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What Is the Reliability and Accuracy of Intraoperative Fluoroscopy in Evaluating Anterior, Lateral, and Posterior Coverage During Periacetabular Osteotomy?

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Abstract

Background Periacetabular osteotomy (PAO) is an established treatment for acetabular dysplasia in the skeletally mature individual. Fluoroscopy is used intraoperatively for osteotomy completion and to judge fragment correction. However, a comprehensive study validating fluoroscopy to judge anterior, lateral, and posterior coverage in PAO has not been reported.

Questions/purposes (1) Are radiographic and fluoroscopic measures of anterior, lateral, and posterior acetabular coverage reliable? (2) Do fluoroscopic measures of fragment correction accurately measure anterior, lateral, and posterior coverage when compared with postoperative radiographs?

Methods We performed a retrospective study of patients undergoing PAO with a primary diagnosis of acetabular dysplasia. Between 2012 and 2014 two surgeons performed 287 PAOs with fluoroscopy. To be included in this retrospective study, patients had to be younger than 35 years old, have a primary diagnosis of dysplasia (not retroversion, Perthes, or skeletal dysplasia), have adequate radiographic and fluoroscopic imaging, be a primary PAO (not revision), and in the case of bilateral patients, only the first hip operated on in the study period was included. Based on these criteria, 46% of the PAOs performed were included here (133 of 287). A total of 109 (82%) of the patients were females (109 of 133), and the mean age of the patients represented was 24 years (SD, 7 years). Pre- and postoperative standing radiographs as well as intraoperative fluoroscopic images were reviewed and lateral center-edge angle (LCEA), Tönnis angle (TA), anterior center-edge angle (ACEA), anterior wall index (AWI), and posterior wall index (PWI) were measured. Two fellowship-trained hip preservation surgeons completed all measurements with one reader performing a randomized sample of 49 repeat measurements 4 weeks after the initial reading for purposes of calculating intraobserver reliability. Intra- and interrater reliability was assessed using an intraclass correlation coefficient (ICC) model. Agreement between intraoperative fluoroscopic and

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Each author certifies that his or her institution approved the human protocol for this investigation and that all investigations were conducted in conformity with ethical principles of research.

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postoperative radiographic measures was determined by estimating the ICC with 95% confidence intervals and by Bland-Altman analysis.

Results Intrarater reliability was excellent (ICC > 0.75) for all measures and good for postoperative AWI (ICC = 0.72; 95% confidence interval [CI], 0.48-0.85). Interrater reliability was excellent (ICC > 0.75) for all measures except intraoperative TA (ICC = 0.72; 95% CI, 0.48-0.84). Accuracy of fluoroscopy was good (0.60 < ICC < 0.75) for LCEA (ICC = 0.73; 95% CI, 0.55-0.83), TA (ICC = 0.66; 95% CI, 0.41-0.79), AWI (ICC = 0.63; 95% CI, 0.48-0.74), and PWI (ICC = 0.72; 95% CI, 0.35-0.85) and excellent (ICC > 0.75) for ACEA (ICC = 0.80; 95% CI, 0.71-0.86). Bland-Altman analysis for systematic bias in the comparison between intraoperative fluoroscopy and postoperative radiography found the effect of such bias to be negligible (mean difference: LCEA 2°, TA 2°, ACEA 1°, AWI 0.02, PWI 0.11).

Conclusions Fluoroscopy is accurate in measuring correction in PAO. However, surgeons should take care not to undercorrect the posterior wall. Based on our study, intraoperative fluoroscopy may be used as an alternative to an intraoperative AP pelvis radiograph to judge final acetabular fragment correction with an experienced surgeon. However, more studies are needed including a properly powered direct comparative study of intraoperative fluoroscopy and intraoperative radiographs. Moreover, the impact of radiographic correction achieved during surgery should be studied to determine the implications for patient-reported outcomes and long-term survival of the hip.

Level of Evidence Level IV, diagnostic study.

Introduction

Periacetabular osteotomy (PAO) has been popularized for the treatment of symptomatic acetabular dysplasia in the skeletally mature patient. This operation involves a number of complex three-dimensional surgical decisions that are guided by a two-dimensional imaging technique during surgery. Intraoperative radiography and fluoroscopy are imaging options for judging fragment correction in PAO. Radiography is associated with increased radiation doses for the patient and surgeon [10, 11]. Contemporary techniques of PAO for acetabular dysplasia commonly use fluoroscopy to guide osteotomies and to judge the correction of the acetabular fragment. Prior studies reported on the accuracy of fragment correction during PAO [11, 12, 22]. A small study reported on 22 patients undergoing PAO and found no differences between intraoperative radiographic and fluoroscopic measurements and higher radiation doses with radiography [11]. A similar small study with a single reader concluded that the lateral center-edge angle (LCEA), Tönnis angle (TA), and anterior center-edge angle (ACEA) were accurate fluoroscopic measures of fragment correction in a small sample with a single reader [12]. A larger study confirmed the reliability and accuracy of judging lateral correction with LCEA and TA to judge lateral coverage in a larger sample of patients with multiple readers [22]. However, the study only addressed correction of lateral coverage and not anterior or posterior coverage of the femoral head.

Since that time, the anterior wall index (AWI) and posterior wall index (PWI) were introduced as measures of anterior and posterior wall coverage, respectively [19]. The wall indices are surrogates for anterior and posterior wall coverage and an indirect way of assessing acetabular version. Measuring the AWI and PWI in surgery is important to avoid excessive ante- or retroversion that may impact the outcome of PAO [1]. Although much is discussed about balancing the walls during PAO, it remains unclear whether measurement of the AWI and PWI with fluoroscopy is reliable or accurate. Given that fluoroscopy is a posteroanterior (PA) image of the hip and radiography is an AP projection of the pelvis, the reliability and accuracy of these new measures of anterior and posterior coverage are unknown. In addition, there has not been a paper with a large cohort of patients that demonstrates reliability and accuracy of a comprehensive evaluation of the fluoroscopic correction in PAO.

Therefore, in this study, we asked two questions: (1) Are radiographic and fluoroscopic measures of anterior, lateral, and posterior acetabular coverage reliable? (2) Do fluoroscopic measures of fragment correction accurately measure anterior, lateral, and posterior coverage when compared with postoperative radiographs?

Patients and Methods

After receiving institutional review board approval, we performed a retrospective study of medical records and imaging data of all patients at our institution undergoing PAO from January 2012 to November 2014. The study was performed in 2017 and 2018. This period was chosen to approximate the study size in the largest study on the topic to date [22]. Patients were included if they had a diagnosis of acetabular dysplasia (determined by an LCEA or ACEA of < 20°), preoperative and postoperative standing AP and false profile pelvic radiographs, and fluoroscopy images including final images of a PA and false profile views with hardware in place in our imaging system. Patients were excluded if they were aged > 35 years (surgery was performed at a different facility and images from intraoperative fluoroscopy were not available), they were missing any of the previously described imaging views, they had a Perthes-like deformity, they had a diagnosis of skeletal dysplasia, they underwent a concurrent femoral

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osteotomy, or they underwent revision PAO. These diagnoses were excluded because they are more complex deformities and therefore could have compromised the accuracy or reliability of the measures. In addition, patients undergoing bilateral PAOs during the study period only had their first side included. The patients included and excluded from the study are illustrated (Fig. 1).

There were 133 PAOs included after application of these criteria. There were 109 (82%) females and 71 (53%) right hip PAOs. The average age was 24 years (SD, 7 years). The average body mass index (BMI) was 25 kg/m^2 (SD, 5 kg/m^2). Twenty-two (14%) were considered obese (BMI > 30 kg/m^2). Surgery was performed by one of two surgeons using a technique previously described [15]. Surgeon 1 (Y-JK) performed 49 PAOs and Surgeon 2 (MBM) performed 84 PAOs. Both had 15+ years of subspecialty practice performing PAOs at the time of the study.

Patients' medical records were reviewed for all demographic and clinical variables by study personnel not involved in the clinical care of the patients (JDW, FH). Patient age at the time of surgery, height, and weight were recorded. BMI was calculated from height and weight. A BMI of > 30 kg/m^2 was considered obese. Operative reports were reviewed for side of surgery and the surgeon performing the surgery. Standing AP pelvis and false profile radiographs obtained during the preoperative evaluation were used to measure the LCEA, TA, ACEA, AWI, and PWI as previously described [7, 13, 19]. Two fellowship-trained hip surgeons performed all the measurements (JDW, MGF) with one surgeon performing a repeated random sample of 49 hips after a 4-week washout period (JDW) for purposes of calculating intraobserver reliability. Both readers had completed one fellowship (MGF, pediatric orthopaedics; JDW, orthopaedic sports medicine) and were current hip fellows at the time of the study. The observers performed their measurements in a blinded fashion to each other and between imaging techniques. The reader who performed two sets of measures was also blinded to their prior measurements.

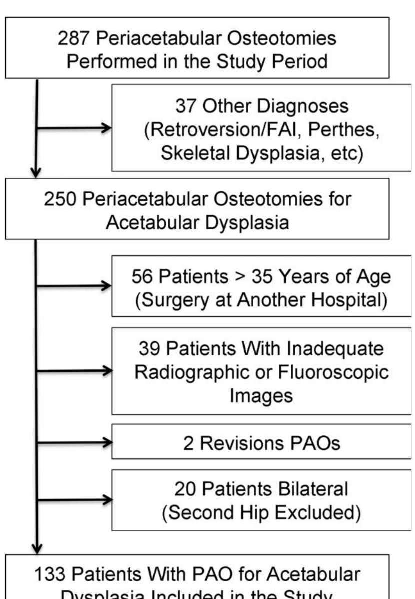

Fig. 1 STROBE diagram shows patients included and excluded from the study.

Because this study was retrospective, there was not a standardized protocol for obtaining the fluoroscopic images intraoperatively. However, the two surgeons involved in the study use a standard technique for obtaining images during surgery. First, the fluoroscopy machine is placed such that a PA pelvis image including the pelvic ring and the obturator foramen is obtained. The tilt and rotation of the machine are then adjusted to approximate the preoperative standing AP pelvis radiograph. Rotation was judged by coccyx alignment with the pubic symphysis and tilt was judged by the distance from the coccyx to the pubic symphysis. When the surgeon is satisfied with the pelvic tilt and rotation, the boom is moved toward the operative side until the hip is well visualized and the image is obtained. To obtain the false profile radiograph, the fluoroscopy machine is frogged with the image intensifier shifted 50° to 55° away from the operative side until there was approximately one femoral head diameter between the two femoral heads [14]. The image is qualitatively compared with the preoperative false profile radiograph and the amount of rotation is adjusted to approximate the preoperative radiograph. Goals of correction were an LCEA and ACEA of 25° to 35°, a TA of 0° to 10°, and a PWI of approximately 1.0, which corresponds to the posterior wall crossing the center of the femoral head and the AWI measuring approximately one-third of the femoral head radius.

Statistical Analysis

Power analysis indicated that we would require a minimum of 46 radiographs to be reviewed by two raters to test for an intraclass correlation coefficient (ICC) of at least 0.80 compared with 0.90 using a one-sided test with α set to 0.05 to achieve 80% power. Interrater reliability was assessed using an ICC (3, 2) model and intrarater reliability was assessed using an ICC (2, 1) model [18]. Interpretations of ICC estimates were based on the scale from Fleiss and Cicchetti and Sparrow: < 0.40, poor; 0.40 to 0.59, fair; 0.60 to 0.74, good; and > 0.74, excellent [6, 8]. Agreement between intraoperative fluoroscopy and postoperative radiograph measurements was analyzed by estimating the ICC (2, 2) between measurements along with the corresponding 95% confidence interval (CI) [18].

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Table 1. Intra- and interrater reliability for all acetabular measurements

Acetabular measurement	Intrarater reliability (N = 49)		Interrater reliability (N = 133)	
Preoperative radiograph	ICC	(95% CI)	ICC	(95% CI)
LCEA	0.98	(0.96-0.99)	0.95	(0.93-0.96)
TA	0.88	(0.79-0.93)	0.86	(0.81-0.90)
ACEA	0.96	(0.93-0.98)	0.97	(0.95-0.98)
AWI	0.91	(0.84-0.95)	0.87	(0.82-0.91)
PWI	0.87	(0.76-0.92)	0.93	(0.85-0.96)
Intraoperative fluoroscopy	ICC	95% CI	ICC	(95% CI)
LCEA	0.94	(0.83-0.97)	0.79	(0.63-0.87)
TA	0.90	(0.83-0.95)	0.72	(0.48-0.84)
ACEA	0.95	(0.91-0.97)	0.86	(0.81-0.90)
AWI	0.94	(0.89-0.97)	0.87	(0.82-0.90)
PWI	0.97	(0.94-0.98)	0.88	(0.83-0.92)
Postoperative radiograph	ICC	95% CI	ICC	(95% CI)
LCEA	0.81	(0.66-0.89)	0.81	(0.74-0.86)
TA	0.84	(0.71-0.91)	0.83	(0.66-0.91)
ACEA	0.92	(0.85-0.96)	0.88	(0.83-0.91)
AWI	0.72	(0.48-0.85)	0.84	(0.78-0.88)
PWI	0.86	(0.76-0.92)	0.87	(0.83-0.91)

ICC = intraclass correlation coefficient; CI = confidence interval; LCEA = lateral center-edge angle; TA = Tönnis angle; ACEA = anterior center-edge angle; AWI = anterior wall index; PWI = posterior wall index.

Lastly, Bland-Altman analysis was used to further quantify the agreement between intraoperative fluoroscopy and postoperative radiographs, including graphic assessment and the estimation of systematic bias by calculating the mean difference and the 95% limits of agreement (LOAs) between the intraoperative fluoroscopic images and the postoperative radiographs [3, 4].

Results

Radiographic and fluoroscopic measures of anterior, lateral, and posterior coverage of the acetabulum are reliable. Intrarater reliability was excellent for all measures except for postoperative AWI (ICC = 0.72; 95% CI, 0.48-0.85) (Table 1). Interrater reliability was excellent for all measurements except for intraoperative TA (ICC = 0.73; 95% CI, 0.48-0.84) (Table 1).

The agreement between fluoroscopic measures of fragment correction and those obtained on postoperative radiographs generally was good. Agreement between intraoperative fluoroscopy and postoperative radiographs was good for LCEA, TA, AWI, and PWI and excellent for ACEA (Table 2). Bland-Altman analysis for systemic bias in the comparison between intraoperative fluoroscopy and postoperative radiography found the effect of any such bias to be negligible (mean differences: LCEA 2°, TA 2°, ACEA 1°, AWI 0.02, PWI 0.11) (Table 2). Accuracy was also compared by surgeon and there was no difference in accuracy between the two surgeons; all 95% CIs overlapped

Table 2. Agreement between intraoperative fluoroscopy and postoperative radiograph (N = 133)

Acetabular measurement	ICC	95% CI	Mean difference	± SD	95% LOA
LCEA	0.73	0.55-0.83	-2	± 4	-11 to 7
TA	0.66	0.41-0.79	2	± 4	-5 to 10
ACEA	0.80	0.71-0.86	-1	± 5	-12 to 9
AWI	0.63	0.48-0.74	0.02	± 0.10	-0.18 to 0.22
PWI	0.72	0.35-0.85	-0.11	± 0.15	-0.40 to 0.18

ICC = intraclass correlation coefficient; CI = confidence interval; LOA = limits of agreement; LCEA = lateral center-edge angle; TA = Tönnis angle; ACEA = anterior center-edge angle; AWI = anterior wall index; PWI = posterior wall index.

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Table 3. Agreement between intraoperative fluoroscopy and postoperative radiograph (N = 133) by surgeon

Acetabular measurement	Number	ICC	(95% CI)	Mean difference	SD	95% LOA
Surgeon 1						
LCEA	49	0.78	(0.58-0.88)	-2	± 4	(-10 to 6)
AI	49	0.65	(0.34-0.81)	2	± 4	(-6 to 10)
ACEA	49	0.77	(0.57-0.88)	-2	± 6	(-14 to 9)
AWI	49	0.70	(0.45-0.83)	0.04	± 0.10	(-0.16 to 0.24)
PWI	49	0.64	(0.10-0.83)	-0.12	± 0.15	(-0.41 to 0.17)
Surgeon 2						
LCEA	84	0.70	(0.47-0.82)	-2	± 5	(-11 to 7)
AI	84	0.64	(0.35-0.79)	2	± 4	(-5 to 10)
ACEA	84	0.81	(0.71-0.88)	-1	± 5	(-10 to 9)
AWI	84	0.57	(0.34-0.72)	0.01	± 0.10	(-0.19 to 0.21)
PWI	84	0.76	(0.45-0.88)	-0.10	± 0.15	(-0.39 to 0.19)

ICC = intraclass correlation coefficient; CI = confidence interval; LOA = limits of agreement; LCEA = lateral center-edge angle; TA = Tönnis angle; ACEA = anterior center-edge angle; AWI = anterior wall index; PWI = posterior wall index.

(Table 3). The mean correction was 16° for LCEA, 13° for TA, 19° for ACEA, and 0.28 for PWI (Table 4). No change was detected for AWI from preoperative to postoperative radiographs (Table 4).

Discussion

Fluoroscopy is commonly used to judge fragment correction during PAO to correct acetabular dysplasia. Accuracy of fluoroscopy in judging the correction obtained has been demonstrated for LCEA, TA, and ACEA [12, 22]. Our study further validates these three measures as reliable and accurate for judging correction intraoperatively with a mean difference of ≤ 2° for all three measures. In addition, we evaluated the recently described AWI and PWI to judge anterior and posterior wall coverage. We found that these measures were reliable and had good accuracy in determining anterior and posterior coverage similar to the accuracy of the LCEA, TA, and ACEA. This study provides a comprehensive evaluation of the reliability and accuracy of the measures of acetabular coverage in all planes.

Our study has limitations. Because it was retrospective, there was no standardized investigational protocol between the two surgeons for image collection. However, the two surgeons obtained these images in a similar manner and the lack of structured standardization likely makes the study results more generalizable to common surgical practice. Only patients with acetabular dysplasia who were younger than 35 years of age were included in the study. This represents a selection bias and therefore the findings of our study cannot be generalized to patients undergoing PAO for the treatment of femoroacetabular pincer impingement with acetabular retroversion or overcoverage, Perthes deformity, skeletal dysplasia, and revision PAO, or those older than 35 years. Our findings should only be applied to patients with acetabular dysplasia undergoing primary PAO who are younger than 35 years of age. The radiographs used in this study were standing AP pelvis and false

Table 4. Summary of acetabular measurements (N = 133)

Acetabular measurement	Preoperative radiograph		Intraoperative fluoroscopy		Postoperative radiograph		Correction from preoperative to postoperative radiograph	
	Mean	± SD	Mean	± SD	Mean	± SD	Mean	95% CI
LCEA	10	± 8.1	28	± 4.9	26	± 5.4	16	(15-18)
TA	19	± 6.1	4	± 3.5	6	± 4.6	-13	(-14 to -11)
ACEA	10	± 9.9	30	± 6.2	29	± 7.1	19	(17-21)
AWI	0.25	± 0.12	0.25	± 0.09	0.27	± 0.11	0.02	(-0.01 to 0.05)
PWI	0.76	± 0.20	1.14	± 0.16	1.03	± 0.19	0.28	(0.23-0.33)

CI = confidence interval; LCEA = lateral center-edge angle; TA = Tönnis angle; ACEA = anterior center-edge angle; AWI = anterior wall index; PWI = posterior wall index.

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profile radiographs; consequently, these findings cannot be generalized to practices where supine AP pelvis radiographs are the AP image of choice for patient evaluation. Another consideration is the experience of the surgeons who performed the PAOs in this study. Both surgeons had at least 15 years of experience in subspecialized hip preservation practice during the study period and the results may not be generalizable to the novice hip surgeon. Further studies would be useful looking at surgeons earlier in their career. In addition, postoperative radiographs were after osteotomy healing, so we did not account for settling of the fragment or change in pelvic position from acetabular correction or rehabilitation effect on core stability and strength. Finally, there is potential for assessor bias; however, the two readers were not involved in the clinical care of the patients and the readings were set in a blinded fashion.

Most of the measures that we evaluated had excellent intra- and interrater reliability on both fluoroscopic and radiographic images. Few studies have investigated the reliability of fluoroscopy assessment of the acetabular correction during PAO. One small study evaluated multiple measures of correction on fluoroscopy but only had a single reader and confirmed intrarater reliability with a small sample of 10 patients [12]. Therefore, it did not address interrater reliability and was underpowered to address intrarater reliability [12]. A larger study by one of the current authors evaluated the use of the LCEA and TA for intraoperative correction and showed similar intra- and interrater reliability as those reported here for the LCEA and TA [22]. However, this study only looked at lateral coverage with LCEA and TA. It did not evaluate anterior or posterior coverage with ACEA, AWI, and PWI, which is important for assessing PAO correction given that excessive anterior coverage in a detriment to posterior coverage and may cause impingement and impact the long-term survival of PAO [22].

Prior studies looking at the reliability of these measures on AP pelvis radiographs have reported excellent intra- and interrater reliability of the LCEA, TA, and ACEA [9, 14, 16, 20]. The AWI and PWI, measurements of anterior and posterior coverage of the femoral head by the acetabulum and indirect measurements of acetabular retroversion, were reported to have excellent intra- and interrater reliability on radiographic images [2, 19]. Although assessment of these measurements is used to evaluate the appropriate correction of the acetabulum during PAO, there are no studies that we are aware of that have evaluated the reliability and accuracy of these measures during fluoroscopy. We report a comprehensive, well-powered evaluation of reliability of LCEA, TA, ACEA, AWI, and PWI on both radiographic and fluoroscopic images. All measurements exhibited excellent intra- and interrater reliability except for intraoperative fluoroscopic TA, which had good interrater reliability, and postoperative AWI, which showed good intrarater reliability.

Fluoroscopy is commonly used to judge fragment correction during PAO. Prior studies validated the use of LCEA and TA as measures of lateral coverage and showed they were correlated to postoperative radiographs [12, 22]. One study also concluded that the ACEA was accurate with good correlation to postoperative radiographs [12]. However, no study has investigated a comprehensive evaluation of acetabular coverage including anterior, lateral, and posterior coverage measures. We confirm that LCEA, TA, and ACEA are accurate when measuring lateral and anterior coverage of the acetabulum. In addition, we evaluated the accuracy of the AWI and PWI to measure anterior and posterior coverage, respectively. These measures showed good accuracy with postoperative radiographs. The correlation with the wall indices compared with the other measures investigated may be the result of the differing mechanics of fluoroscopy versus radiography [10]. The fluoroscopic images are PA images with the center of the beam closer to the hip, whereas the radiographic images are AP images with the center of the beam in the center of the pelvis. This likely leads to parallax that causes some distortion and in turn inaccuracy of the images when comparing the AWI and the PWI. Given the parallax, there is a tendency to overestimate the PWI with fluoroscopy (mean difference -0.11), so care should be taken not to undercorrect the posterior wall when evaluating fluoroscopically. However, our data suggest the AWI and PWI are still at least good estimators of anterior and posterior coverage of the femoral head when used intraoperatively. This can assist the surgeon in avoiding acetabular retroversion postoperatively that can lead to inferior outcomes of PAO [1]. Understanding the relationship of the anterior and posterior wall coverage is important in comprehensively evaluating coverage of the femoral head. Two independent investigations of different patterns of dysplasia reported the importance of judging anterior and posterior wall coverage of the femoral head [17, 21]. Intraoperative evaluation of the wall indices is especially important when a PAO is used to correct posterolateral instability [5].

Our work further validates the reliability and accuracy of fluoroscopy to judge PAO fragment correction intraoperatively and as an alternative to the intraoperative radiograph. We confirm prior studies that showed that LCEA, TA, and ACEA are reliable and accurate measures of acetabular fragment correction when used fluoroscopically [12, 22]. In addition, we report excellent reliability and good accuracy of the AWI and PWI in judging fragment correction. This can assist with judging acetabular version intraoperatively to help the surgeon avoid retroversion postoperatively that can negatively affect outcomes [1]. Going forward, properly powered direct comparative studies are needed to compare the accuracy of intraoperative

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fluoroscopy and an intraoperative radiograph to judge intraoperative correction, especially when it comes to anterior and posterior wall coverage as measured by the acetabular wall indices. This will help to determine the most effective imaging modality for the assessment of intraoperative PAO correction.

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