Title
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Journal
Anesthesia & Analgesia, 124(5)

ISSN
0003-2999

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Publication Date
2017-05-01

DOI
10.1213/ane.0000000000001839

Peer reviewed

Published in final edited form as:
Anesth Analg. 2017 May ; 124(5): 1678–1685. doi:10.1213/ANE.0000000000001839.

Assessing the Agreement between Radiologic and Clinical Measurements of Lumbar and Cervical Epidural Depths in Patients Undergoing Prone Interlaminar Epidural Steroid Injection

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Did a Section Editor solicit this submission? No

IRB: University of California Davis Medical Center

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This manuscript was screened for plagiarism using Plagiarisma.

integrity of the original data and the analysis reported in this manuscript. Conflicts of Interest/ Financial Disclosure: None

Abstract

Background—Fluoroscopy-guided epidural steroid injection (ESI) is commonly performed to treat radicular pain, yet can lead to adverse events if the needle is not advanced with precision.[1, 2, 3] Accurate preoperative assessment of the distance from the skin to the epidural space holds the potential for reducing the risks of adverse effects from ESI. It was hypothesized that the distance from the skin to the epidural space as measured on preoperative magnetic resonance imaging (MRI) would agree with the distance traveled by a Touhy needle to reach the epidural space during midline, interlaminar ESI. This study compared the final needle depth measurement at the point of loss of resistance (LOR) from cervical or lumbar ESI to the distance from the skin to the anterior and posterior borders of the epidural space on the associated cervical and lumbar preoperative MRI.

Methods—This retrospective chart review analyzed the procedure notes, MRI, and demographic data of patients who received a prone, interlaminar ESI at an outpatient chronic pain clinic between June 1, 2013 and June 1, 2015. The following data were collected: BMI, age, gender, intervertebral level of the ESI, and LOR depth. We then measured the distance from the skin surface to the anterior border of the ligamentum flavum (ligamentum flavum depth, or LFD) and dura (dura depth, or DD) on MRI. A total of 335 patients were categorized into the following patient subgroups: age ≥ 65 years, age < 65 years, BMI ≥ 30 kg/m^2 (obese), BMI < 30 kg/m^2 (non-obese), male, and female. Secondary analyses were then performed to compare the agreement between LOR depth and DD with that between LOR depth and LFD within each patient subgroup. Intra-class correlation coefficient (ICC) and Bland-Altman plot were used to assess the agreement between DD or LFD and LOR depth.

Results—Data from 335 ESIs were analyzed, including 147 cervical ESIs and 188 lumbar ESIs. Estimated ICC values for the agreement between LOR depth and LFD for all lumbar and cervical measurements were 0.88 (95% CI 0.85 – 0.91) and 0.72 (95% CI 0.64 – 0.79), respectively. Estimated ICC values for the agreement between LOR depth and DD for all lumbar and cervical measurements were 0.86 (95% CI 0.82 – 0.89) and 0.69 (95% CI 0.60 – 0.77), respectively.

Conclusions—This study assessed the agreement between MRI-derived measurements of epidural depth and those determined clinically. MRI-derived measurements from the skin to the anterior border of the ligamentum flavum, which represents the most posterior aspect of the epidural space, revealed stronger agreement with LOR depths than did measurements to the dura, or the most anterior aspect of the epidural space. These results require further analysis and refinement before supporting clinical application.

Introduction

Epidural steroid injection (ESI) is commonly performed under fluoroscopic guidance to treat radicular pain.[1, 2] Patients are usually awake, remain in the prone position, and are exposed to radiation throughout the procedure. Inaccurate needle passage and steroid deposition into the subarachnoid space may lead to serious complications including post-dural puncture headache, arachnoiditis, and spinal cord injury, among others.[3] Accurate preoperative assessment of the distance a needle must travel to reach the epidural space holds the potential for reducing risks, as well as improving outcomes related to procedure time, radiation exposure, and patient comfort.

Prior reports have commented on the use of imaging modalities to facilitate the placement of epidural catheters.[4, 5, 6, 7] Carnie et al demonstrated that preoperative chest CT can be used to predict the distance traveled by a Touhy needle to reach the epidural space.[5] This study was limited to thoracic epidural analgesia in patients undergoing thoracotomy. Franklin et al utilized MRI to measure the distance from the skin to the lumbar epidural space in children.[6] Based on these measurements, they created a formula to predict the epidural depth. However, their radiologic measurements were not compared to clinical measurements of epidural depth. Similarly, Zhao et al utilized MRI to measure the distance from the skin to the cervical and high thoracic epidural spaces in adults, yet did not compare their MRI measurements to clinical measurements of epidural depth.[7]

The agreement between MRI measurements of epidural depth and the clinical determination of epidural depth via the loss of resistance (LOR) technique in patients undergoing prone ESI has not been investigated. This report assessed the agreement between LOR depths and radiologic measurements to the anterior and posterior borders of the cervical and lumbar epidural spaces on preoperative MRI. The anterior border of the epidural space was defined as the distance from the skin surface to the dura (recorded as the dura depth, or DD). The posterior border of the epidural space was defined as the distance from the skin surface to the anterior border of the ligamentum flavum (recorded as the ligamentum flavum depth, or LFD). Secondary analyses were performed to compare the agreement between LOR depth and DD with that between LOR depth and LFD within each of the following patient subgroups: age ≥ 65 years, age < 65 years, BMI ≥ 30 kg/m^2 (obese), BMI < 30 kg/m^2 (non-obese), male, and female.

Methods

Study Design

This retrospective chart review was approved by the Institutional Review Board (IRB) at the University of California, Davis, and performed at an affiliated chronic pain clinic in Sacramento, CA. The requirement for written informed consent was waived by the IRB.

We reviewed cervical and lumbar ESIs performed by pain management fellows and attending physicians between June 1, 2013 and June 1, 2015. A unique subject code (1, 2, 3, etc) was assigned to each patient, and only one ESI was reviewed for each patient. The Electronic Medical Record (EMR) was accessed and demographic data (BMI, age, and gender) were recorded.

Each of the following inclusion criteria was met by all patients: preoperative cervical or lumbar MRI performed at the UC Davis Medical Center and available for review in the EMR; midline, interlaminar cervical or lumbar ESI performed at the UC Davis Medical Center, and intra-operative fluoroscopy images with epidurogram available for review in the EMR; patient age greater than 18-years-old; and BMI calculated with height and weight recorded on the ESI procedure date. Exclusion criteria included the following: paramedian approach to the epidural space described in the procedure note or determined by the reviewer during data collection via the analysis of fluoroscopy images; transforaminal injection; and poor MRI quality, which was subjectively determined by the reviewer based on overall clarity, ability to identify the skin surface, and excessive patient rotation limiting the ability to define the midline on sagittal images. Furthermore, only closed MRI were analyzed in this study, as opposed to open, upright MRI. Subjects were not excluded based on the length of time that had transpired from the date of the MRI to the date of the procedure. If a patient had more than one MRI available for review in the EMR, only the preoperative MRI closest to the procedure date was reviewed for this study. Past medical history was not reviewed and patients were not excluded based on spinal pathology or surgical hardware seen on MRI.

The intervertebral level of the injection (such as C7-T1, L4-L5, etc.) and the LOR depth were recorded from the ESI procedure note within the EMR. Appropriate epidural placement of either a 20 gauge, 3.5 inch Touhy needle or an 18 gauge, 6 inch Touhy needle was confirmed in all patients via epidurography at the time of the ESI utilizing approximately 1 ml of either Iohexol 1 mg/ml or gadolinium-based contrast medium. Midline placement of the Touhy needle was again confirmed during data collection for this study by analyzing the saved fluoroscopy images.

Study subjects were grouped based on either lumbar or cervical location of the ESI. These subjects were then further categorized based on age (< 65 years or ≥ 65 years), BMI (< 30 kg/m^2 or ≥ 30 kg/m^2, corresponding to obesity class I and above), and gender (male or female) to perform secondary analyses comparing the agreement between LOR depth and DD with that between LOR depth and LFD within each patient subgroup.

MRI Measurements

The most recent preoperative MRI available on the date of the procedure was identified. Images were accessed via the (Philips) iSite Enterprise Standard URL Based Integration (SUBI) Window.[a]

All measurements from MRI were made by one investigator, who was trained on this measurement by a board-certified neuroradiologist. In each case, analysis proceeded in the following order: the sagittal and axial T1-weighted MRI sets were identified, magnified, and placed side-by-side on the computer monitor; the “scout line mode” was selected for each image to allow simultaneous navigation through both windows; navigation continued until the scout line on the axial image was aligned with the spinous process cephalad to the desired intervertebral space; the corresponding sagittal image was identified as the patient’s midline.

On the sagittal image, a straight line was drawn from the skin surface to the anterior border of the ligamentum flavum, which represents the most posterior aspect of the epidural space

[a]http://www.medical.philips.com/pwc_hc/ch_fr/products/healthcare_informatics/products/enterprise_imaging_informatics/isite_pacs/isite_radiology/index.wpd. Accessed December 7, 2015.

and where LOR occurs, and recorded as the LFD. The use of T1-weighted MRI images created a distinct contrast between the dark ligamentum flavum and bright epidural fat, thus allowing for precise measurement to the posterior border of the epidural space, even in the presence of variability in ligamentum flavum continuity in the cervical epidural space. A second, straight line was then drawn from the skin surface to the dura, which represents the most anterior aspect of the epidural space, and recorded as the DD. All MRI measurements were recorded to the nearest one-hundredth centimeter. Figures 1 and 2 exemplify these measurements on lumbar and cervical MRI, respectively.

Validation of Methods

Inter-rater reliability was assessed by comparing measurements of epidural depth on preoperative MRI that were collected by two investigators: an anesthesia resident physician (post-graduate year 4 level) and a board-certified neuroradiologist. While the resident physician collected data on all subjects, the neuroradiologist randomly selected 51 lumbar MRI and 50 cervical MRI of patients who underwent ESI, and measured the LFD and DD for the studied intervertebral levels utilizing the same protocol as did the resident physician. The intra-class correlation coefficient (ICC) was used to quantify the agreement between the MRI measurements taken by these two investigators.

Statistical Analysis

The agreement between DD or LFD and LOR depth was analyzed with consideration to the entire cohort and patient age (< 65 years or ≥ 65 years), BMI (< 30 kg/m^2 or ≥ 30 kg/m^2), and gender (male or female) with ICC and Bland-Altman plot.[8] The p-values for comparing the expected ICC for the agreement between LOR and DD with that between LOR and LFD were determined by using the bootstrap approach (1,000 bootstrapping sample sets used) by resampling with replacement the patients within the entire cohort and, as secondary analyses, by resampling with replacement the patients within each patient subgroup in order to estimate the standard error of the difference between the estimator of the expected ICC for the agreement between LOR and DD and that between LOR and LFD. These comparisons were planned a priori. The following classification was used for ICC's: "great" (0.81 – 1.00), "substantial" (0.61 – 0.80), "moderate" (0.41 – 0.60), "fair" (0.21 – 0.40), "slight" (0.00 – 0.20), and "poor" (< 0.00).[9] Because the entire cohort analyses are primary and subgroup analyses are secondary, only an adjustment for assessing both lumbar ESI and cervical ESI for the entire cohort was made. Therefore, p-values < 0.025 = 0.05/2 from the primary analyses were considered statistically significant based on Bonferroni correction to adjust for multiple testing. All statistical analyses were performed with SAS Version 9.4 (SAS Institute Inc., Cary, NC, USA) and R 3.3.0 (R Development Core Team, 2016).

Results

A total of 549 charts were reviewed. Of these, 214 were excluded for the following reasons: no BMI recorded on the date of the procedure (N = 4), paramedian approach to the epidural space documented in the procedure note (N = 91), no preoperative MRI available for review in the EMR (N = 116), and poor image quality secondary to patient rotation or obesity with skin surface outside of image field (N = 3). Data from 335 ESIs were analyzed. Of these, 147 were cervical ESIs and 188 were lumbar ESIs. One measurement occurred at C4-C5, 146 at C7-T1, 8 at L3-L4, 40 at L4-L5, and 140 at L5-S1. Patient demographics and measurements of epidural depth are shown in Table 1.

Comparison of lumbar MRI measurements of LFD and DD taken by the board-certified neuroradiologist and anesthesia resident revealed “great” agreement with estimated ICC values of 0.96 (95% CI 0.93 – 0.98) and 0.95 (95% CI 0.92 – 0.97), respectively. Comparison of cervical MRI measurements of LFD and DD taken by the board-certified neuroradiologist and anesthesia resident again revealed “great” agreement with estimated ICC values of 0.93 (95% CI 0.87 – 0.96) and 0.94 (95% CI 0.89 – 0.96), respectively.

Lumbar ESI

“Great” agreement was demonstrated between lumbar LFD and LOR depths with estimated ICC of 0.88 (95% CI 0.85 – 0.91). “Great” agreement was also demonstrated between lumbar DD and LOR depths with estimated ICC of 0.86 (95% CI 0.82 – 0.89). For all demographic groups receiving lumbar ESI, measurements of LFD revealed stronger agreement with the LOR than did measurements of DD. Table 2 displays how the expected ICC value for agreement between the LOR and DD compared to that between the LOR and LFD within each patient subgroup, and the estimated ICC value with 95% CI. The differences in agreement between lumbar measurements of LOR depth with LFD and DD were not statistically significant for any patient subgroup.

Bland-Altman plots assessed the agreement between the MRI-derived measurements of lumbar epidural depth and the LOR depths. The limits of agreement that would be considered clinically significant were not determined by this pilot study. All Bland-Altman plot data for patients who received a lumbar ESI are presented in Table 3.

For measurements from the skin surface to the dura, the mean (95% CI) difference (LOR – DD) was −0.267 (−0.378 – −0.156) cm. The limits of agreement (−1.823 to 1.290 cm), which were calculated using mean (2 SD), estimated the LOR depth to be between 1.29 cm longer and 1.82 cm shorter than the measured distance to the dura in 95% of the studied patients. These Bland-Altman data are shown in Figure 3. For measurements from the skin surface to the ligamentum flavum, the mean (95% CI) difference (LOR – LFD) was 0.108 (−0.008 – 0.217) cm. The limits of agreement (−1.415 to 1.632 cm), which were calculated using mean (2 SD), estimated the LOR depth to be between 1.63 cm longer and 1.42 cm shorter than the measured distance to the ligamentum flavum in 95% of the studied patients. These Bland-Altman data are shown in Figure 4.

Cervical ESI

“Substantial” agreement was demonstrated between cervical LFD and LOR depths with estimated ICC of 0.72 (95% CI 0.64 – 0.79). “Substantial” agreement was also demonstrated between cervical DD and LOR depths with estimated ICC of 0.69 (95% CI 0.60 – 0.77). For all demographic groups receiving cervical ESI, measurements of LFD revealed stronger agreement with the LOR depth than did measurements of DD. This difference was statistically significant ($p < 0.01$) for cervical ESI in male patients, obese patients, and those less than 65-years-old. Table 4 displays how the expected ICC value for agreement between the LOR and DD compared to that between the LOR and LFD within each patient subgroup, and the estimated ICC value with 95% CI. The differences in agreement between cervical measurements of LOR depth with LFD and DD were statistically significant for the entire cohort, along with male patients, obese patients, and those less than 65-years-old.

Bland-Altman plots assessed the agreement between the measured cervical epidural depths and the LOR. The limits of agreement that would be considered clinically significant were not determined by this pilot study. All Bland-Altman plot data for patients who received a cervical ESI are presented in Table 5.

For measurements from the skin surface to the dura, the mean (95% CI) difference (LOR – DD) was −0.286 (−0.414 – −0.157) cm. The limits of agreement (−1.876 to 1.304 cm), which were calculated using mean (2 SD), estimated the LOR depth to be between 1.30 cm longer and 1.88 cm shorter than the measured distance to the dura in 95% of the studied patients. These Bland-Altman data are shown in Figure 5. For measurements from the skin surface to the ligamentum flavum, the mean (95% CI) difference (LOR – LFD) was −0.078 (−0.205 – 0.050) cm. The limits of agreement (−1.656 to 1.500 cm), which were calculated using mean (2 SD), estimated the LOR depth to be between 1.50 cm longer and 1.66 cm shorter than the measured distance to the ligamentum flavum in 95% of the studied patients. These Bland-Altman data are shown in Figure 6.

Discussion

This study compared MRI-derived measurements of epidural depth to LOR depths (confirmed by epidurogram) observed in patients during prone, interlaminar ESI. Many patients receive epidural analgesia due to back or leg pain.[10, 11] The potential for inappropriate advancement of the Touhy needle into the subarachnoid space imparts significant risk.[12, 13, 14] Although these procedures are commonly performed under fluoroscopic guidance, accurate preoperative assessment of LOR depth may help decrease the risk of complications for a substantial number of patients, particularly if the procedure is anticipated to be difficult due to surgical hardware or patient anatomy.

Previous investigators have defined the epidural depth as the distance from the skin surface to the ventral border of the ligamentum flavum on sagittal MRI.[6, 7, 15] Since the anterior-posterior thickness of epidural fat varies along the vertebral column and mid-line gaps have been described through the entire length of the ligamentum flavum in the cervical region in over 50% of human cadaver dissections, the reliability of measurements that depend on this structure is not certain.[16, 17, 18] With respect to the variations in both epidural fat thickness and continuity of the ligamentum flavum, our report utilized MRI measurements from the skin surface to both borders of the epidural space: the dura mater and ligamentum flavum. Measuring both distances allowed for the calculation of the anterior-posterior thickness of the epidural space. Our data suggest that the anterior-posterior thickness of the epidural space is greater in the lumbar region, which also suggests that the margin for error in placement of the Touhy needle is greater for lumbar ESI than cervical ESI.

Measured distances of LFD and DD on MRI reveal at least "substantial" agreement with the LOR depth as represented by the estimated ICC values. Specifically, measurements of LFD agree better with the LOR than do measurements of DD although this difference was not statistically significant for all patient subgroups. Better agreement between LOR and measurements to the posterior aspect of the epidural space, than with the anterior aspect, makes sense since the LOR is observed upon posterior entry into the epidural space.

Comparing supine MRI measurements to prone LOR measurements presents several limitations. First, LOR measurements are estimated on Touhy needles, and not measured in a standardized fashion. Although midline placement of the Touhy needle was confirmed by intra-operative fluoroscopy imaging and epidurography (both at the time of the ESI and during data collection for this study) and all paramedian approaches to the epidural space were excluded, imperfect midline placement of the Touhy needle in the sagittal plane is a source for error. Furthermore, many LOR depths are documented to the nearest 0.5 cm, yet the Touhy needles used in this study are marked at every 1 cm interval. Also, MRI measurements can be recorded to the nearest one-hundredth centimeter as in our study, which is far more precise than the measurement an interventionalist can note when performing the procedure. Lastly, it is not clear whether all MRI scans will be of high enough quality to allow proper identification of borders of the epidural space in patients presenting for ESI.

Compression of subcutaneous tissue on supine MRI may under-estimate epidural depth relative to those in the prone position, a source for error that may become magnified in the obese population. For both cervical and lumbar ESI, obese patients demonstrated the weakest agreement between LFD or DD and the LOR depth. Furthermore, Bland-Altman analyses revealed that cervical MRI measurements of LFD and DD in obese patients demonstrated less agreement with LOR than did measurements in non-obese patients. The presence of a cervical "hump pad," or fatty tissue in the low cervical spine, may explain the inability of MRI to agree with the cervical LOR depth in obese patients.[15]

Inappropriate sample size may contribute to wide limits of agreement in patient subgroups. The length of time between MRI acquisition and the procedure date may also contribute to lack of agreement, particularly if the patient's weight has changed, and could be the focus of future studies. Furthermore, additional research to determine clinically significant limits of agreement is necessary.

Other sources for error include motion artifact, patient rotation, and poor image resolution. For example, MRI of the skin surface requires an enlarged field of view and increased sensitivity, lending itself to potential inaccuracy in determination of the margins of the subcutaneous tissues, and possible inaccurate estimation of the depth from skin to epidural space.[19]

Several variables may contribute to agreement, and high correlation is not entirely sufficient evidence of complete agreement. Correlation can be falsely increased by the range of measurements.[20] For example, the greater range of lumbar MRI measurements may contribute to the higher lumbar ICC values. Regardless, agreement between LFD and LOR depth is supported by Bland-Altman analyses, which suggest that the LOR can be assessed preoperatively with MRI by a non-radiologist.

At this time, great caution should be used in translating these data to the clinical administration of an epidural injection. At present, information from MRI regarding potential needle depth should be viewed as inadequate due to lack of standardized approaches to MRI and injection protocols. At best, these findings are supportive and must be tempered with restraint. Confirmation of this method as a useful tool will require further investigation. Additional research is necessary to elucidate and replicate these findings of high agreement between MRI measurements and LOR depth and inter-rater reliability using this methodology. For instance, it seems plausible that MRI based assessment of LOR may reduce complication rates associated with ESI and improve outcomes related to procedure time, radiation exposure, and patient comfort.

To our knowledge, this is the first study to compare MRI measurements of epidural depth to clinical measurements in patients receiving prone, interlaminar, midline cervical or lumbar ESI. Pending further study, these results suggest that the relatively simple MRI methodology proposed in this study may reliably agree with LOR depth.

Acknowledgments

Funding: The project described was supported by the National Center for Advancing Translation Sciences (NCATS), National Institutes of Health (NIH), through grant #UL1 TR001860.

The authors of this manuscript acknowledge and thank David Willis for obtaining procedure logs from the chronic pain clinic and the Sacramento Region Community Foundation. The project described was supported by the National Center for Advancing Translation Sciences (NCATS), National Institutes of Health (NIH), through grant #UL1 TR001860.

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Figure 1.
Measurement of L5-S1 ligamentum flavum depth (LFD) and dura depth (DD) on magnetic resonance imaging. Two straight lines are shown: one extending from the skin surface to the anterior border of the ligamentum flavum (LFD), identified by the superior line (A), which measures 68.9 mm, and recorded as 6.89 cm; and another extending from the skin surface to the dura (DD), identified by inferior line (B), which measures 71.6 mm, and recorded as 7.16 cm.

Figure 2.

Measurement of C7-T1 ligamentum flavum depth (LFD) and dura depth (DD) on magnetic resonance imaging. Two straight lines are shown: one extending from the skin surface to the anterior border of the ligamentum flavum (LFD), identified by the superior line (A), which measures 71.7 mm, and recorded as 7.17 cm; and another extending from the skin surface to the dura (DD), identified by inferior line (B), which measures 74.1 mm, and recorded as 7.41 cm.

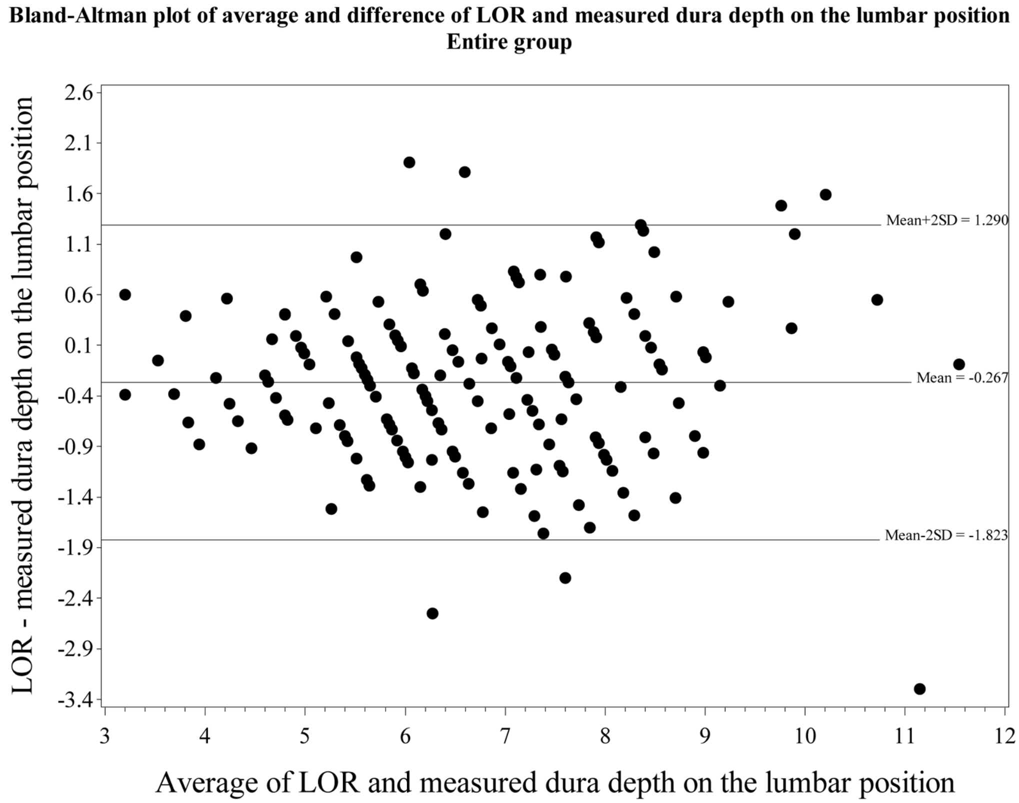

Figure 3.

Bland-Altman plot showing the agreement between the loss of resistance (LOR) and measured dura depth (DD) on MRI for lumbar epidural steroid injection. The mean (95% CI) difference (LOR – DD) = −0.267 (−0.378 – −0.156) cm, and the limits of agreement are shown (−1.823 to 1.290 cm).

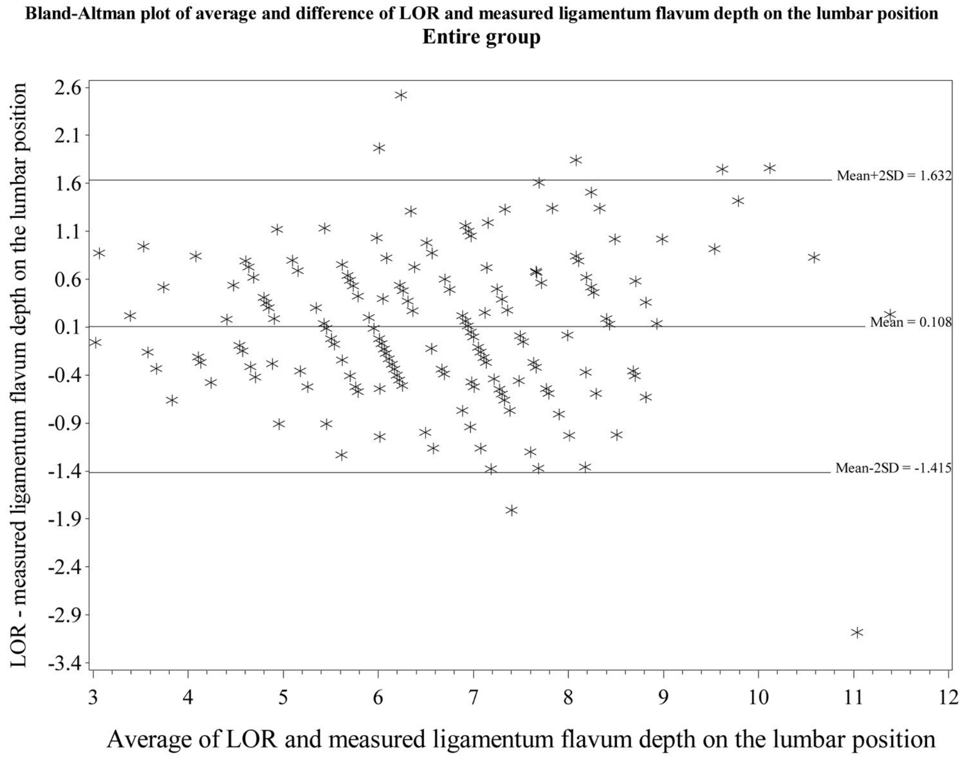

Figure 4.

Bland-Altman plot showing the agreement between the loss of resistance (LOR) and measured ligamentum flavum depth (LFD) on MRI for lumbar epidural steroid injection. The mean (95% CI) difference (LOR – LFD) = 0.108 (−0.008 – 0.217) cm, and the limits of agreement are shown (−1.415 to 1.632 cm).

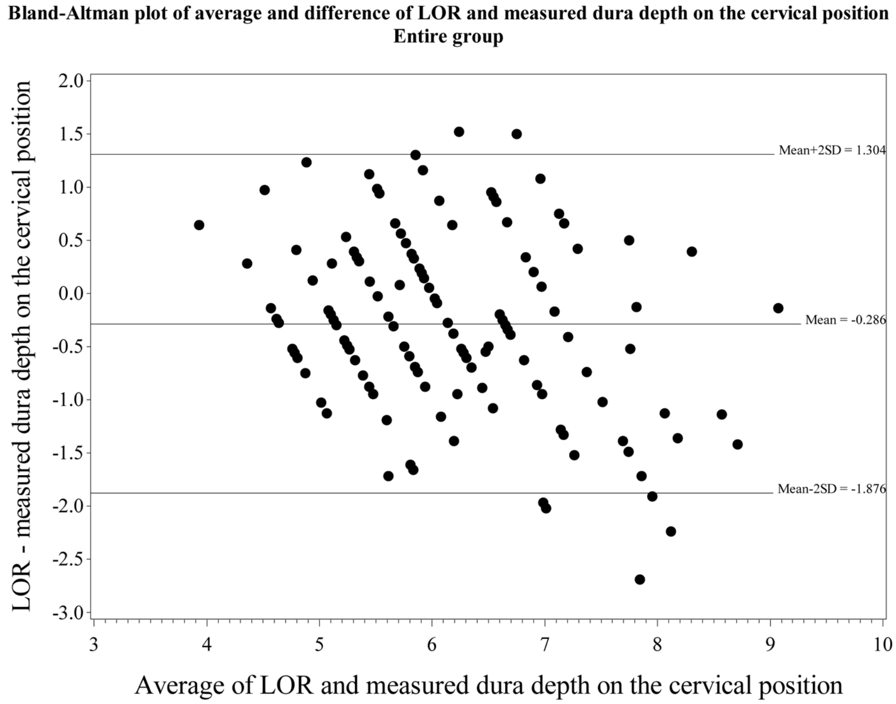

Figure 5.

Bland-Altman plot showing the agreement between the loss of resistance (LOR) and measured dura depth (DD) on MRI for cervical epidural steroid injection. The mean (95% CI) difference (LOR – DD) = −0.286 (−0.414 – −0.157) cm, and the limits of agreement are shown (−1.876 to 1.304 cm).

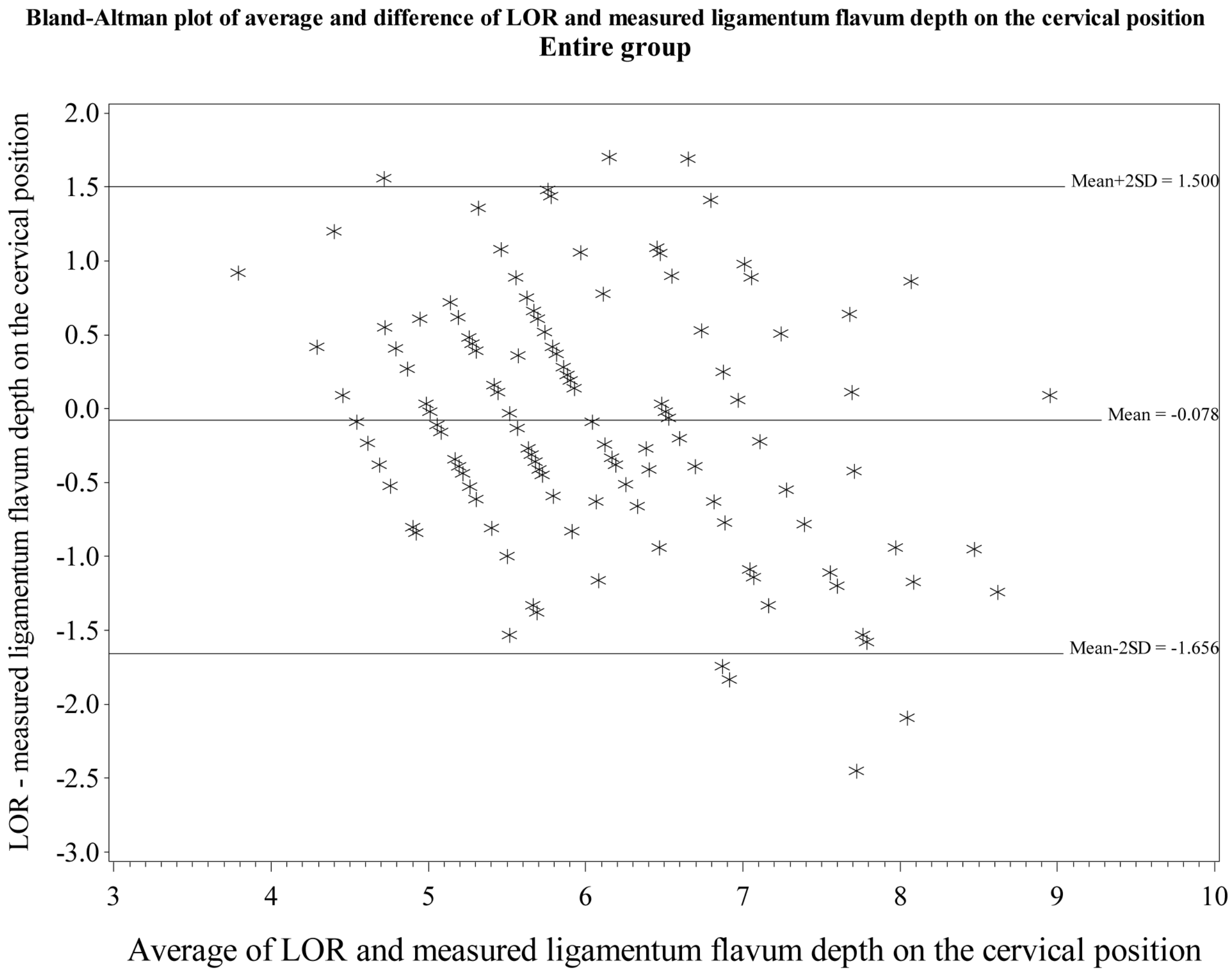

Figure 6.

Bland-Altman plot showing the agreement between the loss of resistance (LOR) and measured ligamentum flavum depth (LFD) on MRI for cervical epidural steroid injection. The mean (95% CI) difference (LOR – LFD) = −0.078 (−0.205 – 0.050) cm, and the limits of agreement are shown (−1.656 to 1.500 cm).

Table 1

Demographic data and measurements of epidural depth based on ESI location

	Lumbar ESI (N = 188)	Cervical ESI (N = 147)
Demographic Data		
Male (N)	87 (46.3%)	62 (42.2%)
Female (N)	101 (53.7%)	85 (57.8%)
Age (years)	56.4 ± 14.2	53.8 ± 10.2
BMI (kg/m^2)	29.1 ± 5.5	28.7 ± 5.0
Measurements		
LOR (cm)	6.6 ± 1.6	6.0 ± 0.9
LFD (cm)	6.5 ± 1.5	6.1 ± 1.2
DD (cm)	6.8 ± 1.5	6.3 ± 1.2
DD – LFD (cm)	0.38 ± 0.18	0.21 ± 0.07

Data are mean ± standard deviation or N = number (%). ESI = epidural steroid injection. BMI = body mass index. LOR = loss of resistance. LFD = ligamentum flavum depth. DD = dura depth.

Table 2

Estimated ICC demonstrating the agreement between LOR and measurements of DD and LFD for lumbar ESI

	N	Estimated ICC[a]		P-value[b]
		LOR and DD	LOR and LFD	
All patients	188	0.86 (0.82 – 0.89)	0.88 (0.85 – 0.91)	0.10
Age < 65 years	132	0.87 (0.82 – 0.90)	0.88 (0.83 – 0.91)	0.40
Age ≥ 65 years	56	0.83 (0.73 – 0.90)	0.88 (0.80 – 0.93)	0.15
BMI < 30 kg/m^2	110	0.81 (0.73 – 0.87)	0.84 (0.78 – 0.89)	0.15
BMI ≥ 30 kg/m^2	78	0.75 (0.64 – 0.83)	0.77 (0.66 – 0.85)	0.38
Female	101	0.87 (0.81 – 0.91)	0.88 (0.83 – 0.92)	0.15
Male	87	0.86 (0.79 – 0.90)	0.87 (0.80 – 0.91)	0.47

ICC = intra-class correlation coefficient. LOR = loss of resistance. DD = dura depth. LFD = ligamentum flavum depth. ESI = epidural steroid injection. N = number. BMI = body mass index.

[a] Data are estimated ICC (95% CI).

[b] P-value comparing the expected ICC value for agreement between LOR and DD with that between LOR and LFD within each patient subgroup.

Table 3

Bland-Altman data comparing LOR to measurements of LFD and DD for lumbar ESI

	Agreement of LOR and LFD		Agreement of LOR and DD	
	Mean Difference (cm)[a]	Limits of Agreement (cm)	Mean Difference (cm)[b]	Limits of Agreement (cm)
All patients	0.108 (−0.008 – 0.217)	−1.415 to 1.632	−0.267 (−0.378 – −0.156)	−1.823 to 1.290
Age < 65 years	0.099 (−0.040 – 0.238)	−1.529 to 1.728	−0.276 (−0.413 – −0.139)	−1.883 to 1.331
Age ≥ 65 years	0.129 (−0.036 – 0.293)	−1.126 to 1.383	−0.244 (−0.433 – −0.056)	−1.687 to 1.198
BMI < 30 kg/m^2	0.134 (0.011 – 0.257)	−1.180 to 1.448	−0.237 (−0.368 – −0.106)	−1.638 to 1.164
BMI ≥ 30 kg/m^2	0.072 (−0.126 – 0.270)	−1.713 to 1.856	−0.309 (−0.504 – −0.114)	−2.068 to 1.449
Female	0.084 (−0.074 – 0.241)	−1.528 to 1.695	−0.255 (−0.418 – −0.092)	−1.927 to 1.416
Male	0.137 (−0.013 – 0.286)	−1.286 to 1.559	−0.280 (−0.429 – −0.131)	−1.700 to 1.140

LOR = loss of resistance. LFD = ligamentum flavum depth. DD = dura depth. ESI = epidural steroid injection. BMI = body mass index.

[a]Data are LOR – LFD (95% CI).

[b]Data are LOR – DD (95% CI).

Table 4

Estimated ICC demonstrating the agreement between LOR and measurements of DD and LFD for cervical ESI

	N	Estimated ICC[a]		P-value[b]
		LOR and DD	LOR and LFD	
All patients	147	0.69 (0.60 – 0.77)	0.72 (0.64 – 0.79)	< 0.01
Age < 65 years	127	0.70 (0.60 – 0.78)	0.73 (0.64 – 0.80)	< 0.01
Age ≥ 65 years	20	0.68 (0.35 – 0.86)	0.69 (0.37 – 0.86)	0.70
BMI < 30 kg/m^2	96	0.68 (0.56 – 0.77)	0.70 (0.58 – 0.79)	0.34
BMI ≥ 30 kg/m^2	51	0.57 (0.35 – 0.73)	0.63 (0.43 – 0.77)	< 0.01
Female	85	0.67 (0.54 – 0.78)	0.68 (0.55 – 0.78)	0.68
Male	62	0.64 (0.46 – 0.76)	0.70 (0.54 – 0.81)	< 0.01

ICC = intra-class correlation coefficient. LOR = loss of resistance. DD = dura depth. LFD = ligamentum flavum depth. ESI = epidural steroid injection. N = number. BMI = body mass index.

[a]Data are estimated ICC (95% CI).

[b]P-value comparing the expected ICC value for agreement between LOR and DD with that between LOR and LFD within each patient subgroup.

Table 5

Bland-Altman data comparing LOR to measurements of LFD and DD for cervical ESI

	Agreement of LOR and LFD		Agreement of LOR and DD	
	Mean Difference (cm)[a]	Limits of Agreement (cm)	Mean Difference (cm)[b]	Limits of Agreement (cm)
All patients	−0.078 (−0.205 – 0.050)	−1.656 to 1.500	−0.286 (−0.414 – −0.157)	−1.876 to 1.304
Age < 65 years	−0.080 (−0.216 – 0.056)	−1.644 to 1.484	−0.287 (−0.425 – −0.150)	−1.871 to 1.296
Age ≥ 65 years	−0.065 (−0.438 – 0.309)	−1.770 to 1.641	−0.276 (−0.641 – 0.090)	−1.946 to 1.395
BMI < 30 kg/m^2	0.020 (−0.125 – 0.165)	−1.428 to 1.468	−0.185 (−0.331 – −0.040)	−1.637 to 1.267
BMI ≥ 30 kg/m^2	−0.262 (−0.502 – −0.021)	−2.015 to 1.492	−0.475 (−0.718 – −0.231)	−2.251 to 1.301
Female	0.086 (−0.071 – 0.243)	−1.393 to 1.565	−0.118 (−0.277 – 0.042)	−1.621 to 1.386
Male	−0.302 (−0.502 – −0.102)	−1.912 to 1.308	−0.516 (−0.716 – −0.317)	−2.117 to 1.084

LOR = loss of resistance. LFD = ligamentum flavum depth. DD = dura depth. ESI = epidural steroid injection. BMI = body mass index.

[a]Data are LOR – LFD (95% CI).

[b]Data are LOR – DD (95% CI).