Semiromi et al. BMC Surgery (2025) 25:197
https://doi.org/10.1186/s12893-025-02921-w

BMC Surgery

RESEARCH

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The accuracy of C-ARM in evaluating pelvic incidence and lumbar lordosis during surgery compared with EOS radiography after lumbar fixation

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Abstract

Background Achieving the global spinal alignment, especially the pelvis, in spine surgeries is considered the most important factor in the success of these surgeries, which requires an accurate evaluation of the correction angles measured during surgery. This study aimed to evaluate the accuracy of the mobile C-arm X-ray machine (C-ARM) for measuring lumbar lordosis (LL) and pelvic incidence (PI) parameters during lumbar fixation.

Methods In this prospective study, 59 lumbar fixation candidates who underwent surgery between 2020 and 2022 at our medical center, were examined. PI and LL parameters were measured at the fusion site with fluoroscopy, during surgery with C-ARM, and after surgery with EOS locally.

Results The mean age was 54.69 ± 17.62 years. 42 (71.2%) were female. The mean PI based on intraoperative C-ARM and post-surgery EOS findings were 54.57 ± 11.19 and 54.83 ± 11.17, respectively, which this difference was not statistically significant ($P = 0.9$). The mean LL estimate based on C-ARM and EOS findings was similar (P: 0.44).A significant positive linear correlation was observed for the mean PI (r: 0.97, p: 0.001) and LL (r: 0.99, p: 0.001).

Conclusion The mean PI and LL angle during operation (measured with C-ARM) was similar to the mean of these parameters in EOS imaging findings after surgery. C-ARM can be used as a convenient device in the operating room with high precision to measure PI and LL values in spine surgeries.

Keywords Spinal fusion surgery, C-ARM machine, EOS imaging, Pelvic incidence, Lumbar lordosis

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Introduction

Maintaining balance in any position of the body is one of the most important functions of the spine [1]. To achieve this goal, more than a good interaction between muscles, ligaments, and spine is needed, and the position of the pelvis and lower limbs is also critical to maintain this balance [1, 2].

From a sagittal point of view, global balance is generally defined by a perpendicular starting from the center of the seventh cervical vertebra and intersecting the posterior edge of the S1 cover plate [1, 3]. Considering that the position of the pelvis is in line with the spine, it is considered one of the important factors to maintain this position with the least possible force [4, 5]. Recent studies have shown that the spine's balance is particularly important in the surgical treatment of various vertebral abnormalities, especially in lumbar fusion [4, 6–8].

Pelvic incidence (PI), pelvic tilt (PT), lumbar lordosis (LL), sacral tilt (SS), sagittal vertical axis (SVA), spinal curvature, and thoracic kyphosis (TK) are the most important key parameters related to global sagittal balance, which should be considered during spine surgeries [1]. PI as a morphological parameter is an individual variable independent of body condition, which increases in the age range of 4 to about 18 years and then remains stable at older ages [9, 10].PI is the angle between the tangent line on the upper-end plate of the s1 vertebra and the line that connects from the middle point of this line to the center of the femoral head. Therefore, this angle will not change by changing the patient's position [9, 11].

Lumbar global lordosis is the angle formed between the tangent line on the upper-end plate of the L1 vertebra and the tangent line on the lower-end plate of the L5 vertebra. Local lumbar lordosis is an angle formed between the tangent line on the upper-end plate of the highest lumbar vertebra and the tangent line on the lower-end plate of the lowest lumbar vertebra.

The position of the pelvis and other pelvic parameters (PT, SS) are influenced by PI, and the curvature of the spine is adapted accordingly. The expression of LL depends on the size of PI, and if there is a higher PI level, SS increases, leading to an exacerbation of lumbar lordosis. At low values of PI, lumbar lordosis decreases as SS decreases. The standard value for hip extension is defined as 53 ± 9 degrees [12, 13].

Spine fusion surgery is one of the most commonly used orthopedic surgeries in the spine area, which is performed to correct or treat a wide range of spine diseases, which should be paid special attention to correction values and angle measurements [14, 15]. Radiography during surgery in the prone position with the mobile C-arm X-ray machine (C-ARM device) and after surgery in the standing position with the EOS device are among the most important tools for measuring angles in spine surgeries [15, 16].

Examining the correlation between PE and LL values can help estimate the values of correction angles during spinal fusion. Based on our knowledge, no study has evaluated the relationship between these indicators in the two CRM and EOS methods. We aimed to investigate the accuracy and correlation of PI and LL values measured intraoperatively with the C-ARM and after surgery with the EOS imaging.

Methods

This prospective study examined 87 patients who were candidates for lumbar fixation who underwent surgery between 2020 and 2022 at our medical center. Two parameters of PI and LL were measured for all patients during the surgery (using a C-ARM device) and immediately after the surgery with EOS imaging. Fifty-nine patients were included in the study.

Inclusion and exclusion criteria

Inclusion criteria included patients with spinal disorders and candidates for lumbar fixation, access to EOS findings after surgery, and informed consent to participate. Inability to perform radiography with EOS, patients whose head was not visible during fluoroscopy, and patients with a history of hip arthroplasty were defined as exclusion criteria.

Data collection

Surgery and measurement of parameters were performed routinely for patients, and the researcher had no intervention in the study process. The researcher collected all data using a checklist, including demographic characteristics of the patients (age and gender) and radiographic findings during and after surgery (mean PI and LL based on both EOS and C-ARM methods). Intraoperative LL values were measured locally. In other words, only LL was measured in the part of the lumbar spine subjected to fixation. In both C-ARM and EOS methods, angles were measured by a spine fellowship and an orthopedic specialist. The mean of the measured values was taken and recorded as the final value of these angles in the final checklist. The correction amount needed in each parameter was determined based on the comparison with the parameters measured before surgery.

Radiological measurement

Routinely, for all these patients, radiographs were performed during surgery in the prone position with the C-ARM device and after the surgery in the standing position with the EOS device. To measure PE and LL parameters during the operation, a radiograph is prepared from the fusion site of the lumbar region and transferred to the smartphone. If the entire lumbar fusion area is displayed on the C-ARM device monitor, the LL angle is calculated with the SURGIMAP version 1.2.1.70 in the next step [17]. If the entire fusion area is not visible on the C-ARM monitor, a spot view is taken from the beginning of the fusion site. Then, the smartphone and the Measure application set it to zero degrees. Then, the C-ARM device is moved parallel to the end of the fusion site without changing the angle and at the same distance, and a spot view is taken with the same mobile smartphone and the same Measure application, and the LL is calculated. In the same prone position, a spot view radiograph of the pelvic region is performed with the same C-ARM device so that the sacrum and the head of both femurs are visible in that view, and then it is transferred to the smartphone. The PI angle is calculated with the SURGIMAP application in the next step. Also, after surgery, EOS imaging is performed for all patients with a view of the entire spine length. LL angle in the fixation area is entirely measured by the same method used during surgery for each patient. PI angle is measured with the SURGIMAP application [17]. The method of measuring LL is shown in Fig. 1.

In order to ensure accurate measurements during surgery, it was essential to keep the patient fixed in position. However, we deliberately avoided making any positional corrections or adjustments to the patient's position using the operating table. This approach allowed us to maintain a stable and consistent alignment throughout the procedure, ensuring reliable measurements without altering the patient's posture.

All personnel involved in the study received detailed instructions on the use of both C-ARM and EOS radiography applications. We used the iOS 'Measure' application to measure our parameters on C-ARM. Before utilizing this app, we conducted a thorough comparison of its accuracy with a goniometer to measure angles, ensuring its reliability for our study. This prior validation step helped us understand the accuracy of the application and standardize the measurements, minimizing potential discrepancies during data collection.

To calibrate the C-arm, we used a protractor in conjunction with a fixed 90-degree calibration tool to ensure consistent and accurate imaging angles throughout the study. This setup allowed us to verify and maintain proper alignment during all measurements. All measurements were performed by experienced orthopedic surgeons, eliminating the need for additional operator training. To ensure quality control and reliability, each measurement was conducted multiple times by the same surgeon to minimize variability and confirm consistency.

Sample size collection

The appropriate sample size for this study was estimated to be 52 patients with an estimated effect size of 0.61 for the correlation of sagittal balance parameters measured intraoperatively with the C-arm and imaging based on the study by AJ Praeger et al., [18] with an alpha error of 5% and a power of 80% by epidemiologists using G Power version 3.1 software. To increase the power of the study, 59 patients were included.

Statistical analysis

Data were analyzed with SPSS software version 22. Quantitative data were reported as Mean ± SD. Qualitative data were reported with frequency and (%). The Kolmogorov-Smirnov test evaluated the normality of the mean distribution of quantitative variables. Assuming normality, two measurement methods used an independent t-test to compare the mean of quantitative variables. If normality was not established, the Mann-Whitney test was used. The chi-square test was used to compare qualitative variables. The correlation of LL and PI parameters in the two methods was evaluated with the Pearson correlation coefficient. A p-value of less than 0.05 was considered statistically significant.

Results

Fifty-nine patients were examined. 42 (71.2%) of the patients were women. The mean age of the patients was 54.69 ± 17.62 years (range 11 to 85 years). 13 (22%) of the patients were less than 50 years old. The most common cause of surgery in patients was canal stenosis. The demographic characteristics of the patients are summarized in Table 1.

PI and LL based on C-ARM and EOS

No significant difference was observed for mean PI based on intraoperative C-ARM and EOS findings after surgery (P: 0.9). Although the mean LL based on C-ARM was almost 2 degrees higher than EOS, this difference was not statistically significant (P: 0.44). (Table 2) A significant positive linear correlation was reported for both parameters. (Fig. 2)

Discussion

In recent years, studies have shown that restoring sagittal balance is one of the factors affecting success after surgery, which can be achieved by carefully evaluating the corrected angles during orthopedic surgeries, especially spine surgeries [18]. Since in spine surgeries, angle measurement is measured during surgery in the prone position and may differ from the results after surgery, especially for the LL parameter, accurate measurement of the parameters is still one of the challenges. Therefore, access to a simple and accurate tool during surgery can affect the results of these surgeries. C-ARM is the most widely used device used in the operating room to check fusion; therefore, considering the importance of

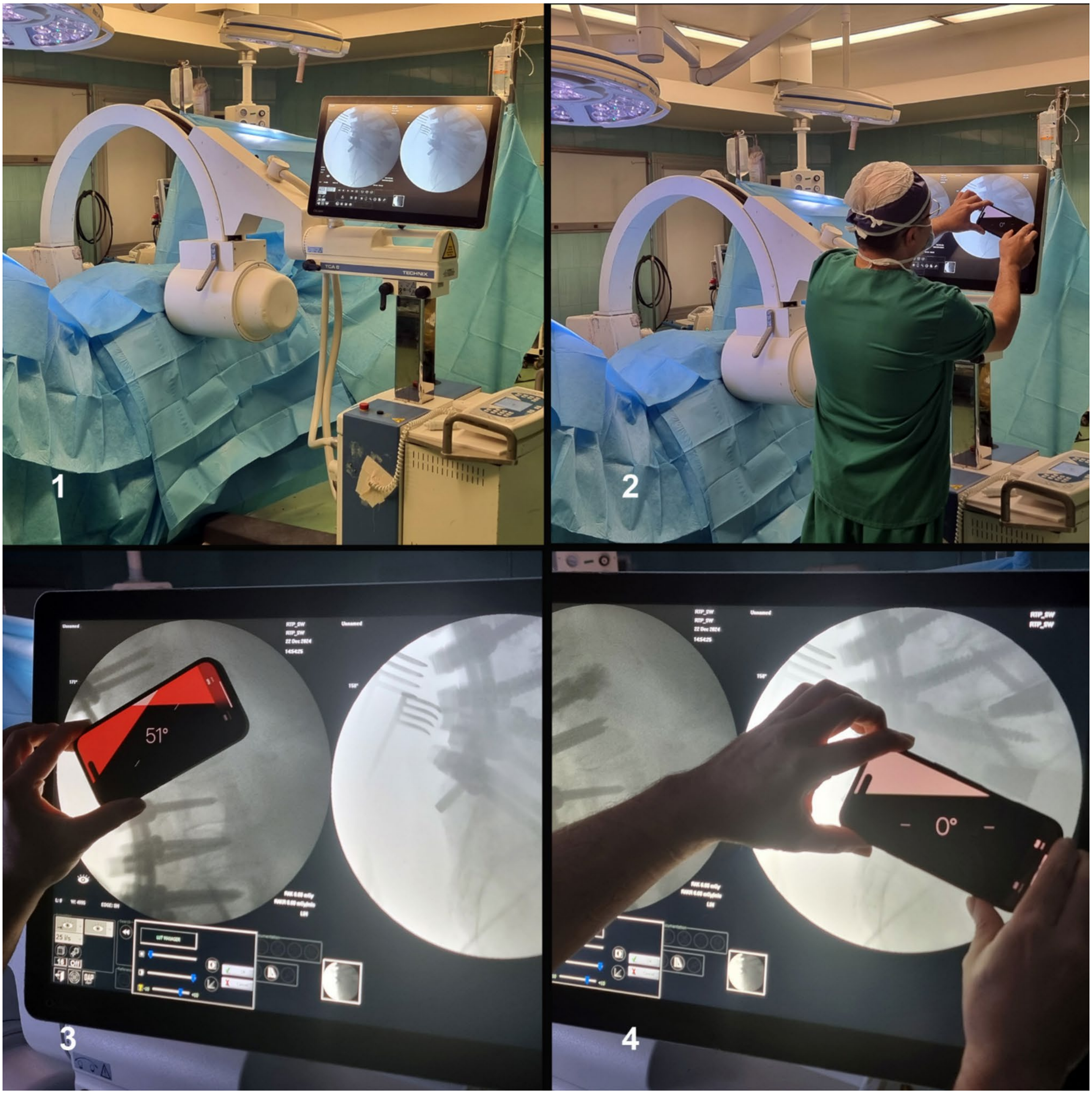

Fig. 1 Intraoperative Measurement of Pelvic Incidence (PI) and Lumbar Lordosis (LL): Outlining the steps and techniques used during surgery. Image 1: Initial C-ARM Position: Positioning at the level of the femoral head and sacrum for the first shot to obtain baseline measurements. Image 2: Adjusted C-ARM Position: Moving the C-ARM caudally for a comprehensive lumbar spine evaluation. Images 3 & 4: iOS Measure App Use: Demonstrating the application setup and the angle measurement process

the subject, this study aimed to investigate the correlation of LL and PI parameters measured during surgery with the C-ARM device with accurate measurements of these parameters after the operation performed by the EOS device, on 59 patients who are candidates for spine surgery.

Based on the results of our study, the majority of patients were female and in the age range of over 50 years. Comparing the findings of C-ARM with EOS for measuring PI showed that the mean PI was almost the same in both methods, and the correlation coefficient was close to 0.98. Although the mean LL in the C-ARM method was slightly higher than EOS, this difference was not statistically significant, and the correlation coefficient of this index was close to 1 in the two methods. In other words, for both PI and LL indices, C-ARM values were similar to those estimated with EOS. C-ARM can measure values with high accuracy during operation. The

Table 1 Demographic characteristics of patients

variable	59 patients
Age (year)	54.69 ± 17.62
Age Group	
• < 50	13(22%)
• ≥ 5	46(78%)
BMI(kg/m^2)	26.2 ± 2.6
Gender	
• Male	17 (28.8%)
• Female	42(71.2%)
Type of Surgery•	
• PSF	56(94.9%)
• PSF + ASF	3(5.1%)
Diagnosis•	
• Canal stenosis	28(47.5%)
• Congenital scoliosis	3(5.1%)
• Listesis Lumbar	22(37.3%)
• Idiopathic adolescent scoliosis	4(6.8%)
• Congenital kyphosis	2(3.3%)

mean LL in the C-ARM method was nearly 2 degrees higher than EOS, which can be justified due to the difference in the position in the two methods at the time of measurement because in the C-ARM method, the patient lies down in a prone position and is measured, but In EOS, the person is evaluated in a standing position; however, this difference in the two methods was not statistically significant and the two methods had the same estimation, which was consistent with the limited results of studies conducted in this field [18].

Based on our knowledge, no study has evaluated the correlation of PI and LL parameters based on two radiographic methods, C-ARM and EOS, and we could not compare the results of this study with similar and opposite studies. However, M Kraus et al. [19] showed by evaluating the diagnostic accuracy of CT scan and C-ARM in spine surgery, although the accuracy of intraoperative CT scan is higher than C-ARM, especially in cases of severe and complex spinal deformities, but according to the progress made and the possibility of preparing 3D radiographs, C-ARM can replace CT scan. In another study, F Greimel et al., [1] evaluated postoperative sagittal radiographic findings in standing radiographs compared to intraoperative radiographs in the prone position with C-ARM in lumbar spine fusion surgery with eighty-two patients. The values of the pelvic parameters PI, pelvic tilt, and sacral slope during the operation (measured with C-ARM) or after the operation (EOS) were consistent. They showed that the global average lordosis angle during surgery was 32.6 ± 7.8 degrees, and after surgery, it was 29 ± 10.8 degrees, and the difference was close to 3.5 degrees. The difference between the mean LL during and after the operation was close to 2 degrees and was less than in this study, which can be justified due to the difference in the measurement method in the two studies.

Table 2 Comparing the results of PI and LL values based on two methods

Index	Device		Mean Difference (°)	95% CI	*P* value
	C-ARM	EOS			
PI ° (Mean ± SD)	54.57 ± 11.19	54.82 ± 11.17	0.25	-0.14,0.66	0.9
LL ° (Mean ± SD)	32.61 ± 15.07	30.49 ± 15.06	2.12	-0.12,4.24	0.44

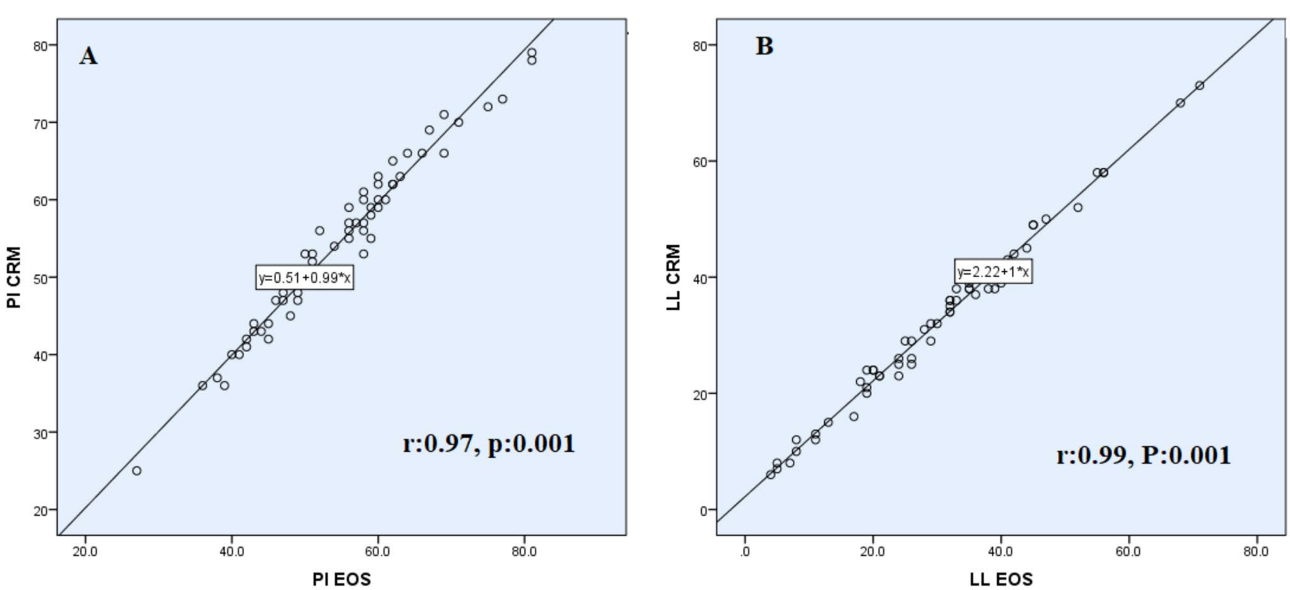

Fig. 2 Correlation of parameters in two devices

In our study, the LL angle was measured locally and only in the surgical area, while in their study, they measured it globally. However, they showed in their study that the values measured during the operation had a good accuracy.

In another study similar to our study, RA Lehman et al. [20] by examining long-cassette radiograph values during surgery and standing radiographs after surgery in idiopathic scoliosis patients, showed that the parameters measured during surgery of adolescent idiopathic scoliosis (AIS) in the radiograph taken from the patients in the form of a long cassette corresponded with the same parameters that were taken from the patients standing after the surgery, which indicates that the use of radiographs during the operation can be a completely reliable guide for decision making. The surgeon has made the changes and is in good agreement with the standing radiograph after the operation.

In 2019, AJ Praeger [18]., evaluated the correlation of intraoperatively measured sagittal balance parameters, including PI, LL, pelvic spine misalignment (PI-LL), and ratio of standing radiographic findings Complete postoperative spine (EOS) as a standard measure, showed on 49 patients, the mean LL during operation (after stabilization) and after operation with a mean difference of $4.5 \pm 6.1°$ during operation compared to later. It was significantly less than the practice. While in our study, no significant difference was reported for the average LL during and after the operation, this difference in the two studies can be justified due to the difference in the method of measuring the LL in the two studies. In our study, intraoperative LL values were measured locally with C-ARM, while LL values were measured globally in their study. They also showed in their study for patients with the lateral position that the mean LL during the operation was 50.9 ± 8.6 degrees; after the operation, it was 53.1 ± 10.1 degrees; the average difference was 2.3 ± 6.5 - The degree that this difference was not statistically significant. In our study, the difference was 2.1 degrees, which was insignificant. These studies have shown that the average values of PI and LL in patients in the prone position during surgery can be similar, and the values can be estimated with high accuracy with the C-ARM device available to surgeons during surgery. Although the mean LL in the standing state is slightly higher than in the prone state, this difference can be justified because of the position. The clinical significance and practical application of our findings lie in the fact that the primary objective in degenerative spine surgery with sagittal malalignment is to restore appropriate postoperative lumbar lordosis based on spinopelvic parameters. By measuring all preoperative spinopelvic parameters, it becomes crucial to monitor and control the correction achieved during surgery. In this study, we utilized intraoperative tools such as the C-arm to guide and confirm alignment. Demonstrating the reliability of the C-arm ensures that the intraoperative corrections can be trusted, thereby improving confidence in the accuracy of postoperative outcomes and ultimately supporting better clinical decision-making.

Our study had some weaknesses that should be noted. In this study, we could only examine a few other parameters that could help estimate the C-ARM's accuracy more accurately than EOS. Designing prospective studies by examining other radiographic indicators helps estimate the results more accurately. Due to the small sample size, the correlation between the indicators in the two methods may be affected by random error and affect its generalizability. The results may be different in a larger sample size, so it is recommended to design prospective studies with a larger sample size to estimate the results more accurately. The most important strength of the present study was to investigate the correlation of PI and LL parameters in C-ARM compared to EOS in spine fusion surgeries in a suitable sample size of patients for the first time.

Conclusion

This study showed a very high correlation between PI and LL parameters in two radiography methods. C-ARM had high accuracy for measuring PI and LL parameters. The local mean LL angle of intraoperative C-ARM findings was two° than that of EOS findings, which the surgeon can consider a 2°difference when measuring intraoperatively to increase accuracy. C-ARM can be used as a convenient, accessible, and high-precision tool to measure PI and LL values in spinal surgeries during surgery.

Acknowledgements
Not applicable.

Author contributions
Study concept and design (FN, HG and HTS), acquisition of data (HTS and AE), analysis and interpretation of data and drafting of the manuscript (MB and HTS), critical revision of the manuscript for important intellectual content (HG and MC), administrative, technical, or material support, study supervision (HTS, HG and FN). All authors reviewed the manuscript. All authors read and approved the final manuscript.

Funding
Not applicable.

Declarations

Ethics approval and consent to participate
This study was conducted in accordance to the Declaration of Helsinki and was approved by the Institutional review board Iran University of medical sciences(IR.IUMS.FMD.REC.1399. 250). The informed consent was waived by the Institutional review board of of Iran University of medical sciences due to its retrospective nature.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Received: 3 November 2023 / Accepted: 15 April 2025
Published online: 06 May 2025

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