Original research

Relationship Between Acetabular Hounsfield Unit Values and Periprosthetic Fractures in Cementless Total Hip Arthroplasty: A Matched Case-Control Study

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ABSTRACT

Background: The association between regional bone status around the acetabulum and the incidence of intraoperative acetabulum fractures has not been extensively studied. We investigated the association of Hounsfield unit (HU) values on computed tomography in the regions of the acetabulum with periprosthetic fractures.
Methods: We retrospectively reviewed records of 301 consecutive patients who underwent cementless total hip arthroplasty between October 2016 and December 2020. Using preoperative computed tomography taken in the 4 weeks preceding total hip arthroplasty, we measured HU values in 4 different acetabulum regions (anterior, medial, posterior, and superior). After identifying fracture cases, we identified a control group—matched in terms of sex, age, and preoperative diagnosis—selected in a 1:3 ratio among nonfracture patients treated in the same inclusive period. As the average HU values differed by region, we used the standardized value to compare fracture-site HUs. We ranked the standardized HU values for each acetabular site and compared the fracture site rank between the groups.
Results: Intraoperative acetabular fractures were observed in 10 hips (3.2%), occurring most frequently in the superior region (40%). The standardized HU values of the fracture site were statistically lower in the fracture group ($P = .039$). We compared the ranks of the standardized HUs of the fractured parts with those of the corresponding parts in the control group; the fracture site had a significantly lower standardized HU rank, indicating that fractures tended to occur in the relatively "weaker-than-expected" parts.
Conclusions: Periprosthetic fractures tended to occur at relatively weak parts of the acetabulum.
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Introduction

Cementless acetabular component fixation is currently the most commonly used technique for acetabular resurfacing of total hip arthroplasty (THA) [1-3]. Its outcomes are excellent, but there are several complications associated with this technique. Intraoperative periprosthetic fractures occur in about 5% of cementless THAs, and most of these fractures are femoral fractures [4-6]. Intraoperative acetabulum fractures are considered relatively rare.

One old report showed that intraoperative acetabulum fractures account for only 0.4% of THA-related fracture on traditional radiographic assessments [7]. The management of these fractures is often challenging, and reports revealed that up to 25% of cases resulted in loosening of the acetabular component with conservative treatment [6,8-10]. These intraoperative acetabulum fractures can occur in various steps of the procedure: during acetabular exposure, acetabular reaming, surgical dislocation of the hip, and, most commonly, insertion of the acetabular component using the press-fit technique [11-14]. Recently, it has been reported that the incidence of intraoperative acetabulum fractures was more likely to be identified using postoperative computed tomography (CT) scans. Studies have reported that >5% of occult intraoperative periprosthetic acetabulum fractures could not be detected using traditional radiographs. It has been suggested that these occult

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periprosthetic acetabular fractures may cause early loosening of the acetabular component [15].

Osteoporosis is considered a risk factor for periprosthetic fractures, including intraoperative hip fractures, and there have been multiple studies that have investigated the relationship between osteoporosis and intraoperative periprosthetic femoral fractures [16,17]. However, there have been few reports on the associations between osteoporosis and intraoperative acetabular fractures. One reason of this discrepancy might be the above-mentioned "false" low incidence of this condition because of limitations in the diagnostic ability of radiographs. Another reason is the availability of bone status assessment tool. The bone mineral density (BMD) of the femur is commonly measured using dual-energy X-ray absorptiometry (DEXA). Although it is possible for DEXA to measure specific regions in the femur, such as femoral neck, trochanteric, or subtrochanteric regions, it is difficult to assess site-specific BMDs in the acetabulum with trajectory-based DEXA because of the complex three-dimensional anatomy of the acetabulum. CT-based BMD assessments have been used for bone status assessment in various anatomical regions. The Hounsfield unit (HU) value on CT was used as a surrogate marker of BMD and can be measured in various anatomical regions, including the pelvis [18-20]. The HU value can be a suitable assessment tool for site-specific bone status evaluation in the acetabulum. To the best of our knowledge, there has been no study investigating the relationship between periprosthetic acetabulum fracture and HU values in the acetabulum.

In this matched case-control study, we hypothesized that intraoperative acetabular fractures, diagnosed by CT, more likely occur in the acetabula with low BMD, as measured by HU values, than in those with high HU values, and the fracture is more frequently located in the "weak" part of the acetabulum when a fracture occurs. Therefore, this study aimed to elucidate (1) the association between intraoperative acetabulum fracture diagnosed by CT and the HU values in the acetabulum and (2) the association between the location of fracture and relative rank of standardized HU values within the same hip.

Material and methods

Patients

This study was approved by the institutional review board (number: 3407), and the requirement for informed consent was waived because of the retrospective nature of the study. We reviewed the records of consecutive patients who underwent cementless THA between October 2016 and December 2020 in an academic tertiary care institution. In total, 335 cementless THA operations (male n = 66, female n = 235) were performed in 301 patients within this period. We excluded cases with revision surgery (n = 11), a history of acetabulum osteotomy (n = 9), septic arthritis of the hip joint (n = 3), or previous acetabular fractures (n = 2). A total of 310 hips (male, n = 58; female, n = 220) in 278 patients were included in this study. Basic demographic information, including age, sex, body mass index, preoperative diagnosis, operative time, and implants, was collected.

Surgical technique

All surgeries were performed by 2 board-certified orthopedic surgeons with over 10 years of experience in hip arthroplasty. The conventional posterior approach was used in all cases. The implants used during the study period were Pinnacle (Depuy Synthes, Warsaw, IN; n = 291), Trident hydroxyapatite hemispheric shell (Stryker, Mahwah, NJ; n = 8), R3 (Smith & Nephew, London, UK; n = 8), G7 (Zimmer Biomet, Warsaw, IN; n = 2), and Delta TT (Lima Corporate, Udine, Italy; n = 1). All acetabular components of the implant systems were hemispherical in shape.

We placed cups at the position of the true acetabulum with the cup center edge at <0° for all patients, except for patients with severe dysplasia (Crowe type 3 or 4) where high position placement might be accepted. The acetabulum was under-reamed by 1 mm, and the acetabular cup was placed using the press-fit impaction technique to secure the initial stability. At the discretion of the 2 surgeons, 1 to 3 screws were routinely inserted regardless of the rigidity of the press fit in all cases.

Table 1
Patient demographics.

Demographics	All patients (n = 278)	Occult fracture group (n = 10)	Control group (n = 30)	P value
Female, n (%)	220 (79.1)	10 (100.0)	30 (100.0)	—
Median, age (range) [y]	66 (22-92)	71.5 (55-89)	70.5 (53-84)	.759
BMI (range) [kg/m²]	23.6 (14.3-44.3)	21.87(18.4-30.8)	23.41 (16.5-42.1)	.367
Preoperative diagnosis, n (%)				
Osteoarthritis	233 (75.2)	8 (80.0)	24 (80.0)	—
Avascular necrosis of the femoral head	38 (12.3)	0	0	—
Rapidly destructive coxopathy	21 (6.8)	1 (10.0)	3 (10.0)	—
Rheumatoid arthritis	10 (3.2)	0	0	—
Femoral neck fracture	6 (1.9)	1 (10.0)	3 (10.0)	—
Pigmented villonodular synovitis	1 (0.3)	0	0	—
Alkaptonuria	1 (0.3)	0	0	—
Operative time (range) [min]	100.6 (51-210)	99.3 (75-138)	96.0 (69-133)	.647
Acetabular cup, n				
Pinnacle	291	9	30	—
Trident	8	1	0	—
R3	8	0	0	—
G7	2	0	0	—
Delta TT	1	0	0	—
Cup size (range) [mm]	51.3 (46-60)	49.8 (48-52)	50.3 (46-54)	.374
Number of screws (range)	1.27 (1-4)	1.5 (1-3)	1.37 (1-3)	.593

Pinnacle (Depuy Synthes, Warsaw, IN), Trident hydroxyapatite hemispheric shell (Stryker, Mahwah, NJ), R3 (Smith & Nephew, London, UK), G7 (Zimmer Biomet, Warsaw, IN), and Delta TT (Lima Corporate, Udine, Italy).
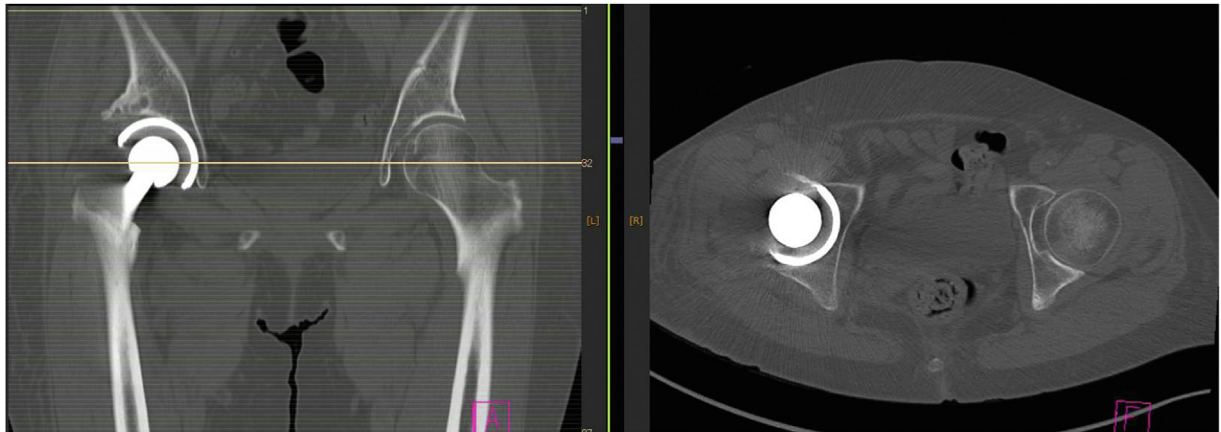BMI, body mass index.

Figure 1. Postoperative coronal computed tomography image of the hip joint. The axial image was sliced at the center of the head.

Radiological assessment for fracture and case-control matching

As part of an institutional quality assessment study, we performed preoperative and postoperative CT scans for templating using a specialized software program within 4 weeks before surgery and for implant position assessment 2 weeks after surgery following the study protocol. Patients also underwent follow-up radiographs immediately after the surgery and at 1, 3, 6, and 12 months postoperatively. A radiological analysis for the detection of acetabular fractures was performed by a board-certified hip surgeon using postoperative CT scans and radiographs. The surgeon was blinded to the patients' information and did not participate in the surgeries.

The periacetabular fractures were classified as follows based on the location of the main fracture line according to the classification of Hasegawa et al. [21]: superior, anterior, posterior, and medial. We selected 3 control patients per one fracture case matched by age, sex, and preoperative diagnosis from nonfracture patients who underwent THA in the same study period (Table 1).

HU measurement

The HU scale is a linear transformation of the original linear attenuation coefficient measurement, which is an analog of radiation transparency, by setting the radiodensity of distilled water at standard pressure and temperature as 0 HU, and that of air as −1000 HU.

All preoperative CT examinations were performed with the 128-slice Siemens CT system (SOMATOM Edge Plus, 120 kVp, 0.75-mm slices; Siemens, Munich, Germany). The HU values of the acetabulum were measured according to the regions representing the fracture classification: medial, anterior, posterior, and superior.

The measurements of HU values in the anterior, posterior, and medial regions were performed using the axial slice of the center of the femoral head (Figs. 1 and 2). For the superior region's HU measurement, the coronal reconstruction slice of the anteroposterior center of the acetabulum was used (Fig. 3). The area of interest was defined as the maximum elliptic mean value that did not include the cortex. Except for the double floor part of the medial wall, the bony cysts were included in the measurement. We defined
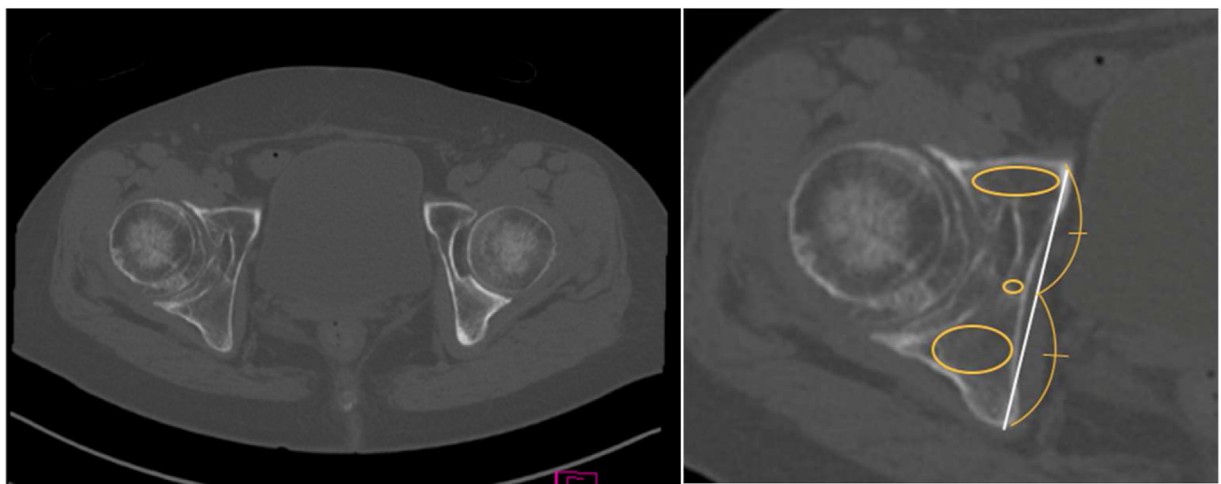

Figure 2. Preoperative axial computed tomography image of the hip joint. Image is at the same level as the postoperative image and sliced at the center of the head. Anterior, posterior, and medial walls were measured with the maximum elliptic mean value and did not include the cortex. The measurement of the medial wall was taken at the bisector of the anterior-posterior diameter of the acetabulum without a double floor.
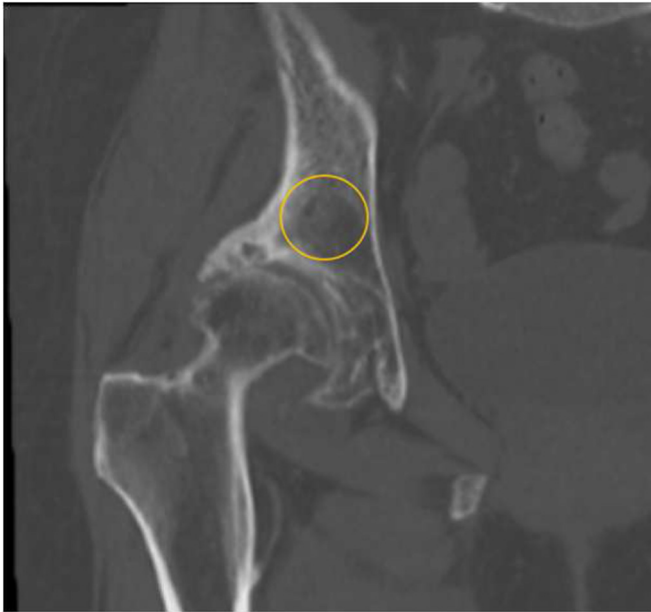
Figure 3. Maximum elliptic mean. In the superior wall, the coronal image at the center of the medial wall was used to measure the maximum elliptic mean without the cortical bone.

the occult fracture as new acetabular fractures that could not be identified on immediate postoperative radiographs but could be identified on postoperative CT, which was same as in previous reports [21,22]. We considered occult fractures to be present fracture line on all axial, sagittal, and coronal CT images.

Moreover, the HUs of the acetabular regions were independently measured by 2 board-certified orthopedic surgeons who did not participate in the surgeries and were blinded to another rater's measurement. The average of the 2 raters' measurements was used for the analysis. Data were also used to assess inter-rater reliability, whereas one of the raters measured the HU values of the acetabulum with a 6-week interval to assess intrarater reliability.

Because the means of HU values were different by regions, we calculated the standardized HU values in each region using the means and standard deviations (SD) of the case and control groups, to make the values comparable. In addition, we ranked the standardized HU values of each part within the same patient from the highest to lowest part (If the standardized HU values in the medial, anterior, posterior and superior regions were −0.32, −0.10, 0.50, and 0.88, respectively, the ranking was as follows: 1 = superior, 2 = posterior, 3 = anterior, and 4 = medial), and we compared the ranks of the fractured part of the fracture group with those of the corresponding parts of the control group.

Statistical analysis

The patient characteristics were described using frequency and percentage for categorical variables, mean and SD, or median and interquartile range, as appropriate. Bivariate analyses of matched case-control groups were conducted using the Mantel-Haenzel test for categorical variables and generalized estimating equations model, accounting for the cluster effect within each case-control group, for continuous variables. Regarding HU values, the standardized HU values in each region using the means and SDs of the case and control groups were calculated. For the statistical analyses of the HU differences between the case and control groups, raw values were used for the comparisons of the average, and in each region, the standardized value was used for the comparisons of fracture-site HU value. The ordinal logistic regression with generalized estimating equation model was used for the comparison of ranks of standardized HU values. Interclass correlation coefficients were calculated for inter-rater/intrarater reliabilities of HU measurements. We defined intraclass correlation coefficient > 0.90 as excellent, 0.75-0.90 as good, 0.50-0.75 as moderate, and <0.50 as poor. The Bland-Altman plots were used for detecting systematic errors. All statistical analyses were performed using R software (version 4.0.3), and statistical significance was defined as $P < .05$.

Results

Patient demographics are shown in Table 1. No intraoperative periprosthetic acetabulum fractures were recognized during the surgery or from the immediate postoperative radiograph. Occult fractures diagnosed by CT were observed in 10 hips (3.2%); 4 were located at the superior, three at the medial, two at the posterior, and one at the anterior region (Table 2). One superior fracture did not involve component-contacting surface (extra-articular), and all the others involved the component-contacting surface. Acetabular components were placed at the position of the true acetabulum in all patients included in the final analysis. The intraclass correlation coefficients for inter-rater and intrarater reliability of each acetabulum site were moderate to excellent (Fig. 4, Table 3). The Bland-Altman plots showed no obvious systematic error (Supplemental File 1).

The result of HU measurement for each acetabular site is shown in Table 4. The HU values in the fracture group were lower than those of the control group. There was a statistically significant difference in HU values using the standardized values between the 2 groups at the fracture site ($P = .039$). Comparing the ranks of the standardized HU of the fractured part of the fracture group with those of the corresponding parts of the control group, the fracture site had significantly lower standardized HU rank, indicating that the fracture tended to occur in the relatively "weaker-than-expected" parts (Table 5).

Table 2
The details of the occult fracture cases.

	1	2	3	4	5	6	7	8	9	10
Sex	Female	Female	Female	Female	Female	Female	Female	Female	Female	Female
Age (y)	67	69	84	81	70	73	55	64	63	89
Preoperative diagnosis	OA	OA	OA	OA	OA	OA	RDC	OA	OA	FNF
Side	Right	Left	Left	Right	Right	Right	Left	Right	Left	Right
Acetabular cup	Pinnacle gription	Pinnacle gription	Pinnacle gription	Trident	Pinnacle gription	Pinnacle gription	Pinnacle gription	Pinnacle gription	Pinnacle gription	Pinnacle gription
Cup size (mm)	48	52	52	48	50	48	48	50	50	52
Fracture location	Superior	Medial	Superior[a]	Superior	Posterior	Anterior	Superior	Medial	Posterior	Medial

FNF, femoral neck fracture; OA, osteoarthritis; RDC, rapidly destructive coxopathy.
[a] Extra-articular.

All patients with fracture eventually achieved bone fusion with 1-year postoperative follow-up. No patient had a dislocation or cup loosening during the study period. No significant difference was noted in the mean numerical rating scale 1 week after THA (2.6 vs 1.6, $P = .375$) or numerical rating scale at discharge (0.7 vs 0.1, $P = .250$).

Discussion

In this study, we found that patients with intraoperative acetabulum fracture had lower HU values at the fracture site than the patients without fractures. There have been various reports on periprosthetic fractures of the acetabulum; however, only a few reports have evaluated the relationship between CT-based HU value and the incidence of acetabular fractures. Moreover, the fracture tended to occur in the relatively weak part of the acetabulum.

We used postoperative CT for the detection of acetabulum fracture There are multiple reports showing the usefulness of CT to diagnose occult periprosthetic fractures. The reported incidence of these fractures using CT was over 10-fold higher than that using traditional radiographs [7]. Hasegawa et al. [21] reported that 41 of 486 hips (8.4%) had an occult fracture diagnosed only by postoperative CT. Another report demonstrated that 16 of 232 hips (6.9%) that underwent cementless THA had an occult fracture [22]. In the present study, occult fractures were observed in 10 hips (3.2%). Although the results varied by studies, the sensitivity of CT for intraoperative acetabular fracture is substantially higher than that of radiographers.
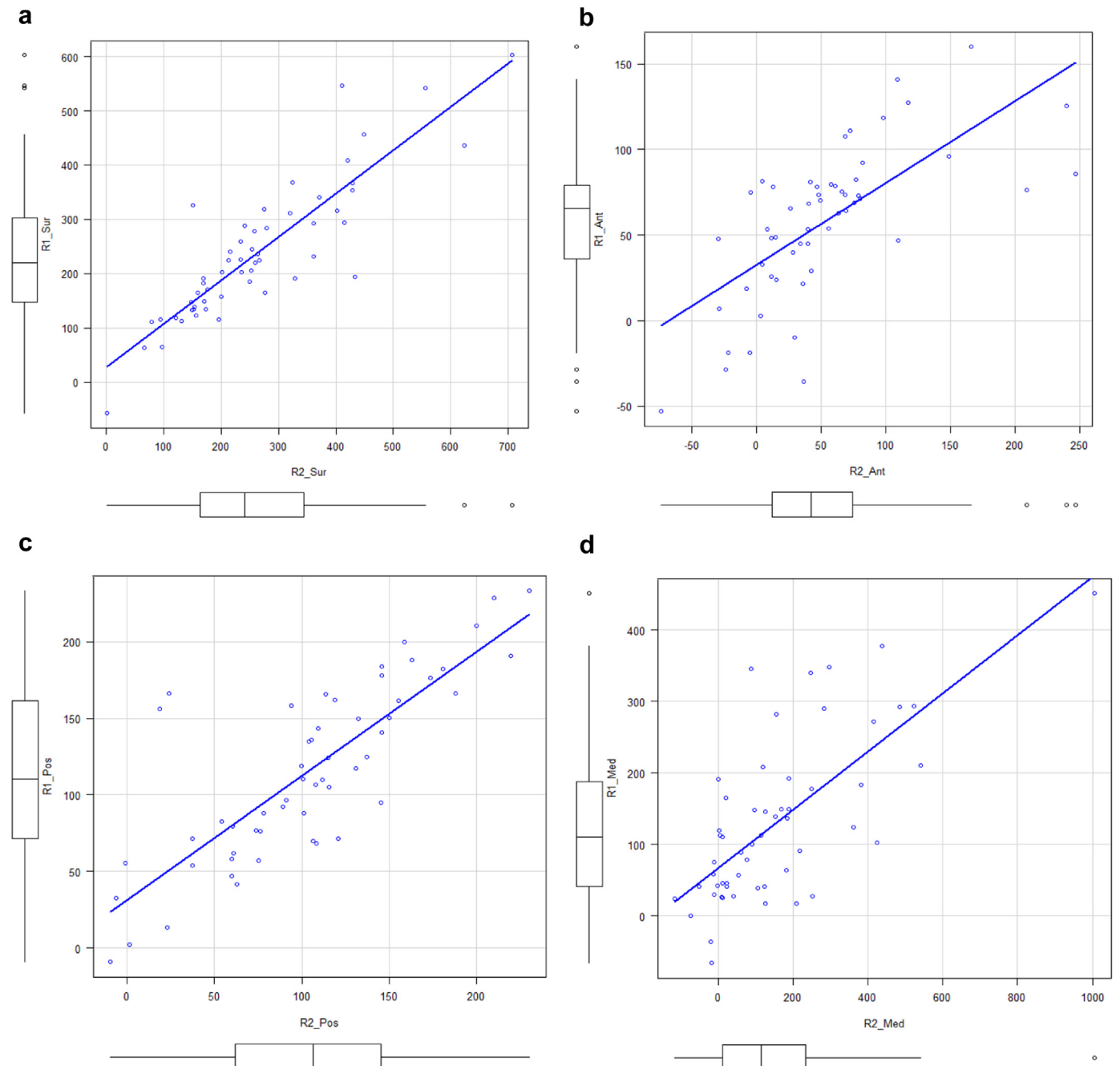

Figure 4. Scatter plot of reliability at each region of the acetabulum. The plot shows inter-rater reliability assessed at the (a) superior, (b) anterior, (c) posterior, and (d) medial walls.

Table 3
The ICCs for inter-rater and intrarater reliabilities of acetabular Hounsfield unit measurements.

	Inter-rater reliability	Intrarater reliability
	ICC (LCL-UCL)	ICC (LCL-UCL)
Medial	0.61 (0.41-0.75)	0.76 (0.63-0.86)
Anterior	0.64 (0.46-0.74)	0.74 (0.6-0.84)
Posterior	0.80 (0.67-0.88)	0.85 (0.74-0.92)
Superior	0.86 (0.75-0.92)	0.95 (0.91-0.97)

ICC, intraclass correlation coefficient; LCL-UCL, lower and upper bound 95% confidence interval.

The shape of the acetabular cup and press-fit impaction technique are considered the potential risk factors for intraoperative fracture. Some studies suggested that the shape of the acetabular component could be a risk factor. Previous reports revealed that press-fit impaction of a nonhemipherical elliptical cup is more likely to cause intraoperative fracture of the acetabulum than press-fit impaction of a hemispherical cup [7,23,24]. Hasegawa et al. reported that the nonhemispherical peripheral self-locking cup is predominantly associated with the occurrence of occult fractures [21]. In their study, nonhemispherical cups were used in 264 of 486 (55%) cases, and in 30 of 41 cases of acetabular fractures, nonhemispherical cups were used [21]. The incidence of occult fracture in the nonhemispherical cup was 11.4%, whereas that of hemispherical cup was 5.0%. Contrarily, Yun et al. reported less difference between nonhemispherical and hemispherical cups [22]. In their study, a nonhemispherical cup was used in 92 of 232 (40%) cases; and occult fractures were found in 9 of 140 (6.4%) cases for hemispherical cup and 7 of 91 (7.7%) cases for nonhemispherical cup [22]. In our study, only the hemispherical cups were used. Although it is still controversial, this may explain the lower incidence of occult fractures in our study.

Yun et al. also reported that reducing the amount of under-reaming may help to reduce the risk of periprosthetic acetabular fractures [22]. In our study, the acetabulum was under-reamed by 1 mm in all cases, similar to the tudy by Yun et al. [22]. There is still little evidence of the ideal amount of under-reaming, and further studies are required. However, it may be a safe option to avoid under-reaming over 1 mm to minimize the risk of fracture. One potential disadvantage of minimum under-reaming is the risk for fixation failure of the acetabular cup. As a countermeasure to this problem, screw fixation may be beneficial, especially for patients with bone fragility [21,22,25].

Previous studies demonstrated that the common fracture locations were the superior and medial regions [21,22], which are consistent with our results. One possible reason is the directions of applied force during cup insertion, which are medial and superior. In addition, the combination of sclerosis and force might be an issue. Hasegawa et al. reported that the bone quality of the superior wall is usually dense or sclerotic, and mechanical stress during press-fit fixation may be concentrated in the superior wall [21] because a biomechanical study demonstrated that the higher seating force, especially associated with a peripheral self-locking design, may result in an increased risk of fractures in high-density bone stock [26]. In terms of the medial wall, excessive reaming and medialization of cup might have played roles. Takigami et al. [27] reported that inappropriate acetabular reaming causes pelvic discontinuity. Based on biomechanical studies, Sanki et al. [28] reported that the thicknesses of the medial cortex and acetabular cancellous bone were important factors to avoid acetabulum fracture during cementless cup insertion. Surgeons should be aware of the fact that these technical factors might cause intraoperative acetabular fractures.

We used HU values on CT as the surrogate marker of BMD. To the best of our knowledge, there has been no study using the acetabulum HU values. However, this method has been used in previous studies investigating bone status in various anatomical regions, such as the proximal femur and spine [18-20]. There have been several reports on the close relationship between HU values and fractures. Christensen et al. [29] reported that the proximal femoral HU value was a long-term predictor of the incidence of proximal femoral fracture. Lee et al. [30] reported that a low HU value in the lumbar spine is closely associated with fragility fracture incidence. There was one report investigating the association between HU value and THA-related fractures. Kim et al. reported that a low preoperative proximal femoral HU value is associated with the presence of intraoperative periprosthetic fractures of the femur [31]. According to our results, occult fracture occurrence was significantly higher in cases with low HU values than in the control group. This result is comparable to those of studies on other body parts.

According to Hasegawa et al., the risk of intraoperative periprosthetic acetabular fracture was not associated with absolute bone density [21]. The risk of fracture is due to the combined bone strength and force applied during cup insertion. Fractures can occur in areas with sufficient bone stock [15,21,22]. Sharkey et al. [24] reported that sclerotic unyielding bone combined with under-reaming and osteoporosis may be a predisposing factor of fracture. We used the standardized values of each acetabular site and showed that the fractures occurred in areas of relative bone fragility. Although the exact mechanism of this result is yet to be determined, we believe this information will be of value for the prevention and early diagnosis of intraoperative acetabular fractures. If one part of the acetabulum showed an unproportionally low value, a modification of surgical technique and careful postoperative evaluation may be needed as this part has a higher risk for fracture.

The sample size of our study might have been insufficient to demonstrate that occult fracture was associated with poor outcomes. However, previous reports have shown that fractures were

Table 4
Hounsfield unit measurement at each site of the acetabulum in the fracture and control groups.

Site	Occult fracture		Control		P value
	HU value	Standardized value	HU value	Standardized value	
Average	119.10 (67.28)	−0.34 (1.06)	148.34 (62.88)	0.11 (0.99)	.210
Medial	98.65 (85.94)	−0.30 (0.75)	144.01 (123.83)	0.10 (1.08)	.284
Anterior	54.68 (45.56)	0.23 (1.28)	52.04 (45.52)	0.35 (1.27)	.834
Posterior	97.24 (47.66)	−0.05 (1.12)	110.67 (59.68)	0.40 (1.34)	.519
Superior	225.82 (160.73)	−0.34 (1.20)	286.65 (126.31)	0.11 (0.94)	.218
Fracture site	102.57 (90.74)	−0.66 (0.80)	176.70 (130.15)	0.07 (1.00)	.039[a]

Data are expressed as means (standard deviations).
[a] Significant difference ($P < .05$).

Table 5
Standardized score rank of the fracture site.

Rank	Fracture	Control	P value
1	0 (0.0)[a]	6 (20.0)[a]	.009[c]
2	1 (10.0)[a]	9 (30.0)[a]	
3	4 (40.0)[a]	9 (30.0)[a]	
4	5 (50.0)[a]	6 (20.0)[a]	
Mean (SD)	3.40 (0.70)[b]	2.50 (1.04)[b]	.011

[a] Number of hip (%).
[b] Means (standard deviations) calculated as continuous values.
[c] Ordinal logistic regression analysis. Significant difference ($P < .05$).

associated with poor outcomes; thus, we believe that fracture is a potential factor for poor outcomes. Performing preoperative and postoperative CT for all patients with low bone density is challenging owing to the cost and exposure hazards associated with CT. However, we believe that if CT is obtained for other reasons, the HU values should be measured. Further research is needed to calculate cutoff values in each acetabular location for high risk of fracture and combine the results with DEXA to screen patients who need CT.

This study has several limitations. First, the number of fracture patients were low, and the adjustment of confounding factors was limited. Although all surgeries were performed with the posterior approach, the details of surgical technique and implants used were not standardized. In the fracture group, Pinnacle was used for 9 patients, whereas Trident was used for 1 patient.

Although all the implants were hemispherical in shape, various implants were used during the study period. The optimal technique, such as the amount of reaming, might differ based on the implant. Because we did not routinely measure BMD with DEXA or quantitative CT, it is not possible to directly compare BMD with HU values. In additon, our patients were predominantly female and only East Asians [32]. Because racial differences in the bone quality and the risk of osteoporosis have been reported, care must be taken when applying these results to other patient populations. These results demonstrated that occult fractures had no significant impact on the short-term outcomes. However, long-term clinical data were not available; thus, whether these fractures affect the long-term outcomes should be clarified. In addition, only limited outcome data were available owing to the retrospective nature of this study. Functional outcomes and patient-reported outcome measures, including patients' satisfaction with THA, were not analyzed in this study. These issues should be addressed in future studies.

Conclusions

Intraoperative acetabulum fractures were predominantly observed in the superior acetabular wall. The HU values in the fracture site were significantly lower in the fracture group. The comparison of the ranks of the standardized HU of the fractured part of the fracture group with those of the corresponding parts of the control group demonstrated that the fracture site had significantly lower standardized HU rank, indicating that the fracture tended to occur in the relatively "weaker-than-expected" parts.

Conflicts of interest

The authors declare that there are no conflicts of interest.
For full disclosure statements refer to https://doi.org/10.1016/j.artd.2021.11.016.

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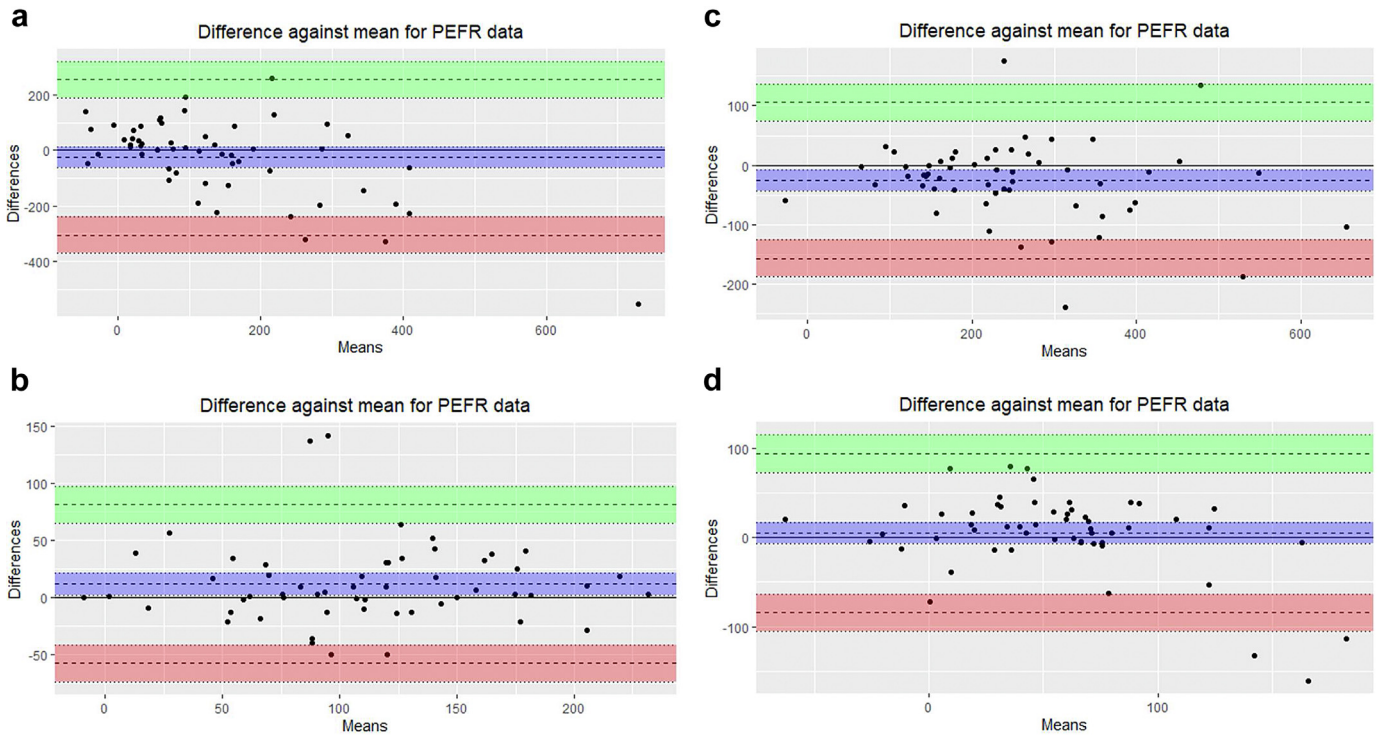
Supplemental File 1. Bland-Altman plot for inter-rater reliability analysis of each acetabulum location. The limits of agreement are shown as dotted, black lines with 95% confidence intervals (green and red areas), bias (as dotted black line) with 95% confidence intervals (blue area), and regression fit of the differences of the means (as solid black line). (a) Medial wall. (b) Posterior wall. (c) Superior wall. (d) Anterior wall.