



# Postoperative computed tomography assessment of anteromedial cortex reduction is a predictor for reoperation after intramedullary nail fixation for pertrochanteric fractures

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## Abstract

**Purpose** Postoperative radiographs are routinely used to assess fracture reduction following intramedullary nail fixation for pertrochanteric fractures, even though computed tomography (CT) is a superior modality. We aimed to determine the association between reduction quality assessed by CT and rates of reoperation and to evaluate the association of reoperation and reduction quality according to the assessment modality (plain radiographs vs. CT).

**Methods** A retrospective analysis of 299 consecutive patients treated with intramedullary nail fixation for pertrochanteric fractures was conducted. Fracture reduction measured by postoperative radiographs and CT was categorized as anatomical type, extramedullary type, or intramedullary type. Postoperative data for analysis included reduction status, tip-apex distance (TAD), screw position in the femoral head, sliding distance, and conditions associated with reoperation.

**Results** Of the 299 patients included with a mean age of  $83.1 \pm 8.2$  years, there were six patients who required reoperation (2.0%). According to the CT assessments, there were 42 intramedullary reductions (14.0%). Patients with a non-intramedullary reduction based on postoperative CT images were significantly more likely to have proper placement of the screw, a reduced TAD, a reduced sliding distance, and a lower reoperation rate than those with an intramedullary reduction ( $P < 0.05$ ). The reduction quality assessed by postoperative CT was significantly associated with reoperation (95% CI, 1.45–29.31).

**Conclusions** Intramedullary reduction assessed by CT was associated with reoperation. The reduction quality based on CT findings was more predictive for reoperation than that from plain radiographs.

**Keywords** Intramedullary nail · Pertrochanteric fracture · Postoperative computed tomography · Reduction · Reoperation · Trochanteric fracture

## Introduction

Several studies have reported a cut-out failure rate of 1–2% following internal fixation for pertrochanteric fractures [1–4]. Radiographs are often used to assess and classify postoperative fracture reduction, typically employing the Baumgaertner criteria [5] and the criteria based on the anteromedial cortex [2, 6, 7]. The factors that assess the quality of fracture reduction and risk of cut-out include the Baumgaertner criteria [3, 8], anteroposterior (AP) radiograph

assessment [9], and lateral radiograph assessment for the anteromedial cortical reduction [1, 2]. However, previous studies on other fractures have shown that postoperative computed tomography (CT) is a superior modality for evaluating fracture reduction [10–12].

Recent CT-based studies on pertrochanteric fractures have reported that patients with good reduction experience significantly better clinical and radiological outcomes than those with poor reduction [11, 12]. However, to the best of our knowledge, only one study has reported on the efficacy of CT assessment for predicting reoperation [12]. Therefore, more information is needed to determine whether a CT assessment of the fracture reduction is highly accurate for predicting clinical outcomes.

This study aimed to determine the association between reduction quality according to postoperative CT findings and reoperation following intramedullary nail fixation for

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perthrochanteric fractures. In addition, we assessed whether postoperative plain radiograph or CT more accurately predicted reoperation. We hypothesized that adequate reduction based on postoperative CT images would be associated with a low incidence of reoperation.

## Materials and methods

### Study design

We conducted this retrospective cohort study at a single general hospital according to the principles developed by the World Medical Association's Declaration of Helsinki. The study protocol was approved by the appropriate ethics committee (Approval No. 906).

### Patients

Data for 386 consecutive patients with AO Foundation/Orthopedic Trauma Association (AO/OTA) 31-A1 and 31-A2 fracture types [13] who underwent intramedullary nail fixation for an acute pertrochanteric fracture between May 2006 and April 2020 at a single general hospital were collected. The inclusion criteria were patients older than 60 years of age with a postoperative follow-up period of at least 3 months. The exclusion criteria were the presence of pathologic fractures, previous surgery for an ipsilateral proximal hip fracture, and missing postoperative CT assessment. After completing the data collection process, we excluded one patient with previous surgery for a proximal hip fracture and 86 patients without postoperative radiographs and CT assessments. After excluding 87 patients, 299 patients were included for the final analysis. Patients provided written informed consent to participate in the study.

### Surgical procedures

Patients underwent a closed reduction that was performed on a fracture table under fluoroscopic guidance. If adequate fracture reduction was not achieved, an anteromedial cortical reduction was performed via an additional mini-open reduction procedure [14]. A proximal femoral nail antirotation (PFNA) (DePuy Synthes, Warsaw, IN, USA), Japanese PFNA, Trigen InterTAN (Smith & Nephew plc, Watford, England, UK), Natural Nail Cephalomedullary Asia Nail (CM; Zimmer Biomet, Warsaw, IN, USA), or OM Femoral Nail System-ASULOCK (Japan Medical Dynamic Marketing, Tokyo, Japan) was selected as the intramedullary nail used during surgery based on the surgeon's preference. If a fracture gap remained after the nail was inserted, the surgeon reduced it intraoperatively with a compression technique specific for each implant.

### Preoperative measurements

Two orthopedic surgeons reviewed patient medical records. Demographic data included age, sex, height, body weight, dual-energy X-ray absorptiometry, total hip and lumbar spine T-score values, American Society of Anesthesiologists physical status, and AO/OTA fracture classification [13].

### Postoperative measurements

The primary outcome in this study was reoperation, and the secondary outcome was the sliding distance. Postoperative variables included reduction status on the radiographs and CT images following pertrochanteric fracture surgery, implant type, tip-apex distance (TAD) [5], the position of the screw in the femoral head [3, 15], the sliding distance at the 2-week and 3-month follow-up [1], and conditions associated with reoperation, such as screw cut-out, screw cut through, non-union, or implant breakage. The screw positioning of the femoral head was defined as proper if the fixation device was placed at the center-center or the center-inferior position of the femoral head on the radiographs [15]. The sliding distance was measured after calibrating based on the lag screw diameter, such as the TAD measurement. Follow-up radiographs were obtained until the bone union was achieved.

### Evaluation of the quality of the reduction

The overall alignment of the fracture reduction was assessed according to the Baumgaertner criteria [5]. The Baumgaertner criteria were categorized as good, acceptable, or poor based on displacement and alignment of the fracture with postoperative radiographs [5]. The anteromedial cortex reduction was assessed on the AP and lateral radiographs [4] and CT images. To obtain stability, the anteromedial cortex was used to reduce the pertrochanteric fracture [11]. The anteromedial cortex fracture reduction quality was classified as anatomical, extramedullary, or intramedullary based on the relationship between the proximal fragment (femoral head-neck) and the distal fragment (femoral shaft) on the postoperative AP and lateral radiographs, and the three-dimensional and multiplanar reconstruction CT images [1, 4, 11]. CT images with a 2-mm slice thickness were obtained using a 64- or 256-slice multidetector CT scanner depending on the period of the patient's presentation. The CT images were reviewed with a digital picture archiving and communication system that used standard resolution monitors. The borderline for the anteromedial cortex's bone contact area was defined as half of the cortical thickness on both plain radiographs and CT images. A bone contact area of over

half of the cortical thickness was classified as an anatomical type (Fig. 1A, B). The extramedullary type was defined by a head-neck fragment located over half of the cortical thickness medially or anteriorly to the cortex of the femoral shaft (Fig. 2A, B). The intramedullary type was defined by a head-neck fragment located over half of the cortical thickness laterally or posteriorly to the cortex of the femoral shaft (Fig. 3A, B). The anatomical and extramedullary types in this study were considered adequate reductions based on postoperative CT findings [1, 2, 11, 12].

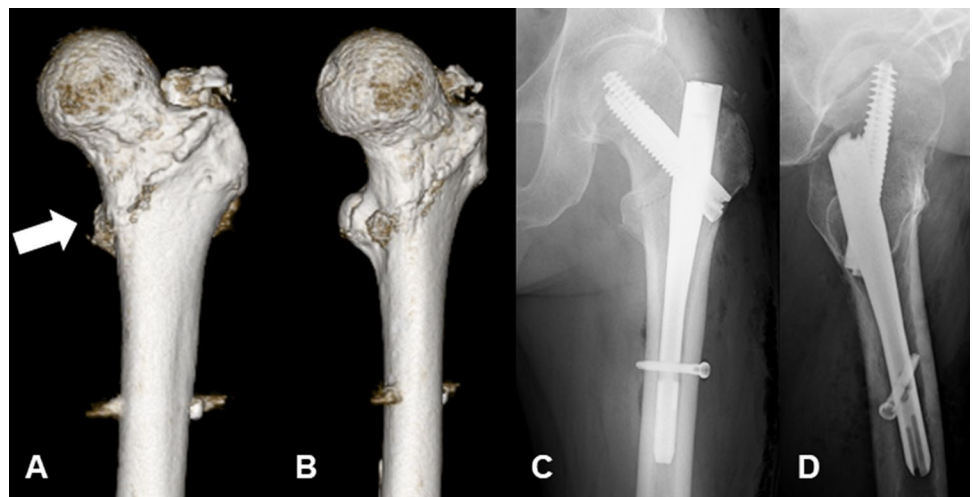
Two orthopedic surgeons with 11 and 12 years of orthopedic experience independently classified the anteromedial cortex fracture reduction as adequate or inadequate based on postoperative CT images. The interobserver reliability was estimated with intraclass correlation coefficients (ICCs). Based on a similar study [17], an ICC of 0.7 (substantial agreement) was defined as acceptable inter-rater reliability. We defined an error margin of 20% to calculate the sample size using sample size calculations for Cohen's Kappa [18]. Because a minimum of 51 cases was needed to examine

the ICC [19], we ultimately assessed 63 cases to accommodate possible cases with an unclassifiable fracture reduction type. The two surgeons with knowledge of the criteria independently measured the postoperative CT images of the 63 randomly selected cases. One month after the initial assessment, one surgeon repeated the measurements of the 63 postoperative CT images to assess intraobserver reliability.

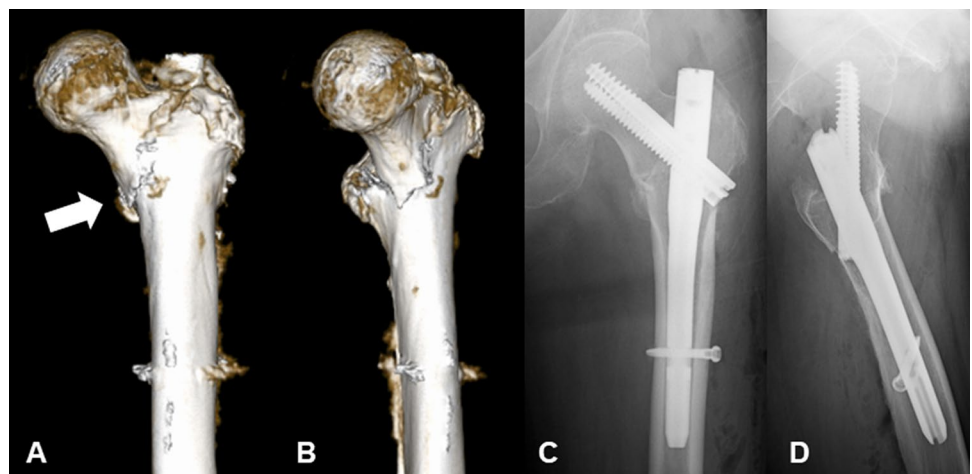
### Statistical analysis

Data are presented as mean  $\pm$  standard deviation unless otherwise stated. In comparisons between the two groups for categorical variables, when the expected value in one of the table cells is less than 5, we used Fisher's exact test; otherwise, we used the chi-squared test. A Student's *t*-test or Mann-Whitney *U* test was used for continuous variables according to the data distribution confirmed for normality by a Kolmogorov-Smirnov test. Differences among the three groups were compared using one-way analysis of variance.

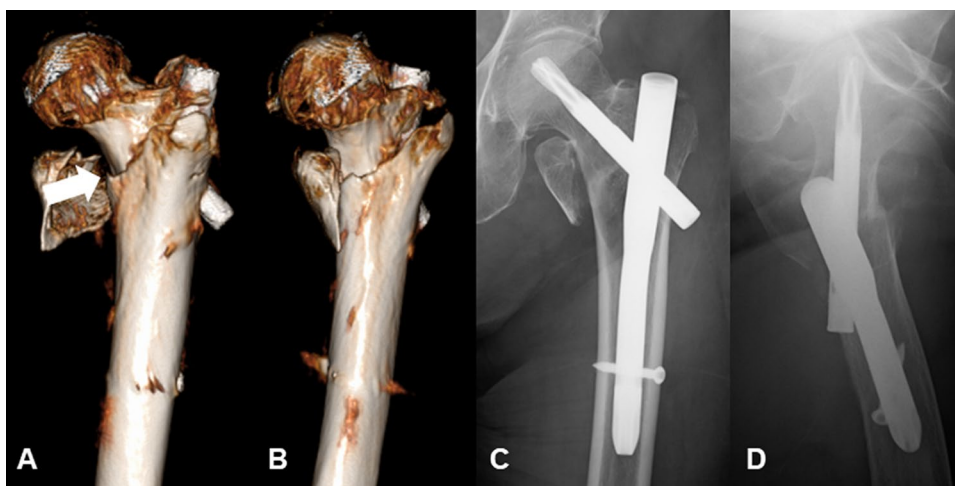
**Fig. 1** A, B Three-dimensional computed tomography of the anatomical reduction type. The bone contact area is over half of the cortical thickness of the anteromedial cortex (arrow). Anteroposterior (C) and lateral (D) plain radiographs



**Fig. 2** A, B Three-dimensional computed tomography of the extramedullary reduction type. The head-neck fragment is located over half of the cortical thickness both medially and anteriorly to the cortex of the femoral shaft (arrow). Anteroposterior (C) and lateral (D) plain radiographs



**Fig. 3** **A, B** Three-dimensional computed tomography of the intramedullary reduction type. The head-neck fragment was located over half of the cortical thickness laterally and posteriorly to the cortex of the femoral shaft (arrow). Anteroposterior (**C**) and lateral (**D**) plain radiographs



All of the tests were two-sided, and  $P < 0.05$  was considered statistically significant.

Using the weighted Cohen's Kappa coefficient, ICCs were evaluated to determine interobserver and intraobserver agreement [18]. Statistical analyses were performed using Stata MP 16.0 (StataCorp, Texas, USA) and R version 3.5.0 (R Foundation for Statistical Computing, Vienna, Austria).

## Results

Of the study population with a mean age of  $83.1 \pm 8.2$  years at operation, there were 237 women (79.2%) and 62 men (20.7%). Six patients required reoperation (2.0%), including four for cut-out, one for blade perforation, and one for non-union. Table 1 summarizes the patients' baseline characteristics and radiographic findings. The adequate reduction group had a higher proportion of patients with proper screw placement compared to the inadequate reduction group (93.8% vs. 81.0%,  $P = 0.01$ ). The TAD was significantly lower in the adequate reduction group than in the inadequate reduction group. The mean TAD for both groups was less than 25 mm [20]. At two weeks, the sliding distance was significantly reduced in the adequate reduction group compared with the inadequate reduction group. A higher proportion of patients with an inadequate reduction underwent reoperation than those with an adequate reduction (7.1% vs. 1.2%,  $P = 0.04$ ).

Table 2 summarizes the findings from the postoperative CT assessments according to the quality of anteromedial cortex fracture reduction (anatomical, extramedullary, or intramedullary). The radiological findings indicated improved outcomes in the following order: extramedullary, anatomical, and intramedullary types.

Table 3 shows the association between reoperation and reduction quality according to postoperative plain radiographs or CT assessments. No poor reductions were

identified according to the Baumgaertner criteria. The reduction quality assessed with postoperative CT images was significantly associated with reoperation. Inadequate reduction for reoperation had a 50.0% sensitivity, 86.7% specificity, positive likelihood ratio of 3.76, negative likelihood ratio of 0.58, and an odds ratio of 6.51 (95% confidence interval [CI], 1.45–29.31).

Findings of inadequate reductions based on the AP view were consistent on postoperative CT and were highly predictive of an inadequate reduction (7/7 cases, 100%) (Table 4). An adequate reduction based on the lateral view was more predictive for an adequate reduction based on postoperative CT compared with the AP view (92.5% [246/266 cases] vs. 88.0% [257/292 cases]). However, an adequate reduction based on both AP and lateral views less accurately predicted adequate reduction compared to postoperative CT (246/261 cases, 94.3%).

The interobserver agreement for reduction quality based on postoperative CT was moderate with a kappa value of 0.52 (95% CI 0.31–0.68). The intraobserver agreement was substantial with a kappa value of 0.86 (95% CI 0.78–0.91).

## Discussion

Our results show that the intramedullary reduction as assessed by postoperative CT was an important indicator for reoperation. The reduction quality based on the postoperative CT assessment was more predictive for reoperation than the plain radiograph assessment following intramedullary nail fixation for pertrochanteric fractures.

The extramedullary and anatomic reductions on postoperative CT assessments showed a reduced sliding distance and was associated with a reduced reoperation rate compared to that in patients with intramedullary reduction. Based on our findings, we propose that postoperative CT assessment

**Table 1** Baseline characteristics and radiographic findings of patients with pertrochanteric fractures

	The quality of the anteromedial cortex fracture reduction on postoperative computed tomography		p value
	Adequate reduction (n = 257)	Inadequate reduction (n = 42)	
Age (years)	83.1 ± 8.2	83.2 ± 8.7	0.96
Women, n (%)	204 (79.4)	33 (78.6)	1.00
Height (cm)	149.9 ± 8.8	149.6 ± 9.9	0.81
Body weight (kg)	48.2 ± 9.9	45.3 ± 9.1	0.08
T score (femur)	- 3.1 ± 1.1	- 3.0 ± 1.2	0.74
T score (lumbar)	- 2.2 ± 1.4	- 2.2 ± 1.2	0.96
ASA (1/2/3)	5/190/62	0/32/10	1.00
Fracture side, Right, n (%)	123 (47.9)	19 (45.2)	0.86
AO/OTA fracture classification (1.2/1.3/2.2/2.3)	36/13/182/26	2/2/32/6	0.33
Implant type (ASULOCK/CM/INTERTAN/PFNA/PFNAJ)	6/23/121/27/80	0/3/13/3/23	0.08
Proper screw placement, n (%)	241 (93.8)	34 (81.0)	0.01
TAD (mm)	15.7 ± 4.9	18.2 ± 7.5	0.01
Neck-shaft angle (degree)	132.3 ± 4.2	132.4 ± 4.8	0.82
Sliding distance, 2 weeks (mm)	2.9 ± 3.0	5.2 ± 3.9	< 0.01
Sliding distance, 3 months (mm)	5.1 ± 4.0	6.8 ± 5.3	0.05
Reoperation, n (%)	3 (1.2)	3 (7.1)	0.04

Values are presented as mean ± standard deviation or n(%), ASA American Society of Anesthesiologists physical status, TAD tip-apex distance, OM Femoral Nail System- ASULOCK (JMDM); Natural Nail Cephalomedullary Asia Nail (ICM); Zimmer Biomet); Trigen *InterTAN* (Smith & Nephew); Proximal femoral nail antirotation ([PFNA]; DePuy Synthes), Japanese PFNA

**Table 2** Radiographic outcome according to the quality of fracture reduction on anteromedial cortex with postoperative CT

	Adequate reduction		Inadequate reduction Intramedullary type (n = 42)	p value
	Extramedullary type (n = 122)	Anatomical type (n = 135)		
TAD (mm)	14.8 ± 4.5	16.4 ± 5.1	18.2 ± 7.5	< 0.01
Sliding distance, 2 weeks (mm)	2.8 ± 3.2	3.0 ± 2.8	5.2 ± 3.9	< 0.01
Sliding distance, 3 months (mm)	4.6 ± 3.7	5.6 ± 4.3	6.8 ± 5.3	0.02
Reoperation	1 (0.8)	2 (1.5)	3 (7.1)	0.04

Values are presented as mean ± standard deviation or n (%). TAD tip-apex distance  
Differences among the three groups were compared using a one-way analysis of variance

could play a valuable role in the evaluation of reduction quality and selection of rehabilitation program. Our findings also revealed that an intramedullary reduction type was associated with the intraoperative necessity of open reduction. If there is any doubt about intramedullary reduction, then sufficient procedures must be performed to achieve an extramedullary or anatomic reduction.

Regarding adequate reduction, the extramedullary reduction achieved a slightly reduced sliding distance and a reduced reoperation rate compared with the anatomic reduction. After internal fixation, the head-neck fragment

could slide along the lag screw distally. Specifically, three-dimensional motions, which are translation and rotation motions between the lag screw and the femoral head along the screw axis, occur due to motion or weight-bearing of the leg after the operation [21, 22]. However, the femoral head is often located slightly anterior and inferior to the femoral neck [23]. Consequently, the lag screw axis is rarely perfectly placed in the anatomical femoral neck axis. Therefore, the extramedullary reduction may provide a wide range of tolerance, which allows the fracture fragments to come into bone contact, achieve bone-to-bone stability, and avoid

**Table 3** Association between reoperation and reduction quality

	Reoperation, <i>n</i> (%)	Sensitivity, (%)	Specificity, (%)	OR (95% CI)
<i>Reduction according to Baumgaertner criteria</i>				
Good	6 (2.2)	–	–	Reference
Acceptable	0	0	93.2	0
<i>Postoperative X-ray, AP</i>				
Adequate	6 (2.1)	–	–	Reference
Inadequate	0	0	97.6	0
<i>Postoperative X-ray, lateral</i>				
Adequate	4 (1.5)	–	–	Reference
Inadequate	2 (6.1)	33.3	89.4	4.23 (0.82–20.73)
<i>Postoperative CT</i>				
Adequate	3 (1.2)	–	–	Reference
Inadequate	3 (7.1)	50.0	86.7	6.51 (1.45–29.31)

*AP* anteroposterior

**Table 4** Association of reduction quality between postoperative XP and CT

Postoperative X-ray			Postoperative CT	
AP view	Lateral view	<i>n</i>	Adequate reduction <i>n</i> , (%)	Inadequate reduction <i>n</i> , (%)
Adequate reduction	Adequate reduction	261	246 (94.3)	15 (5.7%)
Adequate reduction	Inadequate reduction	31	11 (35.5)	20 (64.5%)
Inadequate reduction	Adequate reduction	5	0 (0)	5 (100%)
Inadequate reduction	Inadequate reduction	2	0 (0)	2 (100%)

*AP* anteroposterior, *CT* computed tomography

implant failure in a so-called "controlled collapse" until the fracture has healed [24].

CT was superior to radiography for the evaluation of postoperative reduction. A substantial number of patients with seemingly adequate reduction according to radiograph images were found to have an inadequate reduction on CT images. Our findings revealed that the postoperative CT classification for fracture reduction had moderate inter-rater reliability agreement and substantial intra-rater reliability agreement. This study revealed that inadequate reduction in the AP view, which meant that there remained a varus displacement of the head-neck fragment, corresponded to an inadequate reduction according to CT findings. However, adequate reduction in AP and lateral views (5.7%) could not predict the true adequate reduction based on CT findings. Plain radiographic images are frequently compromised because they are two-dimensional images; thus, it is often difficult to resolve the precise relationship between structures along the course of the radiographs and to distinguish objects with similar densities, which is the case for different fracture types [25, 26]. Postoperative CT is particularly useful to check for loss of reduction when the surgeon suspects inadequate reduction according to radiographic images.

However, to minimize unnecessary radiation exposure and reduce medical costs, it is not routinely performed [27].

Our study's strength is that it is based on a larger number of cases and includes more independent variables than a previous study that evaluated the efficacy of CT assessment for reoperation [12]. CT assessment is considered a better tool because it provides a full-range view of the relationship between the femoral head-neck and shaft fragments [11, 12, 16]. The addition of more cases and variables improved the statistical quality of our study and offered important information. Notably, to our knowledge, this was the first study to assess which modality (plain radiograph or CT image) could more accurately predict the postoperative outcome.

This study had several limitations. First, the retrospective nature of the study resulted in some patients being a loss to follow-up due to missing data, data collection methods for medical records that were not prespecified, and inconsistent quality of the radiographs. Furthermore, over the 13 years of this retrospective study, various surgeons, reduction techniques, and implants in a single center were included; thus, there might be selection biases. Nevertheless, the involvement of many factors suggests that these results are generalizable to the orthopedic community. Second, intraoperative

CT assessment was not available. Intraoperative CT scanning may allow for malreduction revisions, although only limited facilities currently have this capacity. Ultimately, surgeons should understand the benefits and pitfalls of postoperative CT assessment and consider alternatives such as improved interpretation with plain radiographs or another assessment tool such as direct digital palpation. Third, we did not assess some postoperative outcomes, such as a loss of femoral offset in the radiological outcome and functional outcome [28]. Further study should include these critical assessments. Finally, the number of reoperations in this study was small; therefore, our study was not sufficiently powered to detect independent risk factors associated with reoperation by multiple regression analysis. However, our study represents the largest reported cohort study of postoperative CT assessment to date. Ultimately, a prospective multi-center study to evaluate perioperative risk factors for reoperation that includes postoperative CT findings will elucidate the independent risk factors and postoperative CT indications after surgery. Though there were some potential sources of bias in this study, our results have drawn attention to the potential impact of postoperative CT assessment, mainly because CT assessment could predict postoperative outcomes.

## Conclusions

Intramedullary reduction evaluated with postoperative CT was identified as a risk factor for reoperation following intramedullary nailing for pertrochanteric fractures. The reduction quality based on CT assessment was more predictive for reoperation than findings from plain radiographs.

## Declarations

**Conflict of interest** The corresponding author declares that there are no conflicts of interest.

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