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Research Article

ULTRASONOGRAPHY AS AN INTRAOPERATIVE TOOL FOR LOCALIZATION OF THE ANATOMICAL LEVEL IN LUMBOSACRAL SPINE SURGERIES

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ABSTRACT

Objectives: The aims and objectives of the study are to find the effectiveness of ultrasound as a pre-operative adjunct to localize the anatomical intervertebral level of interest and study its accuracy by comparing it with the gold standard intra-operative fluoroscopy and to study factors affecting localization of anatomical vertebral level by ultrasound.

Methods: This was a prospective study conducted in the Department of Neurology Department of Neurosurgery and Neuroimaging and Interventional Radiology, NIMHANS Hospital, Bengaluru, over a period of 1 year. 50 cases of lumbosacral degenerative diseases were included in this study on the basis of pre-defined inclusion and exclusion criteria. All patients underwent ultrasonography of the lumbosacral spine followed by pre-operative X-ray of the lumbosacral spine using the C-ARM. The accuracy of good localization of the desired level of the lumbosacral spine by ultrasound as compared to X-ray was determined. $p<0.05$ was taken as statistically significant.

Results: There were 22 (44%) males and 28 (56%) females with a M: F ratio of 1:1.27. The mean age was 46.7±13.5 years. 46 (92%) cases were diagnosed with prolapsed intervertebral disc (PIVD) and 4 (8%) cases with Grade II spondylolisthesis radiologically. Good localization which constitutes exact localization, close upper, and close lower localization added up to 82% of the cases (41/50) and the rest 18% were tagged as poor localization (9/50). The accuracy of good localization in both the groups of PIVD and spondylolisthesis (listhesis) was 82.6% and 75%, respectively.

Conclusion: Ultrasound can be used as an exceptionally good and accurate method of localizing the anatomical intervertebral level for patients undergoing various lumbosacral spinal surgeries.

Keywords: Ultrasound, Lumbosacral surgeries, Accuracy, Spondylolisthesis.

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INTRODUCTION

The advent of ultrasonography in the medical field has brought about significant advancements in various specialties, including neurosurgery. While the utility of ultrasound in guiding lumbar punctures and neuraxial blocks has been explored extensively, its potential as an intraoperative tool for localizing anatomical levels in lumbosacral spine surgeries remains an underutilized and unexplored aspect [1]. Improved visualization of lumbosacral anatomy, one of the fundamental pre-requisites for successful lumbosacral spine surgery is a comprehensive understanding of the intricate anatomical structures in this region. Ultrasonography provides a non-invasive and radiation-free means to visualize these structures with remarkable clarity. In addition to identifying the lamina and ligamentum flavum, ultrasonography can also delineate the spinal canal, vertebral bodies, and even the intervertebral disc space. This improved visualization enhances the surgeon's ability to precisely plan and execute surgical procedures, potentially reducing the risk of complications [2].

The first report of ultrasound-guided lumbar puncture was published in the Russian literature in 1971 [3]. Since then, there has been an increasing number of anesthesia-related publications on pre-procedural ultrasound examination of the lumbar spine in the successful insertion of a spinal or epidural needle [4]. Recent studies are thriving to prove that neuraxial ultrasound is useful when performing central neuraxial blocks by reducing the technical difficulties of the procedure, the risk of traumatic injuries to the neural structures, and post-procedural complications [5]. Although this is an interesting area of development, these are still experimental and highly challenging techniques, the clinical benefits of which have not been formally established [6].

Ultrasound examination of the lumbar spine is undoubtedly based on sound and thorough knowledge of the anatomy of the lumbar vertebrae, surrounding tissue structures, and the contents of the canal [7]. The ultrasonographic visualization of structures encased within the bony vertebrae in adults is a possibility through the interlaminar and interspinous spaces between the adjacent vertebrae. Although the ultrasonographic images in the past were of poor quality by today's standards, they were able to define the lamina, ligamentum flavum, spinal canal, and vertebral body. Hence, with today's modern development in ultrasound techniques, it should be feasible to visualize these and other structures like disc space. [8].

Ultrasonography is cheap, easily available, saves time with no exposure of radiation to the patient and the medical staff, and can be used effectively by spine surgeons, yet remains underused in spinal procedures at many neurosurgical institutions. The effectiveness and accuracy of ultrasonographic localization of the anatomical level in the lumbosacral spine and its verification against a more established gold-standard imaging modality still remain underappreciated and unaddressed with a paucity of adequate published literature among the surgical fraternity. Hence, this study was undertaken specifically to delineate the use of ultrasound as a pre-operative adjunct to localize the anatomical intervertebral level of interest and study its accuracy by comparing it with the gold standard intra-operative fluoroscopy [9].

Many randomized controlled trials have delved into the promising domain of utilizing ultrasonography as a pre-operative adjunct to precisely locate the intervertebral level of interest during lumbosacral spine surgeries [10]. We conducted this study to compare its accuracy with the gold-standard intra-operative fluoroscopy; moreover,

this study seeks to shed light on the potential clinical benefits of incorporating ultrasound into this specialized surgical context.

METHODS

This prospective study was carried out in the Department of Neurosurgery and Neuroimaging and Interventional Radiology, NIMHANS Hospital, Bengaluru, during the study period of 1 year. The sample size was calculated on the basis of pilot studies done on the topic of localization of intervertebral level of interest during lumbosacral spine surgeries assuming 90% power and 95% confidence interval, and the sample size required is 45 patients. Based on central limit theorem, sample size was determined to be enough if it was more than 45, and thus, we included 50 patients in our study. Cases of lumbosacral degenerative diseases were selected for the study irrespective of age and sex on the basis of pre-defined inclusion and exclusion criteria. Permission of ethical committee and informed consent of each patient was taken in a written format in English and the local language. Patients with clinical and radiological evidence of lumbosacral degenerative disease posted for surgery or epidural steroid injections underwent a detailed history, clinical examination, and routine pre-operative blood investigations.

All 50 cases recruited in this study underwent ultrasonography of the lumbosacral spine by a single examiner, ultrasonographic localization of the level of interest using ultrasound followed by pre-operative X-ray of the lumbosacral spine using the C-ARM after placing a radio-opaque marker at the site of interest determined by the ultrasound.

All cases planned for surgical intervention and epidural injection underwent ultrasonography of the lumbosacral spine on the day of operation or 1 day before the proposed date of surgery. The patient was placed in a prone position and the back was exposed from the level of the natal cleft up to the inferior angle of the scapula with one hard pillow placed below the abdomen. A keen inspection and palpation of the exposed back were then done to rule out any neurocutaneous markers like a tuft of hair or a visible sinus over the lumbosacral region.

A curved array low-frequency probe of 3–5 MHz was used because of deeper penetration and wider field of view. An initial depth setting of 9 cm was adequate for many of the patients, and the depth settings and gain settings of the ultrasound machine were adjusted as needed during the scanning process. The level of interest was marked transversely by a thin ball point marker after studying the lumbosacral spine in 5 views sonographically parasagittal transverse process view, articular process view and oblique view, and transverse spinal process view and interlaminar view. This marked level was then confirmed with a radio-opaque marker by fluoroscopy in the operation theater/intervention suite in the prone position just before the incision. Based on the above comparison, all the X-ray images of the cases included in this study were analyzed by an experienced neuroradiologist at our institution which allowed each case to be categorized in one of the following headings. From surgical point of view, these cases were further divided into good localization which constituted exact and close localizations or poor localization which constituted far and very far localizations (Fig. 1 and Table 1).

The soft-tissue thickness which was recorded in every X-ray was the height in centimeters measured from the skin surface up to the tip of the spinous process of the upper vertebral body involved in the level of interest. Statistical analysis was done using SPSS version 21.0 software. Quantitative data were presented as mean and standard deviation. Qualitative data were presented with incidence and percentage tables. For quantitative data, unpaired t-test was applied and for qualitative data, Chi-square test was used. $p<0.05$ was taken as statistically significant.

Inclusion criteria

1. Clinically symptomatic and radiologically evident cases of lumbosacral degenerative diseases such as prolapsed intervertebral disc (PIVD) disease or spondylolisthesis planned for surgical intervention or epidural steroid injection.

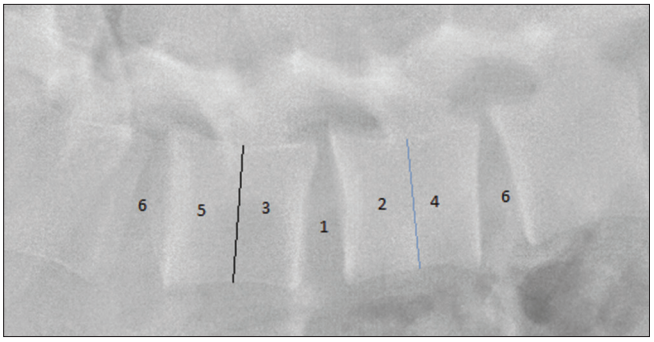

Fig. 1: Depicting the method of analysis of X-ray

Exclusion criteria

1. Previously operated cases on the lumbosacral spine and adjacent regions.
2. History of current or previously diagnosed congenital or acquired diseases (infectious, neoplastic, or traumatic) of the lumbosacral spine.
3. Incomplete imaging of the spine.
4. Medically managed cases who refused to give consent for any surgical intervention.
5. Occult neurocutaneous markers of spinal dysraphism and anatomical variants such as lumbarization or sacralization of vertebrae.

RESULTS

Out of 50 studied cases of lumbosacral degenerative diseases, there were 22 (44%) males and 28 (56%) females with a M: F ratio of 1:1.27. The most common affected age group was found to be between 41 and 50 years (56%) followed by 31–40 (24%). The mean age was 46.7±13.5 years (range: 23–81 years) (Table 2).

Out of the 50 studied cases, 46 cases were diagnosed with PIVD and 4 cases with Grade II spondylolisthesis radiologically. The most common level marked was L4-L5 level which constituted 24/50 cases (48%), followed by L5-S1 constituting 21/50 cases (42%), only 5/50 cases involving the L3-L4 level (10%) (Table 3).

After analyzing the 50 X-rays and dividing into different categories, ultrasound could exactly localize the given intervertebral disc level in 50% of the cases (25/50 cases), it localized to the lower half of the corresponding upper vertebral body in 16% of the cases (8/50 cases), to the upper half of the corresponding lower vertebral body in 16% of the cases (8/50 cases), to the upper half of the corresponding upper vertebral body in 2% of the cases, and to the lower half of the corresponding lower vertebral body in 8% of the cases. In 8% of cases, the localization was either one level above or below the level of interest. In surgical interest, good localization which constitutes exact localization, close upper and close lower localization added up to 82% of the cases (41/50) and the rest 18% were tagged as poor localization (9/50) (Fig. 2).

The accuracy of good localization in both the groups of PIVD and spondylolisthesis (listhesis) was 82.6% and 75%, respectively, hence suggesting that there is no prominent effect of the type of lumbosacral degenerative disease on the localization of the desired level by ultrasound (Table 4).

The accuracy of ultrasound localization of different levels of the lumbosacral spine was also studied. The highest accuracy of exact and good localization was seen at the L4-L5 level with rates of 70.8% and 91.7%, respectively. The lowest accuracy was seen at the L3-L4 level with exact and good localization rates of 20% and 60%, respectively. At

Table 1: ???

Localization	Type of localization	Imaging features
Good localization	Exact localization	When the marker exactly corresponded the disc space of interest.
	Close upper localization	When the marker corresponded between the inferior end plate of the upper vertebral body adjacent to the disc space of interest and the mid-point of the height of the same vertebral body.
	Close lower localization	When the marker corresponded between the superior end plate of the lower vertebral body adjacent to the disc space of interest and the mid-point of the height of the same vertebral body.
Poor localization	Far upper localization	When the marker corresponded between the superior end plate of the upper vertebral body adjacent to the disc space of interest and the mid-point of the height of the same vertebral body.
	Far lower localization	When the marker corresponded between the inferior end plate of the lower vertebral body adjacent to the disc space of interest and the mid-point of the height of the same vertebral body.
	Very far localization	When the marker corresponded beyond one full vertebral body height adjacent to the disc level of interest.

Table 2: Gender distribution and age in the studied cases

Age	No of cases	Percentage
Gender		
Males	22	72.50
Females	28	27.50
Total	50	100.00
Age		
18–30 years	3	6.00
31–40 years	12	24.00
41–50 years	28	56.00
Above 50	7	14.00
Total	50	100.00

Mean age=34.86±8.25 years

Table 3: Radiological diagnosis and marked level in studied cases

Age	No of cases	Percentage
Radiological diagnosis		
Prolapsed intervertebral disc	46	92
Grade II spondylolisthesis	4	8
Total	50	100.00
Level marked		
L4-L5	24	48.00
L5-S1	21	42.00
L3-L4	5	10.00
Total	50	100.00

Table 4: Accuracy of localization with respect to pathology

Accuracy of localization	X-ray		Total (%)
	Good	Poor	
Diagnosis			
Listhesis count (%)	3 (75)	1 (25)	4 (8)
PIVD count (%)	38 (82.6)	8 (17.4)	46 (92)
Total	41 (82)	9 (18)	50 (100)

p=0.5603 (not significant). PIVD: Prolapsed intervertebral disc

the L5-S1 level, the accuracy rates of exact and good localization were 33.3% and 76.2%. This finding was statistically significant (p=0.016, Mann–Whitney U test), hence indicating that correct localization of the L4-L5 level by ultrasound is technically more possible and easier than the other levels (Table 5).

The soft-tissue thickness of each case was recorded and analyzed. In the 41 cases where the ultrasound localization of the desired level had a good localization as seen on X-ray, the mean soft-tissue thickness was 2.1 cm (±1.1, range –0.4–5.5).

On the other hand, in the 9 cases where the ultrasound localization of the desired level was poor as seen on X-ray, the mean soft-tissue thickness was 1.6 cm (±0.8, range –0.4–3.0), indicating that soft-tissue thickness might not have a role in the accurate localization of the level in lumbosacral spine by ultrasound.

Table 5: Accuracy of localization with respect to vertebral level

Accuracy of localization	X-ray		Total (%)
	Good	Poor	
Diagnosis			
L3-L4 count (%)	3 (60)	2 (40)	5 (100)
L4-L5 count (%)	22 (91.7)	2 (8.3)	24 (100)
L5-S1 count (%)	16 (76.2)	5 (23.8)	21 (100)
Total	41 (82)	9 (18)	50 (100)

(p=0.016, Mann–Whitney U test)

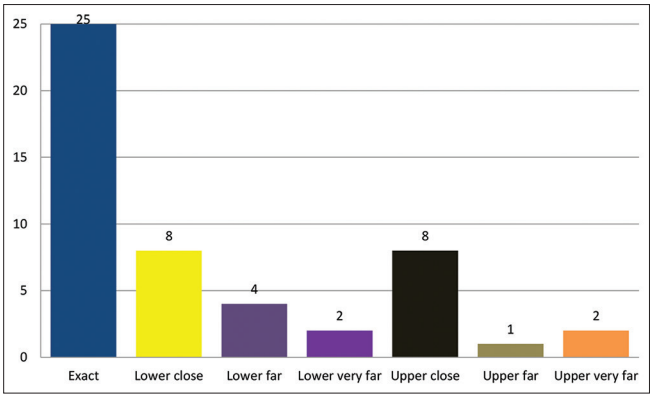

Fig. 2: Accuracy of localization on ultrasound examination

The accuracy of good localization of the desired level of the lumbosacral spine by ultrasound was 80% in the first 25 cases performed in this study, progressively increased to an accuracy level of 84% in the second 25 cases performed by the same examiner, which was insignificant statistically.

DISCUSSION

The utilization of ultrasonography as an intraoperative tool for localizing the anatomical level in lumbosacral spine surgeries is a topic of great significance within the field of neurosurgery [11]. The comparison between ultrasonography and X-ray revealed a high degree of concordance between the two methods, suggesting that ultrasonography can serve as a viable alternative to X-ray in many cases [12]. This finding is particularly significant as it addresses concerns about the potential for errors and complications arising from the use of traditional X-ray. The high accuracy and reliability of ultrasonography can be attributed to several factors [13]. First, modern ultrasound technology offers improved image quality and resolution, allowing for clear visualization of relevant anatomical structures. Second, the real-time nature of ultrasound provides dynamic feedback

to the surgeon, enabling adjustments during surgery, which is not possible with static fluoroscopy images. Finally, the absence of ionizing radiation in ultrasonography minimizes health risks for both patients and surgical staff [14].

In this study, the rate of exact and good localization was the highest for L4-L5 level, moderate for L5-S1 level, and lowest for L3-L4 level with a significant statistical difference between them (p=0.016, Mann–Whitney *U*-test). Furness *et al.* studied the accuracy of ultrasonographic localization of different levels of the lumbosacral spine individually, the rates being 60% for L2-L3 level and 71% each for L3-L4 and L4-L5 levels with no cases of L5-S1 mentioned in his study [15]. The above values are in concordance with the study mentioned above, indicating the higher technical feasibility, better visualization, and a more accurate localization of L4-L5 level with ultrasound. The relatively a smaller number of cases affecting L3-L4 level may be the reason for the lowest accuracy of localization of L3-L4 level, this being adjacent to the L4-L5 level with similar anatomy, theoretically, should not significantly differ. Similar accuracy of ultrasonographic localization of different levels was also reported by authors such as Requeijo *et al.* [16] and Lee *et al.* [17].

Although there is no direct evidence to prove the negative impact of excess fat and muscle tissues intervening with the anatomical structures of the spine and the ultrasound beam on visualization and accurate localization, a few studies do mention the negative role of a phase aberration effect that results from the varying speed of sound passing through irregularly placed soft-tissue layers; nevertheless, clinical studies done by Chin *et al.* [18] and Balki *et al.* [19] have shown advantages of ultrasound in obese cases too. In this study, the thickness of soft-tissue overlying the spinous processes of the lumbosacral spine failed to make an impact on the accuracy of localization of the intervertebral level which is in agreement with the findings of the above-mentioned studies.

Achieving adequate competency in performing a complete ultrasound study of the lumbar spine within a short time and the technical difficulties faced by trained physicians in transferring their knowledge of ultrasound assessment of the lumbar spine to the ones not exposed to this procedure have been now identified as a limitation of using ultrasound in lumbar procedures [19]. A steep learning curve and the necessity of performing the procedure on multiple patients for attaining a satisfactory result of the outcomes have become the need of the hour. A pilot study published by Halpern *et al.* who recognized that 2 anesthesiologists, both individually required 36 and 22 patients to be studied, respectively, to be able to identify the designated spinous process of the lumbar spine correctly 90% of the time [20].

In this study, the accuracy of good localization in the first half of the cases was 80%, steadily rising to 84% in the second half. On further analyzing, the accuracy of exact localization in the first half of the cases was 40% steadily rising to 60% in the second half with no statistical significance. The reason for the high accuracy rate of good localization in the first half may be the effect of the ultrasound studies of the lumbosacral spine done on 10 healthy volunteers before starting the study, the inputs from the Consultant and Resident of Neuroradiology who are experienced in the techniques of ultrasound and the gradual familiarity of the ultrasonic anatomy with increasing number of cases.

Limitations of the study

X-ray and ultrasound examinations were done at 2 different places and sometimes on different occasions. Differences in positioning may have given rise to the additional error of localization. This was the important limitation of our study.

CONCLUSION

The accuracy of good surgical localization of the desired level of the lumbosacral disc space using ultrasound was 82%. Hence, it may be safely used for the same in experienced hands. The accuracy of localizing the L4-L5 disc level by ultrasound is 91%, indicating technical feasibility and better visualization of L4-L5 level with ultrasound. With proper training and experience in ultrasound techniques, neurosurgeons/spine surgeons have an incredible potential to open doors to a plethora of indications, advantages, and uses in future spine surgery.

CONFLICT OF INTEREST

None.

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