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Original article

Three-dimensional analyses to predict surgical outcomes in non-displaced or valgus impaction fractures of the femoral neck: A multicenter retrospective study

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ABSTRACT

Introduction: The aim of our study was to (1) report our surgical outcomes of internal fixation in patients with non-displaced or valgus impaction fractures of the femoral neck, (2) introduce our new three-dimensional assessment method using a combination of X-ray and CT imaging, and (3) determine which radiologic measurements significantly predicted fixation failure.
Hypothesis: We hypothesized that high posterior tilt angle and retroversion angle are related to high incidence of non-union and osteonecrosis.
Materials and methods: From January 2009 to December 2016, 64 elderly patients in two institutions with non-displaced or valgus impaction fractures of the femoral neck who had internal fixation using multiple parallel cannulated screws were enrolled. To determine the independent predictors of non-union, osteonecrosis, and re-operation, various clinical variables and radiologic variables, including the valgus angle on coronal CT images, the posterior tilt angle on Lorenz images, and the retroversion angle on axial CT images, were analyzed.
Results: Non-union was identified in nine of the 64 patients (14.1%) and nine of the 55 patients (16.4%) who achieved bony union had femoral head osteonecrosis with subsequent segmental collapse. The multiple logistic regression model showed that a low bone mineral density of the femur, a higher posterior tilt angle on Lorenz image, and a higher retroversion angle on axial CT images were independent predictors of non-union and re-operation.
Discussion: Primary hip arthroplasty should be considered when a posterior tilt angle of more than 9 degrees on Lorenz images or a retroversion angle of more than 13 degrees on axial CT images is identified in patients with osteoporotic valgus impaction fractures.
Type of study and level of proof: III, Retrospective comparative study.

1. Introduction

Internal fixation with multiple parallel cannulated screws has been widely accepted as a standard surgical treatment for non-displaced or valgus impaction fractures of the femoral neck (Garden type I or II) because it is minimally invasive and cost effective [1–3]. However, many previous studies still report a high re-operation rate due to complications, including non-union and late segmental collapse after internal fixation using various parallel implants for the surgical treatment of Garden type I or II fractures [4–6]. Failure of hip fracture surgery in elderly patients is significantly associated with higher mortality and morbidity rates. Thus, primary arthroplasty would be a better surgical option if we could predict the risk of internal fixation failure in patients with Garden type I or II fractures.

Many morphological studies of femoral neck fractures have been conducted to predict internal fixation failure. They reported that the valgus angle on the coronal plane or the posterior tilt angle on the sagittal plane may be significantly associated with surgical outcomes [7–12]. However, there is no consistent measurement method of the valgus angle and posterior tilt. In addition, rotation of the proximal femur can cause serious errors in the measurement of the Garden alignment index on plain X-rays and the posterior tilt angle on Lorenz images. Further, to the best of our knowledge, no

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past study has demonstrated the clinical importance of the retroversion angle on the axial plane of the proximal fragment, although morphologic studies of valgus impaction fractures of the femoral neck should include a three-dimensional perspective.

Thus, we proposed a new three-dimensional assessment method that can help predict failure after internal fixation using multiple parallel cannulated screws. The aims of our study were: (1) to report our surgical outcomes of internal fixation in patients with non-displaced or valgus impaction fractures of the femoral neck; (2) to introduce our new three-dimensional assessment method using a combination of X-ray and CT imaging, and (3) to determine which radiologic measurements significantly predicted fixation failure. We hypothesized that a high posterior tilt angle and retroversion angle are related to high incidence of non-union and osteonecrosis of the femoral head.

2. Material and methods

2.1. Study population

This study followed the guidelines of the Declaration of Helsinki and the KGCP guidelines, and institutional review board approval was obtained. This retrospective multicenter study was based on consecutively collected data from databases in two tertiary university hospitals. From January 2009 to December 2016, 110 patients in two institutions with non-displaced or valgus impaction fractures of the femoral neck underwent internal fixation using multiple parallel cannulated screws. The inclusion criteria were non-displaced or valgus impaction fractures of the femoral neck with low-energy injuries that were treated with in-situ pinning using multiple parallel cannulated screws. We excluded patients with (1) high-energy injuries including falling from a height, vehicle accidents, and crushing injuries, (2) follow-up of less than 1 year, (3) stress fractures, (4) intraoperative reduction, (5) inability to measure the contralateral side of the proximal femur owing to deformity or previous surgery, and (6) incomplete medical records (Fig. 1). Clinically, a low-energy hip fracture was defined as a fracture that occurred as a result of minimal trauma, such as a fall from a standing height or less.

2.2. Surgical technique and postoperative rehabilitation

All operations were performed with the patient in the supine lithotomy position on the unaffected side on a radiolucent surgical table under fluoroscopy. A fracture table was not used because traction was not necessary for in-situ pinning. Three partially threaded 6.5 mm cannulated screws were fixed in an inverted triangle configuration. All screw threads were placed beyond the fracture line for optimal compression. When the risk of lateral wall fracture due to the weakness of cortical bone was identified, washers were utilized. The portal for the inferior screw was placed superior to the lowest level of the lesser trochanter to avoid making a stress riser for subtrochanteric fracture. Sitting, continuous passive motion of the hip and knee joints, and wheelchair ambulation were started on the first postoperative day. Standing and partial weight-bearing ambulation using walking aids were allowed two days after surgery. The same surgical technique and postoperative rehabilitation protocol were applied in two institutions.

2.3. Radiologic measurements

Diagnostic imaging, including X-ray with anteroposterior (AP) , lateral, Lorenz views of the hip, CT scanning, and DEXA scanning for bone mineral density (BMD) was included in the routine protocol for preoperative radiologic assessment. Non-displaced or valgus impaction femoral neck fractures were initially diagnosed by one hip trauma surgeon who has more than five years of experience and one senior radiologist who has more than 10 years of experience in each institution. One senior hip surgeon reviewed all cases in the present study for the diagnosis. For the measurement of the Garden alignment index, the angle of the compression trabeculae of the femoral head on the AP view relative to the longitudinal axis of the femoral shaft was measured (Fig. 2, 2A). The valgus angle on coronal CT images was measured using a modification of Du's measuring method [12]. To measure the valgus angle on coronal CT images, the femoral head center and the deepest point of the fovea centralis, which are distinct and constant anatomical references on the femoral head, were chosen. The angle of the line connecting the deepest point of the fovea centralis and the center of femoral head

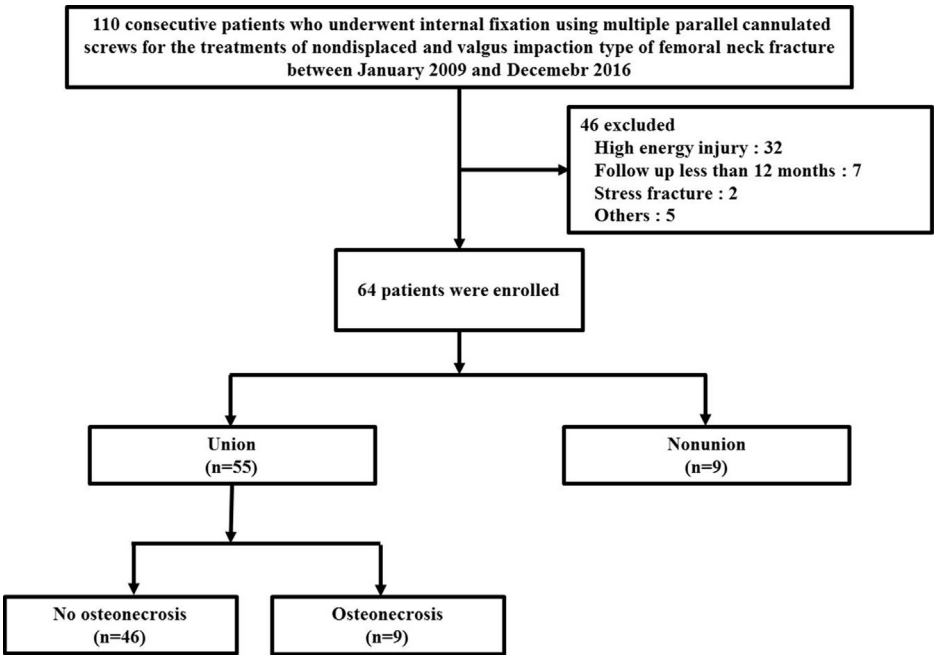


Fig. 1. Flowchart of the study design and the number of non-union and femoral head osteonecrosis with subsequent segmental collapse.

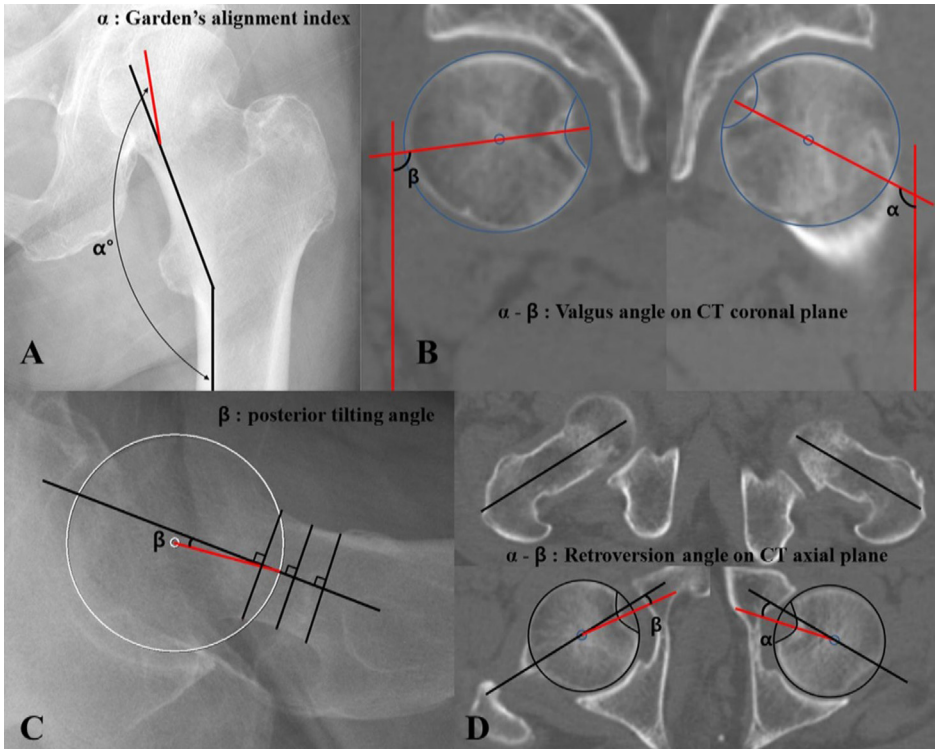


Fig. 2. Measurement method of radiologic variables in the study. A: Garden's alignment; B: Valgus angle on coronal CT image; C: Posteior tilt angle on Lorenz image. D. Retroversion angle on axial CT image.

relative to the longitudinal axis of the femoral shaft was measured (α). In the same way, the angle of the contralateral side was measured (β). The valgus angle on coronal CT images was considered to be the difference between these two angles (α–β) (Fig. 2B). The posterior tilt angle was measured using Palm's method [7]. It was measured as the angle between the mid-column line and the radius column line, which is drawn from the center of the caput circle to the crossing of the caput circle and the mid-column line (Fig. 2 C). To measure the retroversion angle on axial CT images, the center of the femoral head and the deepest point of the fovea centralis on the femoral head were marked in the same way as for the measurement of the valgus angle on coronal CT images. At this point, the angle formed by the line connecting the fovea centralis with the center of the femoral head and the midline of the femoral neck was measured (α). In the same way, the angle of the contralateral side was measured (β). The retroversion angle on axial CT images was considered to be the difference between these two angles (α–β) (Fig. 2D).

2.4. Assessment of outcome measures

The following data were collected to compare the preoperative characteristics of patients with non-displaced or valgus impaction fractures of the femoral neck: follow-up period, age at the time of surgery, sex, affected side, body mass index (BMI), surgical timing (time from injury to surgery), BMD (lumbar and femur), American Society of Anesthesiologists (ASA) class, and preoperative mobility score.

In terms of the radiologic assessment, failed surgical treatment was clarified as non-union and femoral head osteonecrosis with subsequent segmental collapse that required re-operation. Non-union was defined when there was (1) more than 10 mm displacement, (2) progression to varus angulation, (3) more than 5% change between the axis of the screws, (4) more than 20 mm of posterior translation, (5) femoral head perforation, or (6) no evidence of bone healing with significant hip pain after 6 months [13–15]. Femoral head osteonecrosis with subsequent segmental collapse was diagnosed in patients who complained of hip pain and had simple radiographs showing cystic changes and focal bone radiolucency with more than 2 mm of femoral head collapse [16,17]. When non-union of the femoral neck or femoral head osteonecrosis with subsequent collapse was confirmed, hip arthroplasty was performed.

2.5. Statistical analysis

We compared the preoperative details and surgical outcomes of each group using the Pearson's chi-square test or Fisher's exact test for categorical variables and the independent Student's *t*-test or Mann-Whitney U-test for continuous variables, where appropriate. Independent predictors for non-union were identified using a multiple logistic regression model. The following covariates were included: age, sex, BMI, surgical timing, BMD (lumbar spine and femur), ASA class, cognitive impairment, pre-injury mobility score, valgus angle on coronal CT images, posterior tilt angle, and retroversion angle on axial CT images. When multicollinearity due to a high correlation between two explanatory variables was identified, analysis was performed after one of variables was dropped. When the significant predictors were identified as continuous variables, receiver operator characteristic (ROC) curve analysis was performed to determine the cut-off value of the predictor. They were presented using the area under the curve (AUC), *p*-values, 95% CIs, sensitivity, and 1- specificity. The inter-observer reliability of all radiologic measurements was evaluated by the interclass correlation coefficient. The results were interpreted as follows: > 0.8 = almost perfect agreement, 0.7–0.8 = strong, 0.5–0.6 = moderate, 0.3–0.4 = fair, and 0–0.2 = poor. The SPSS software package (version 22.0; IBM Corp., Armonk, NY, USA) was used for all statistical analyses. Statistical significance was set at $p < 0.05$.

3. Results

Sixty-four patients (46 women and 18 men) met the above criteria. Their mean age was 71.7 years (range 51–85). Non-union was identified in nine of the 64 patients (14.1%). The average time to diagnosis was 4.6 months (range 1–6 months). Total hip arthroplasty was performed in five patients, and hemiarthroplasty was performed in four patients. Nine of the 55 patients (16.4%) who achieved bony union had femoral head osteonecrosis with subsequent segmental collapse. The average time to diagnosis of femoral head osteonecrosis was 13.9 months (range 6–39 months), and total hip arthroplasty was performed in all patients.

Comparison of preoperative characteristics and radiologic outcomes between the union group and non-union group is presented in Table 1. There were no significant differences in the follow-up period, age, sex, affected side, BMI, surgical timing, BMD (femur and L-spine), ASA class, presence of cognitive impairment, pre-injury mobility score, the Garden alignment index, or valgus angle on coronal CT images. However, the mean posterior tilt angle and retroversion angle on axial CT images were 7.2° and 10.1° in the union group and 12.8° and 15.3° in the non-union group, respectively, and significant differences between the two groups were identified. A comparison of preoperative characteristics and radiologic outcomes between the groups with and without femoral head osteonecrosis and subsequent collapse is presented in Table 2. The mean posterior tilt angle and the mean retroversion angle on axial CT images were 6.3° and 9.5° in the group without femoral head osteonecrosis, and 11.6° and 13.4° in the group with femoral head osteonecrosis with subsequent segment collapse, respectively, and significant differences between the two groups were identified. However, no significant difference between the two groups was identified for any other variable. A comparison of preoperative characteristics and radiologic outcomes between the groups with and without re-operation is presented in Table 3. The mean posterior tilt angle and retroversion angle on axial CT images were 6.3° and 9.5° in the group without re-operation and 12.2° and 14.3° in the re-operation group, respectively, and significant differences between the two groups were identified. However, there were no significant differences between the two groups for any other variables.

The multiple logistic regression model showed that a low BMD of the femur, a posterior tilt angle on Lorenz images, and a retroversion angle on axial CT images were independent predictors for non-union (OR 0.080, 95% CI 0.015 to 0.419, $p = 0.003$; OR 1.074, 95% CI 1.061 to 1.531, $p = 0.010$; OR 1.355, 95% CI 1.075 to 1.708, $p = 0.010$, respectively). These three variables were also identified as independent predictors of re-operation (OR 0.014, 95% CI 0.128 to 0.795, $p = 0.014$; OR 1.310, 95% CI 1.118 to 1.535, $p = 0.001$; OR 1.286, 95% CI 1.092 to 1.515, $p = 0.003$, respectively). Independent predictors for femoral head osteonecrosis with subsequent segmental collapse were an older age, a low mobility score before injury, the posterior tilt angle, and the retroversion angle (OR 1.234, 95% CI 1.018 to 1.497, $p = 0.033$; OR 0.034, 95% CI 0.158 to 0.928, $p = 0.034$; OR 1.369, 95% CI 1.075 to 1.709, $p = 0.008$, OR 1.363, 95% CI 1.051 to 1.769, $p = 0.020$, respectively) (Fig. 3). The inter-observer correlation coefficient was 0.880 for the Garden alignment index ($p < 0.001$), 0.980 for valgus angle on CT coronal images ($p < 0.001$), 0.874 for posterior tilting angle on Lorenz images ($p < 0.001$), and 0.961 for retroversion ($p < 0.001$).

Table 1
Comparison of preoperative characteristics and radiologic measurements of 64 non-displaced and valgus impaction fracture of femoral neck treated with internal fixation between the groups who achieved union and who did not.

Variables	Union	Non-union	*p*-value
N° of patients	55	9	
Follow-up period, month	16.5 ± 14.6 (12–55)	14.9 ± 10.4 (12–72)	0.756
Age at the surgery, year	71.8 ± 7.4 (51–85)	70.9 ± 8.3 (68–84)	0.738
Sex, female, No. (%)	40 (72.7)	6 (66.7)	0.708
Affected hip, Right, N° (%)	35 (63.6)	5 (55.6)	0.642
BMI, kg/m²	22.2 ± 3.2 (17.0–34.4)	21.7 ± 2.9 (19.0–28.1)	0.742
Surgical timing, days (less than 24 hours), N° (%)	33 (61.8)	4 (44.4)	0.325
BMD (Femur), T-score	− 1.9 ± 0.8 (− 3.7–0.3)	− 2.8 ± 0.7 (− 3.4– − 0.8)	0.002
BMD (Lumbar), T-score	− 1.8 ± 1.2 (− 5.0–1.1)	− 2.0 ± 0.7 (− 4.9– − 1.3)	0.600
ASA, N° (%)			0.146
I, II	43 (78.2)	5 (55.6)	
III, IV	12 (21.8)	4 (44.4)	
Cognitive impairment, N° (%)	13 (23.6)	2 (22.2)	0.926
Pre-injury mobility score	7.9 ± 1.4 (4–9)	7.6 ± 1.0 (5–9)	0.456
Garden's alignment index, (°)	164.7 ± 6.4 (155.0–183.6)	166.6 ± 6.3 (160.6–179.1)	0.396
Valgus angle on CT coronal image (°)	13.3 ± 7.0 (0.0–28.6)	14.1 ± 5.6 (5.6–24.1)	0.737
Posterior tilting angle on Lorenz image (°)	7.2 ± 5.3 (0.0–25.9)	12.8 ± 7.2 (5.9–26.5)	0.008
Retroversion angle on CT axial image (°)	10.1 ± 4.9 (1.5–33.1)	15.3 ± 5.2 (15.4–28.5)	0.005

Values are presented as mean (range), or number (%). BMI; body mass index, BMD; boneineral density, ASA; American Society of Anesthesiologists.

Table 2
Comparison of preoperative characteristics and radiologic measurements of 55 patients who achieved union after internal fixation between the groups who had femoral head osteonecrosis with subsequent collapse and who did not.

Variables	No osteonecrosis	Osteonecrosis	*p*-value
N° of patients	46	9	
Follow-up period, month	17.1 ± 12.9 (12–55)	13.4 ± 22.1 (12–72)	0.500
Age at surgery, year	70.8 ± 7.4 (51–85)	76.9 ± 5.1 (68–84)	0.023
Sex, female, N° (%)	32 (69.6)	8 (88.9)	0.234
Affected hip, Right, N° (%)	31 (67.4)	4 (44.4)	0.191
BMI, kg/m²	22.0 ± 3.2 (17.0–34.4)	22.1 ± 3.2 (19.0–28.1)	0.971
Surgical timing, (days less than 24 hours), N° (%)	28 (60.9)	6 (66.7)	0.743
BMD (Femur), T-score	− 1.9 ± 0.8 (− 3.7–0.3)	− 2.1 ± 0.9 (− 3.4– − 0.8)	0.473
BMD (Lumbar), T-score	− 1.7 ± 1.2 (− 5.0–1.1)	− 2.2 ± 1.2 (− 4.9– − 1.3)	0.317
ASA, N° (%)			0.974
I, II	36 (78.3)	7 (77.8)	
III, IV	10 (21.7)	2 (22.2)	
Cognitive impairment, N° (%)	9 (19.6)	4 (44.4)	0.108
Pre-injury mobility score	8.1 ± 1.4 (4–9)	7.2 ± 1.2 (5–9)	0.105
Garden's alignment index, (°)	164.3 ± 6.6 (155.0–183.6)	166.6 ± 5.4 (160.6–179.1)	0.324
Valgus angle on CT coronal image (°)	13.0 ± 7.4 (0.0–33.0)	14.5 ± 4.3 (0.0–24.1)	0.576
Posterior tilting angle on Lorenz image (°)	6.3 ± 5.1 (0.0–17.1)	11.6 ± 4.6 (5.9–19.8)	0.006
Retroversion angle on CT axial image (°)	9.5 ± 5.0 (1.5–18.6)	13.4 ± 2.8 (7.5–18.0)	0.027

Values are presented as mean (range), or number (%). BMI; body mass index, BMD; boneineral density, ASA; American Society of Anesthesiologists.

Table 3
Comparison of preoperative variables and radiologic measurements between the groups who had re-operation and who did not in 64 patients who non-displaced and valgus impaction type of femoral neck fracture.

Variables	No re-operation	Re-operation	*p*-value
N° of patients	46	18	
Follow-up period, month	17.1 ± 12.9 (12–55)	14.2 ± 16.8 (12–72)	0.461
Age at surgery, year	70.0 ± 7.4 (51–85)	74.9 ± 7.3 (68–84)	0.139
Sex, female, N° (%)	32 (69.6)	14 (77.8)	0.511
Affected hip, Right, N° (%)	31 (67.4)	7 (50.0)	0.196
BMI, kg/m²	22.0 ± 3.2 (17.0–34.4)	21.9 ± 3.0 (19.0–28.1)	0.853
Surgical timing, days (less than 24 hours), N° (%)	28 (60.9)	10 (55.6)	0.697
BMD (Femur), T-score	− 1.9 ± 0.8 (− 3.7–0.3)	− 2.5 ± 0.8 (− 3.4– − 0.8)	0.012
BMD (Lumbar), T-score	− 1.7 ± 1.2 (− 5.0–1.1)	− 2.1 ± 1.0 (− 4.9– − 1.3)	0.253
ASA, N°. (%)			0.336
I, II	36 (78.3)	12 (66.7)	
III, IV	10 (21.7)	6 (33.3)	
Cognitive impairment, N° (%)	9 (19.6)	6 (33.3)	0.242
Pre-injury mobility score	8.1 ± 1.4 (4–9)	7.4 ± 1.1 (5–9)	0.077
Garden's alignment index, (°)	164.3 ± 6.6 (155.0–183.6)	166.6 ± 5.7 (160.6–179.1)	0.190
Valgus angle on CT coronal image (°)	13.1 ± 7.4 (0.0–28.6)	14.3 ± 4.9 (5.6–24.1)	0.510
Posterior tilting angle on Lorenz image (°)	6.3 ± 5.1 (0.0–25.9)	12.2 ± 5.9 (5.9–26.5)	< 0.001
Retroversion angle on CT axial image (°)	9.5 ± 5.0 (1.5–33.1)	14.3 ± 4.2 (15.4–28.5)	0.001

Values are presented as mean (range), or number (%). BMI; body mass index, BMD; boneineral density, ASA; American Society of Anesthesiologists.

ROC analysis demonstrated that the cut-off values of the posterior tilt angle and the retroversion angle were 8.7 mm (sensitivity 0.667, 1-specificity 0.327) and 12.6 mm (sensitivity 0.778, 1-specificity 0.327), respectively, for non-union, 8.1 mm (sensitivity 0.722, 1-specificity 0.283) and 12.2 mm (sensitivity 0.833, 1-specificity 0.370), respectively for re-operation, and 7.3 mm (sensitivity 0.889, 1-specificity 0.326) and 12.2 mm (sensitivity 0.889, 1-specificity 0.370), respectively for femoral head osteonecrosis with subsequent segmental collapse (Fig. 4).

4. Discussion

This study reported about our surgical outcomes in elderly patients with non-displaced and valgus impaction fractures of the femoral neck who were treated with internal fixation using parallel cannulated screws and to determine the independent predictors related to surgical outcomes, including non-union, osteonecrosis, and re-operation using our new radiologic measurement system. Our results showed that the rates of non-union, femoral head osteonecrosis with subsequent segmental collapse, and re-operation were 14% (9/64), 16% (9/55), and 28% (18/64), respectively. The independent predictors for non-union and re-operation were a low BMD of the femur and a high posterior tilt angle on Lorenz images and a high retroversion angle on axial CT images. Older age, a low mobility score before injury, the posterior tilt angle, and the retroversion angle were identified as independent predictors for femoral head osteonecrosis with subsequent collapse.

It is clinically very important for surgeons to predict the surgical outcomes of elderly patients with non-displaced and valgus impaction fractures of the femoral neck. Closed pinning performed in patients who are likely to have poor outcomes can lead to a second operation such as arthroplasty, which is associated with increased mortality and morbidity. If the primary arthroplasty can be selectively performed in high-risk patients with Garden type I and II fractures, we would be able to avoid re-operation, improve surgical outcomes, and reduce medical costs.

Many previous morphologic studies about Garden type I and II fractures have focused on the valgus angle and posterior tilt. Song et al. reported that the mean femoral shortening and sliding distance of the screw were significantly higher in 31-B1.1, which is a fracture with a valgus impaction of more than 15 degrees than in 31-B1.2, which is a fracture with a valgus impaction of less than 15 degrees [18]. Further, they showed that the Harris hip score at the last follow-up was significantly lower, and the risk of avascular necrosis and a second operation after bony union were significantly higher in patients with 31-B1.1 fractures than in patients with 31-B1.2 fractures. Based on these results, they suggested that the preoperative severity of valgus deformity is an important risk factor for the prediction of surgical outcomes. Palm et al. reported that the preoperative posterior tilt in undisplaced (Garden type I and II) femoral neck fractures is thought to influence re-operation [7]. They introduced their new radiologic measurement method of the posterior tilt of the fracture and concluded that their new measurement for posterior tilt appears to be reliable and is able to predict re-operation in patients with undisplaced femoral neck fractures.

Not all studies showed a significant association between the severity of preoperative deformities and surgical outcomes. Lapidus et al. analyzed 382 consecutive patients with Garden type I and II femoral neck fractures who were treated with internal fixation and reported that the overall re-operation rate was 19% (72 of 382 hips), and the re-operation rate due to fracture healing complications was 12% (45 of 382 hips) [10]. However, they could not identify any significant relationship between re-operation due to fracture healing complications and the preoperative variables, including posterior tilt, age, sex, cognitive function, ASA classification, and the time to surgery. Based on these results, they concluded that preoperative posterior tilt measured on lateral radiographs cannot be used as a discriminator for fracture healing complications in Garden type I and II femoral neck fractures. Du and Fu et al. introduced a computer programmed three-dimensional model for the morphologic study of impacted femoral neck fractures [12,19]. In their study, they suggested that impacted femoral neck fractures showed variable degrees of displacement, and the Garden classification for impacted femoral neck fractures has certain limitations.

As seen in these previous reports, much debate remains in terms of predicting the results of surgical treatment in patients with non-displaced and valgus impaction fractures of the femoral neck because the Garden classification using simple radiographs is known to show relatively low inter-observer agreement, and there is no standard or consistent measurement method for the morphologic study of femoral neck fractures [20–22]. For these reasons, we believe that the current understanding of the three-dimensional morphology of valgus impaction fractures is limited. Thus, we introduced a new measurement method for the radiologic evaluation of the three-dimensional morphology of non-displaced and valgus impaction fractures of the femoral neck using a combination of X-ray and CT. We believe that our measurement method is valuable because our three-dimensional morphologic evaluation included the valgus angle on coronal CT images as well as the retroversion angle on axial CT images using distinct and constant anatomical references such as the fovea centralis and femoral head center. The force acting on the femoral head in the axial plane, especially with the hip flexed or when lifting, tends to deflect the fracture site into a more retroverted position, which can be highly associated with fixation failure (Fig. 5). In accordance with our original hypothesis, the

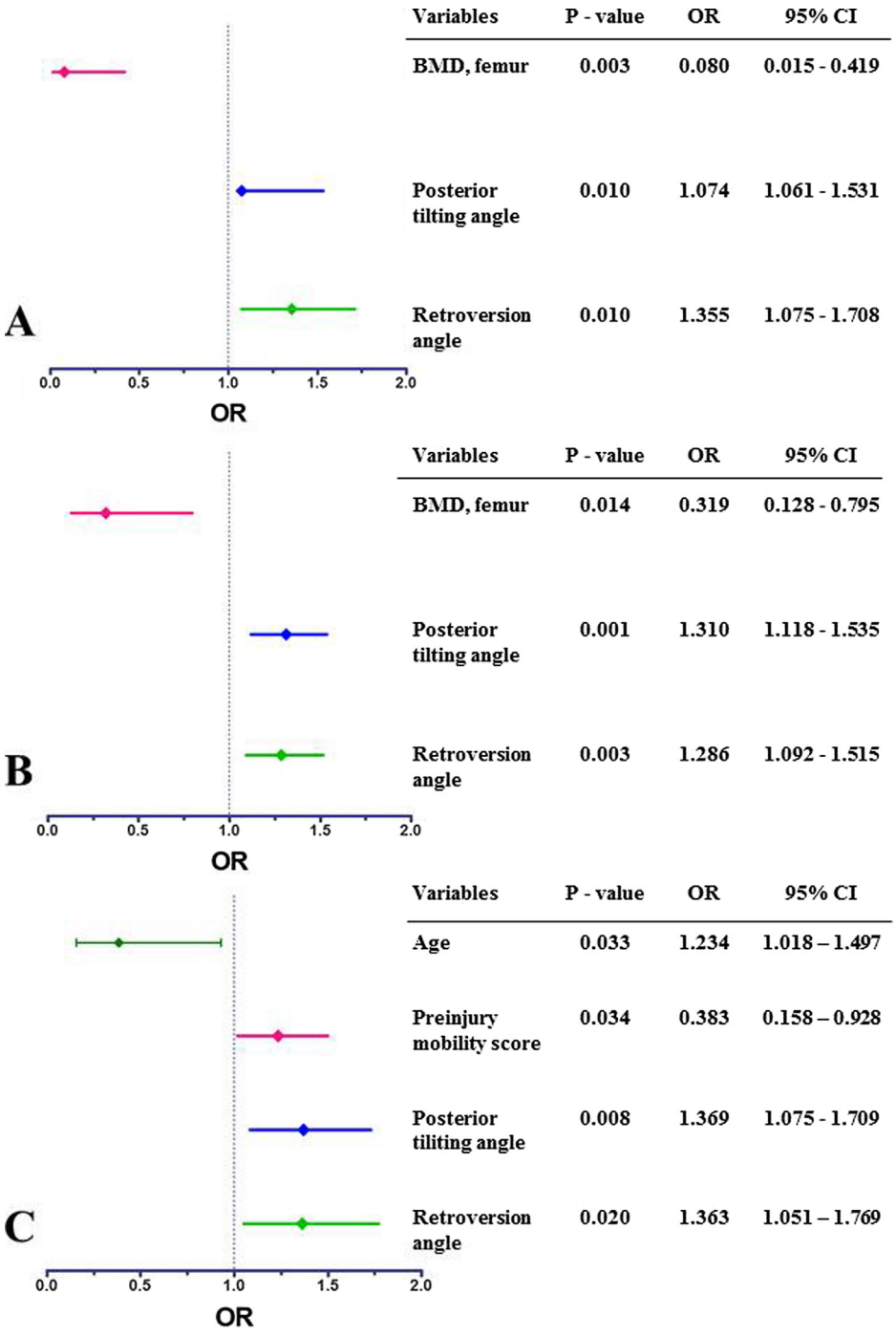
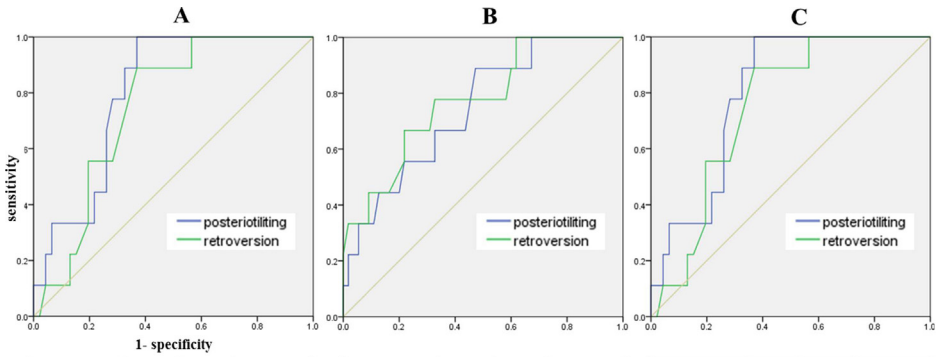


Fig. 3. Multiple regression model showing the independent predictors for non-union (A), reoperation (B), and femoral head osteonecrosis (C).

multiple regression model in the present study demonstrated that the retroversion angle on axial CT images is an independent predictor of non-union, osteonecrosis, and re-operation. The posterior tilt angle that was mentioned as an important risk factor in many previous studies was also identified as an independent predictor of non-union, osteonecrosis, and re-operation in the present study. This is because the posterior tilt angle showed a high correlation with the retroversion angle. Therefore, we believe that the posterior tilt angle on Lorenz image is a simple and reliable radiologic measurement to predict surgical outcomes.

ROC curve analysis showed that the cut-off values of the posterior tilt angle and retroversion angle for non-union were 8.7 degrees and 12.6 degrees, respectively. These outcomes appear to be relatively smaller than those in many previous studies [7,18]. We think that this is because previous studies included younger patients who had high-energy injuries and those who did not have osteoporosis. Based on the fact that the BMD of the femur was identified as an independent predictor in this study, we think that osteoporosis may affect the relatively smaller cut-off value of the preoperative deformity angle. Thus, we believe that primary hip arthroplasty should be considered when valgus impaction fractures have more than 9 degrees of posterior tilt angle on Lorenz images or more than 13 degrees of retroversion angle on axial CT images.

It appears that the incidence of non-union and osteonecrosis was higher in our study than that in previous studies. Our study enrolled only elderly patients with osteoporotic femoral neck



Variables	AUC	P-value	95% CI
Posterior tilting	0.798	0.005	0.676 - 0.920
Retroversion	0.748	0.020	0.611 – 0.885

Variables	AUC	P-value	95% CI
Posterior tilting	0.743	0.020	0.582 - 0.905
Retroversion	0.774	0.009	0.612 – 0.936

Variables	AUC	P-value	95% CI
Posterior tilting	0.798	0.005	0.676 - 0.920
Retroversion	0.748	0.020	0.611 – 0.885

Fig. 4. Receiver operator characteristics (ROC) curve showing the area under curve, *p*-value, and 95% cofidence interval of posterior tilt angle and retroversion angle for non-union (A), reperation (B), and femoral head osteonecrosis with subsequent segmental collapse (C).

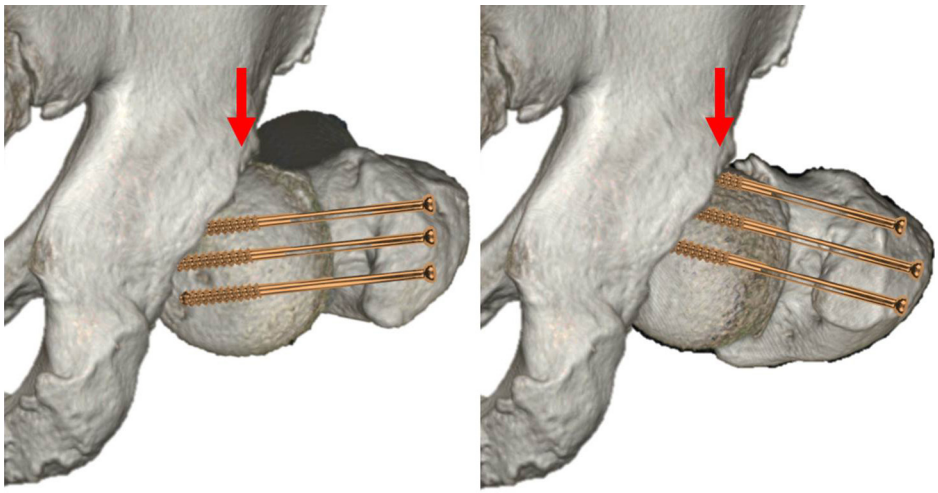


Fig. 5. Drawing of the force acting on the femoral head and fracture in axial plane.

fractures after low-energy injuries, and some of them had significant deformities with valgus or posterior tilt or retroversion. We believe that these preoperative characteristics of the population in the present study may be related to a higher incidence of non-union, osteonecrosis, and re-operation than those of previous studies. In addition, although early ambulation is essential in the rehabilitation in elderly patients with hip fracture to minimize the risk of medical complications such as pneumonia, cardiovascular problems, and venous thromboembolism, unfortunately, it is difficult for elderly patients who have undergone hip fracture surgery to perform only partial weight-bearing ambulation. We believe that this aggressive rehabilitation may also have contributed to the higher incidence of non-union, osteonecrosis, and re-operation.

This study has some limitations. First, this is a retrospective study. However, it was a multicenter study that enrolled 110 consecutive patients who were followed up for more than one year. In particular, we excluded patients younger than 65 years of age and those with fractures caused by high-energy injuries, and this made our cohort more homogenous. Second, there could have been errors in measuring the preoperative deformity of the femoral neck. Although the fovea centralis is a distinct and consistent anatomical reference on the femoral head, the measurements can be affected by the location of the deepest portion of the fovea centralis. To minimize these measurement errors, two orthopedic surgeons who did not participate in our patients' surgeries independently measured the preoperative deformity of the fracture, including the valgus angle, the posterior tilt angle, and the retroversion angle; the average of these measurements was used for the analyses. Third, the follow-up period appeared to be too short to evaluate the incidence of femoral head osteonecrosis with subsequent collapse. However, there was no significant difference in the follow-up period between the groups with and without osteonecrosis, and the average follow-up period of both groups was longer than the average time from surgery to the diagnosis of femoral head osteonecrosis. Fourth, femoral head osteonecrosis can be diagnosed by the characteristic appearance of the infarcted area in the femoral head, which can be identified on magnetic resonance imaging (MRI) by a hypodense area surrounded by a single hypodense line separating normal and osteonecrotic bone on T1 images. However, most patients who were enrolled in the present study did not undergo MRI. We do not perform metal removal operation in elderly patients owing to the concern of re-fracture, which can cause severe metal artifact around the hip joint on MRI. Therefore, we diagnosed femoral head osteonecrosis with subsequent collapse only with simple radiographs.

5. Conclusion

The posterior tilt angle on Lorenz image and the retroversion angle on axial CT images can be good independent predictors for non-union, osteonecrosis, and re-operation in elderly patients with non-displaced and valgus impaction fractures of the femoral neck.

Thus, primary hip arthroplasty should be considered when a posterior tilt angle of more than 9 degrees on Lorenz images or a retroversion angle of more than 13 degrees on axial CT images is identified in patients with osteoporotic valgus impaction fractures.

Disclosure of interest

The authors declare that they have no competing interest.

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Authors' contributions

Study conception and design: K.T. Suh, N.H. Moon, W.C. Shin.
Acquisition of data: W.C. Shin, K.T. Suh, N.H. Moon.
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Drafting of manuscript: W.C. Shin, N.H. Moon.
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