epidural anesthesia: a systematic review and meta-analysis. Regional Anesthesia & Pain Medicine. 2016 Mar 1;41(2):251-60.
22. Guirguis MA, Das SS, White WK, Patterson ME. Ultrasound-Guided Spinal Procedures. The Ultimate Guide to Point-of-Care Ultrasound-Guided Procedures. 2020:237-49.
23. Ashoor TM, Zain EM, Reyad MK, Hasseb AM, Esmat IM. Ultrasound-guided techniques for perioperative analgesia in pediatric lower abdominal surgeries: quadratus lumborum block with bupivacaine versus caudal bupivacaine and neostigmine. Pain Physician. 2023;26(2):137.
24. Ravi KK, Kaul TK, Kathuria S, Gupta S, Khurana S. Distance from skin to epidural space: correlation with body mass index (BMI). Journal of Anaesthesiology Clinical Pharmacology. 2011 Jan 1;27(1):39-42.
25. Nickerson BS, Esco MR, Bishop PA, Fedewa MV, Snarr RL, Kliszczewicz BM, Park KS. Validity of BMI-based body fat equations in men and women: a 4-compartment model comparison. The Journal of Strength & Conditioning Research. 2018 Jan 1;32(1):121-9.
26. Hirabayashi Y, Matsuda I, Inoue S, Shimizu R. The distance from the skin to the epidural space. Journal of anesthesia. 1988 Sep;2:198-201.
27. Shiroyama K, Izumi H, Kubo T, Nakamura R. Distance from the skin to the epidural space at the first lumbar interspace in a Japanese obstetric population. Hiroshima journal of medical sciences. 2003 Jun 1;52(2):27-30.
28. Kim K, Recku G, Fluder E, Corsino A. The distance from the skin to the epidural space in morbidly obese patients undergoing bariatric surgery. Reg Anaesth Pain Med. 2003;28:A4.