What Is The Agreement Between Intraoperative Fluoroscopy And Postoperative Radiographs In Bernese Periacetabular Osteotomy?

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Abstract

Background

It is important to reorient the acetabular fragment in an optimal position and version to ensure a good long-term outcome after Bernese periacetabular osteotomy (PAO). Unfortunately, the intraoperative balance between overcorrection and undercorrection remains challenging for the surgeon. The purpose of this study was to answer two questions: (1) Does the femoral head coverage measured on intraoperative fluoroscopic images agree with that measured on postoperative radiographs? (2) What is the reliability of intraoperative fluoroscopy in identifying hip center correction in PAO?

Methods

A total of 173 patients (173 hips) who underwent PAO in our center from July 01, 2020, to December 31, 2020, were retrospectively reviewed. Imaging data from 111 patients were included in this study. The analysis included measurement of the lateral center-edge angle (LCEA), acetabular index (AI), anterior wall index (AWI), posterior wall index (PWI), extrusion index (EI), and medial offset distance (MO). These measurements were acquired from intraoperative fluoroscopy and postoperative radiographs and compared using the matched-pairs t test. Significance was determined at a p value of < 0.05. Bland–Altman analysis was used to quantify the agreement between intraoperative fluoroscopy and postoperative radiographs.

Results

The mean (SD) of LCEA, AI, AWI, PWI, EI, and MO obtained on the intraoperative fluoroscopy images were 32.86° (5.73°), 0.66° (5.55), 0.29 (0.10), 0.75 (0.17), 11.15% (6.50%), and 8.49 mm (3.68 mm), respectively. On the postoperative radiographs, the corresponding values were 32.91° (6.31°), 1.63° (5.22°), 0.29 (0.15), 0.85 (0.14), 11.27% (7.36%), and 9.60 mm (3.79 mm). The differences in the LCEA, AWI, and EI acquired from the intraoperative fluoroscopy and the postoperative radiographs were not significant ($p = 0.90$, 0.95, 0.83, respectively), but those in the AI, PWI, and MO were ($p < 0.05$). The mean bias (95% limits of agreement) of the LCEA, AI, AWI, PWI, EI, and MO were − 0.04 (-6.85), -0.97 (-7.78), 0 (-0.30), -0.11 (-0.36), -0.12 (-11.92), and − 1.11 (-5.51), respectively.

Conclusion

The LCEA, EI, and AWI can be used to reliably predict postoperative femoral head coverage. The acetabular inclination can be cautiously assessed using AI on intraoperative fluoroscopy. The AWI and PWI demonstrates acceptable agreement between fluoroscopy and radiography in assessing acetabulum

version. Although the MO shows slight bias, it can be helpful in positioning the acetabulum properly during PAO.

Background

Bernese periacetabular osteotomy (PAO), introduced by Ganz in 1988 [1], has become one of the most common surgical procedures for improving femoral head coverage by reorienting the shallow acetabulum. This procedure has been reported to relieve hip pain and improve function in patients with symptomatic dysplastic hips [2–5]. However, Bernese PAO is a complex surgical procedure with a substantial learning curve. The osteotomy is accompanied by four cuts: a complete cut of the superior pubic ramus, an incomplete cut at the ischium (as the posterior column of the innominate bone must remain intact), a cut from the anterior aspect of the iliac wing to a point approximately 1 cm superolateral to the brim of the true pelvis, and a cut connecting the first and the third cut through the posterior column.

After the osteotomy, the acetabulum can be freely rotated and mobilized, which not only improves the femoral coverage but also optimizes the rotation center of the hip joint. Although the anatomy around the acetabulum is complex and close to the iliac vessels and sciatic nerves, it is not very difficult for surgeons to complete osteotomy with intraoperative fluoroscopy monitoring after clearing the learning curve. However, reorienting and confirming the acetabular fragment in an optimal orientation and version [6], as well as balancing overcorrection and undercorrection[7, 8], remain challenging for the surgeon. Eduardo reported that the prevalence of over/undercorrection is 22%, and hips with more severe dysplasia preoperatively were at higher risk for undercorrection as assessed with the lateral center-edge angle (LCEA) [8].

Intraoperative radiography or fluoroscopy, computer-assisted navigation[9], customized templates[10], and another novel device[11] have been used in Bernes PAO for judging and confirming the correction of the acetabular fragment. Of these methods, intraoperative fluoroscopy is still the most common because of its convenience, time efficiency, low cost, and low radial exposure dose. However, anteroposterior (AP) radiography and intraoperative fluoroscopy have different image acquisition protocols. Some studies have investigated the reliability of intraoperative fluoroscopy. Charles reported that the intraoperative fluoroscopic assessment of PAO correction was correlated with that of postoperative radiography, but the study had a small sample size, and the correlation analysis did not represent the agreement of parameters [12]. Another study with a larger sample confirmed the reliability and accuracy of intraoperative fluoroscopy [13]. However, the study only addressed correction of lateral coverage as judged by the LCEA and the acetabular index (AI) and not anterior or posterior coverage of the femoral head. Additionally, neither of the previous studies discussed the accuracy of the hip center with intraoperative fluoroscopy.

In this study, we sought to answer two questions: (1) Does the femoral head coverage measured on intraoperative fluoroscopic images agree with that measured on postoperative radiographs? (2) What is the reliability of intraoperative fluoroscopy in identifying hip center correction in PAO?

Methods

We retrospectively reviewed the radiographs from all 173 patients (173 hips) who underwent PAO for developmental dysplasia of the hip (DDH) in our center between July 01, 2020, and December 31, 2020. As previously described [14], Bernese PAO was performed by one senior surgeon (X. C.) on all of the patients through a modified Smith-Peterson approach. No patients in this cohort underwent bilateral PAO.

All the patients' preoperative computed tomography (CT) images of the pelvis, intraoperative fluoroscopy images, and postoperative standing pelvic AP radiographs were obtained from our hospital's picture archiving and communication system (PACS). Postoperative standing AP radiographs were completed 6 months to 1 year after surgery. We excluded 62 hips (62 patients) from this cohort for the following reasons: previous hip surgeries, simultaneous proximal femur osteotomy (PFO), unavailable postoperative standing AP images of the pelvis due to missed follow-up six months to one year postoperatively, a significantly nonspherical femoral head, as this shape can affect the accuracy of subsequent data measurement and marked pelvic tilt on postoperative standing radiographs due to noncorrection of a subluxated contralateral hip. Finally, the imaging data from 111 patients were included in this study (Fig. 1). There were 98 females and 13 males, and the mean age was 28.93 (range 12–54) years old. Right hips were affected more frequently than left hips in the cohort (72/39).

All standing AP radiographs of the pelvis and the intraoperative fluoroscopic images were obtained as per the protocols recommended in previous studies [8, 12, 15]. In our center, an intraoperative false-profile radiograph is neither routine nor necessary. Intraoperative fluoroscopic images and postoperative AP radiographs of the standing pelvis were analyzed by an orthopedic surgeon (J.P.). The analysis included measurement of the LCEA, AI, anterior wall index (AWI), posterior wall index (PWI), extrusion index (EI), and medial offset distance (MO) as described in previous reports [16–19]. MO was calibrated using the ratio of the femoral head diameter as measured on preoperative CT positioning images to those on intraoperative fluoroscopic images and pelvic radiographs.

Statistical Analysis

The LCEA, AI, AWI, PWI, EI, and MO acquired from intraoperative fluoroscopy and postoperative radiographs were compared using matched-pairs t tests using SPSS (version 24.0). Significance was determined at a p value of < 0.05. Bland–Altman analysis, conducted using GraphPad Software (version 9), was used to quantify the agreement between intraoperative fluoroscopy and postoperative radiographs. The bias was estimated by calculating the mean difference and the 95% limits of agreement (LOA) between the intraoperative fluoroscopic images and the postoperative radiographs.

Results

The results of the matched-pairs t test and the Bland–Altman analysis are shown in table 1. The LCEA, AI, AWI, PWI, EI, and MO obtained on the intraoperative fluoroscopy were 32.86° (SD, 5.73°), 0.66° (SD, 5.55), 0.29 (SD, 0.10), 0.75 (SD, 0.17), 11.15% (SD, 6.50%), and 8.49 mm(SD, 3.68 mm), respectively. The corresponding parameters obtained on postoperative radiographs were 32.91° (SD, 6.31°), 1.63° (SD, 5.22°), 0.29 (SD, 0.15°), 0.85 (SD, 0.14°), 11.27% (SD, 7.36°), and 9.60 mm (SD, 3.79 mm), respectively. According to the matched-pairs T test, the LCEA, AWI, and EI acquired from the two imaging modalities were not significantly different (p = 0.90, 0.95, 0.83); however, the differences in the AI, PWI, and MO between intraoperative fluoroscopy and postoperative radiography were significant ($p < 0.05$).

Table 1. Agreement between intraoperative fluoroscopy and postoperative radiograph (N = 111)

	Matched-Pairs T-Test				Bland-Altman Analysis		
	IN-FL	PO-RA	T value	p	Mean Bias	SD of bias	95% Limits of Agreement
LCEA	32.86±5.73	32.91±6.31	-0.13	0.90	-0.04	3.47	-6.85~6.77
AI	0.66±5.55	1.63±5.22	-2.93	0.05	-0.97	3.48	-7.78~5.85
AWI	0.29±0.10	0.29±0.15	0.07	0.95	0.00	0.15	-0.3~0.3
PWI	0.75±0.17	0.85±0.14	-8.52	0.05	-0.11	0.13	-0.36~0.15
EI	11.15±6.50	11.27±7.36	-0.22	0.83	-0.12	6.02	-11.92~11.67
MO	8.49±3.68	9.60±3.79	-5.20	0.05	-1.11	2.25	-5.51~3.29

LCEA = lateral center-edge angle; AI = acetabular index; AWI = anterior wall index; PWI = posterior wall index; EI=extrusion index; MO=medial offset distance;IN-FL=intraoperative fluoroscopy; PO-RA=postoperative radiograph

The Bland–Altman plots are shown in Fig. 2A-F. The bias and 95% LOA in the comparison between intraoperative fluoroscopy and postoperative radiography indicate that the effect of any such biases is acceptable.

Discussion

To maximize the accuracy of intraoperative fluoroscopy, the influence of pelvic tilt and rotation needs to be eliminated during surgery. We generally confirmed the following two points: the pubic symphysis must be vertical and overlying the coccyx, and the obturator foramen has a similar appearance on the fluoroscopic image as on preoperative standing pelvic plain radiography. These results are consistent with the protocol reported in a previous study [12]. However, some unavoidable factors of intraoperative fluoroscopy may still create errors [20]. First, intraoperative fluoroscopy was performed with a posterior-anterior beam direction. Second, the film focus distance is small. Third, the central beam is usually centered on the femoral head. Previous studies using the intraclass correlation coefficient (ICC) showed that the measurements obtained on intraoperative fluoroscopy images were correlated with those obtained with postoperative radiography [12]. However, correlation analysis cannot be used to assess the agreement between the two methods of clinical measurement [21, 22]. In this study, Bland–Altman plots were used to analyze the agreement between intraoperative fluoroscopy and postoperative radiographs in assessing the outcome of PAO. The results indicated that the biases between the imaging modalities could be neglected.

This study has some limitations. First, because we excluded some patients with previous hip surgeries, simultaneous PFO, a nonspherical femoral head, and a subluxated contralateral hip, our findings cannot be generalizable to patients with these conditions. In addition, all measurements were performed by a single observer (J.P.). Since multiple prior studies have reported on interrater and intrarater reliability in measuring the LCEA, AI, AWI, PWI, EI, and MO, we did not repeat such assessments. Third, we determined that the biases of AI, PWI, and MO as measured on fluoroscopy images was acceptable based on the reference normal values reported in previous studies. Further studies are needed to determine whether these biases affect hip function after PAO.

The LCEA of Wiberg, AI, and EI were used to assess the lateral coverage of the femoral head. Correction of the LCEA between 25° and 40°, AI between 0° and 10°, and EI ≤ 20% were defined as the target ranges after PAO based on previously published normative values[8, 23]. Charles' study indicated that EI were less correlated, with ICCs of 0.66 (0.46–0.79) [12]. Unlike the results from Charles, we found high agreement for EI between intraoperative fluoroscopic images and postoperative standing AP pelvis radiographs. The LCEA and AI have demonstrated a high correlation between intraoperative fluoroscopy and postoperative plain radiographs in previous studies [12, 13]. However, a high correlation does not imply good agreement between the two methods; correlation analysis only quantifies the degree to which two variables are related [21]. Stefanie's study indicated an acceptable agreement between the two images using kappa statistics [24]; however, intraoperatively, they inclined the C-arm by approximately 5° to imitate a pelvic-centered image, differing from conventional methods. In this study, LCEA also showed high agreement between intraoperative fluoroscopic images and postoperative standing AP pelvis radiographs. In contrast to previous studies, our study found that the AI acquired from the postoperative radiographs was larger than that measured on intraoperative fluoroscopy ($p < 0.05$). We suspect that this difference may be due to the difficulty in determining the medial margin of the acetabular sourcil on fluoroscopic images. Charles also considered fluoroscopic images to have poorer resolution than plain radiographs [12], potentially making it more difficult to find the necessary landmarks for measurement. Through Bland–Altman analysis, we considered this difference to be acceptable (mean bias: -0.97°).

Proper acetabular reorientation includes not only lateral but also anterior and poster coverage. Excessive anterior coverage is a detriment to posterior coverage and may cause impingement and adversely affect the long-term survival of PAO [6]. An anterior center-edge angle of Lequesne (ACEA), created on the false-profile view, of < 20° can be indicative of structural instability [23]. Most surgeons prefer to obtain an oblique view of the iliac crest during surgery to achieve a false-profile view. Previous studies have shown that the intraoperative ACEA was greatly correlated with that obtained on postoperative radiographs, with ICCs of 0.71 (95% CI: 0.54–0.82) [12] and 0.80 (95% CI: 0.71–0.86) [15]. We chose not to measure the

ACEA intraoperatively to assess the improvement in anterior coverage; although we can imitate the version of the standing pelvis by tilting the C-arm beam, we cannot simulate the version of the standing pelvis when obtaining an oblique image. Klaus recommended the AWI and PWI to quantify anterior and posterior coverage [19]. According to their report, the mean AWI and PWI were 0.41 and 0.91, respectively, for normal hips. Because these parameters for judging anterior and posterior coverage are measured on images simulating the standing pelvis version, we prefer this method to using the ACEA. In this study, the AWI obtained on intraoperative fluoroscopy images highly agreed with that obtained on postoperative radiographs. Although the mean PWI obtained on intraoperative fluoroscopy images was smaller than that on postoperative radiographs, this difference was acceptable since the mean bias was only 0.11.

A lateralized hip center was considered to be a sign of structural instability. The hip center was considered lateralized if the medial aspect of the femoral head was greater than 10 mm from the ilioischial line [25]. Medialization of the fragment could decrease the joint contact forces by decreasing the bodyweight lever arm. Troelsen found that an MO distance greater than 20 mm correlated with a poor 6.8-year survivorship of PAO [26]. Charles recommended placing the medial aspect of the femoral head only 5 to 15 mm lateral to the ilioischial line [20]. In their study, intraoperative fluoroscopic measurement of the MO distance had the lowest correlations (ICCs: 0.46) with those obtained on postoperative AP pelvis radiographs. Our data indicate that the femoral head was more medial on intraoperative fluoroscopic images than on postoperation AP pelvis radiography. This difference is partly due to the different central beam positions. On the other hand, the effect of the imaging magnification ratio on MO was more significant than that on the angle (LCEA, AI) measurements. To eliminate this effect, the MO was calibrated using the ratio of the femoral head diameter as measured on preoperative CT positioning images to those measured on intraoperative fluoroscopic images and pelvic radiographs. In this study, the mean bias was only − 1.11 mm, and the 95% LOA was − 5.55 mm-3.29 mm. Compared to the acceptable range of 15–20 mm [20, 26], this error is completely negligible.

Conclusion

The LCEA, EI, and AWI can reliably predict postoperative femoral head coverage. The use of AI in the intraoperative assessment of acetabular inclination requires caution. The agreement in the AWI and PWI between the two imaging modalities is acceptable in assessing the acetabulum version. We acknowledge that it is difficult to assess the hip center position intraoperatively. Although the MO demonstrates slight bias, it can nevertheless help position the acetabulum properly during PAO.

Abbreviations

PAO
Periacetabular osteotomy
DDH
Developmental dysplasia of the hip
LCEA

lateral center-edge angle
AI
acetabular index
AWI
anterior wall index
PWI
posterior wall index
EI
extrusion index
MO
medial offset distance
AP
anteroposterior
ICC
intraclass correlation coefficient.

Declarations

Ethics approval and consent to participate

This study was approved by the medical ethics committee of Xinhua Hospital Affiliated to Shanghai Jiao Tong University School of Medicine. All procedures performed in studies were in accordance with the ethical standards of our institutional ethical committee. Informed consent was obtained from the individual participants included in the study.

Consent for publication

Not applicable.

Availability of data and materials

The datasets used and/or analyzed during the study are available from the corresponding author upon reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors’ contributions

Xiaodong Chen contributed to study conception and research design. Xiaodong Chen performed the operations. Jianping Peng and Fei Xiao wrote the manuscript and revised it critically. Jianping Peng contributed to imaging data evaluation. Yang Li, Junfeng Zhu, Chao Shen, Xiuguo Han and Yimin Cui performed the patient perioperative treatment. All authors read and approved the final manuscript. All authors gave consent for publication.

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Figures

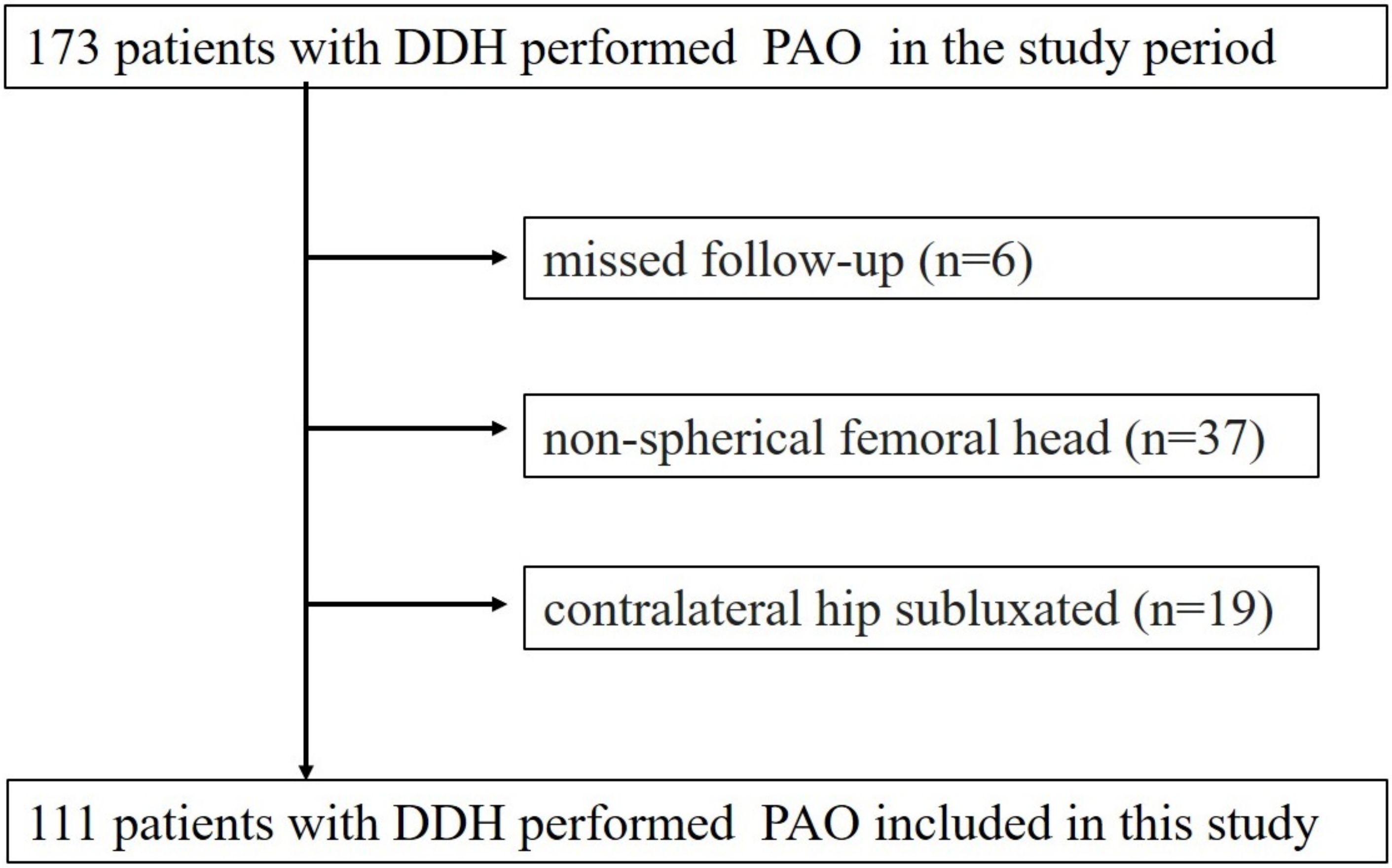

Figure 1

Flowchart showing patient inclusion and exclusion criteria for the study.

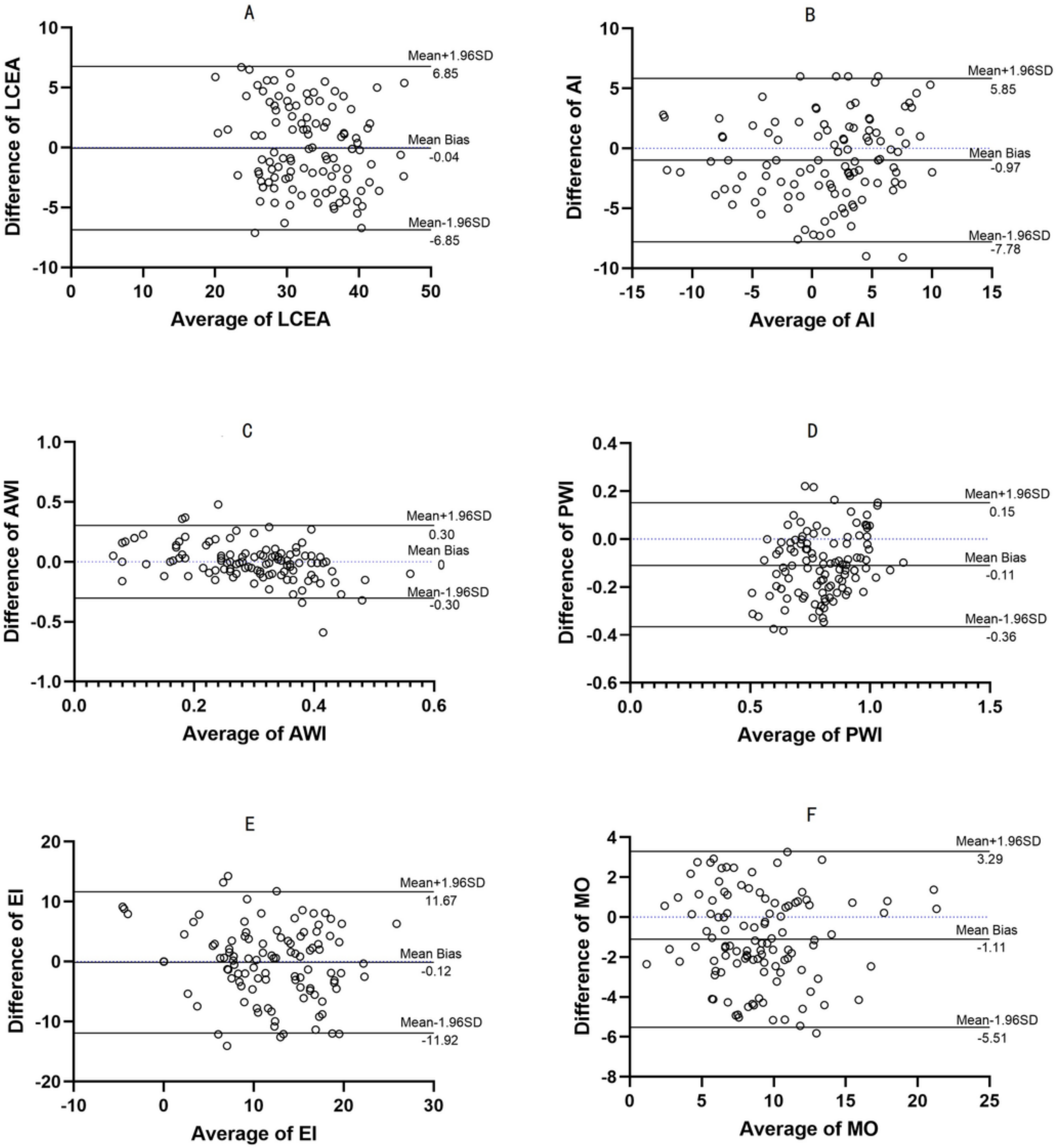

Figure 2

Bland–Altman plot demonstrating the mean biases in the LCEA (A), AI (B), AWI (C), PWI (D), EI (E), MO (F) between intraoperative fluoroscopy and postoperative radiography and the corresponding 95% limits of agreement.