Residual deformity after femoral neck fracture affects the location of osteonecrosis of the femoral head

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Aims

The localization of necrotic areas has been reported to impact the prognosis and treatment strategy for osteonecrosis of the femoral head (ONFH). Anteroposterior localization of the necrotic area after a femoral neck fracture (FNF) has not been properly investigated. We hypothesize that the change of the weight loading direction on the femoral head due to residual posterior tilt caused by malunited FNF may affect the location of ONFH. We investigate the relationship between the posterior tilt angle (PTA) and anteroposterior localization of osteonecrosis using lateral hip radiographs.

Methods

Patients aged younger than 55 years diagnosed with ONFH after FNF were retrospectively reviewed. Overall, 65 hips (38 males and 27 females; mean age 32.6 years (SD 12.2)) met the inclusion criteria. Patients with stage 1 or 4 ONFH, as per the Association Research Circulation Osseous classification, were excluded. The ratios of anterior and posterior viable areas and necrotic areas of the femoral head to the articular surface were calculated by setting the femoral head centre as the reference point. The PTA was measured using Palm's method. The association between the PTA and viable or necrotic areas of the femoral head was assessed using Spearman's rank correlation analysis (median PTA 6.0° (interquartile range 3 to 11.5)).

Results

We identified a negative correlation between PTA and anterior viable areas (rho −0.477; p = 0.001), and no correlation between PTA and necrotic (rho 0.229; p = 0.067) or posterior viable areas (rho 0.204; p = 0.132).

Conclusion

Our results suggest that residual posterior tilt after FNF could affect the anteroposterior localization of necrosis.

Take home message

- Residual posterior tilt caused by malunited femoral neck fractures affects the location of osteonecrosis of the femoral head.
- A negative correlation was found between posterior tilt angle and anterior viable areas of the femoral head.

Introduction

Osteonecrosis of the femoral head (ONFH) is a serious complication observed after femoral neck fractures (FNFs) and can easily progress to hip joint dysfunction, which affects a patient's quality of life and activities of daily living. The incidence of

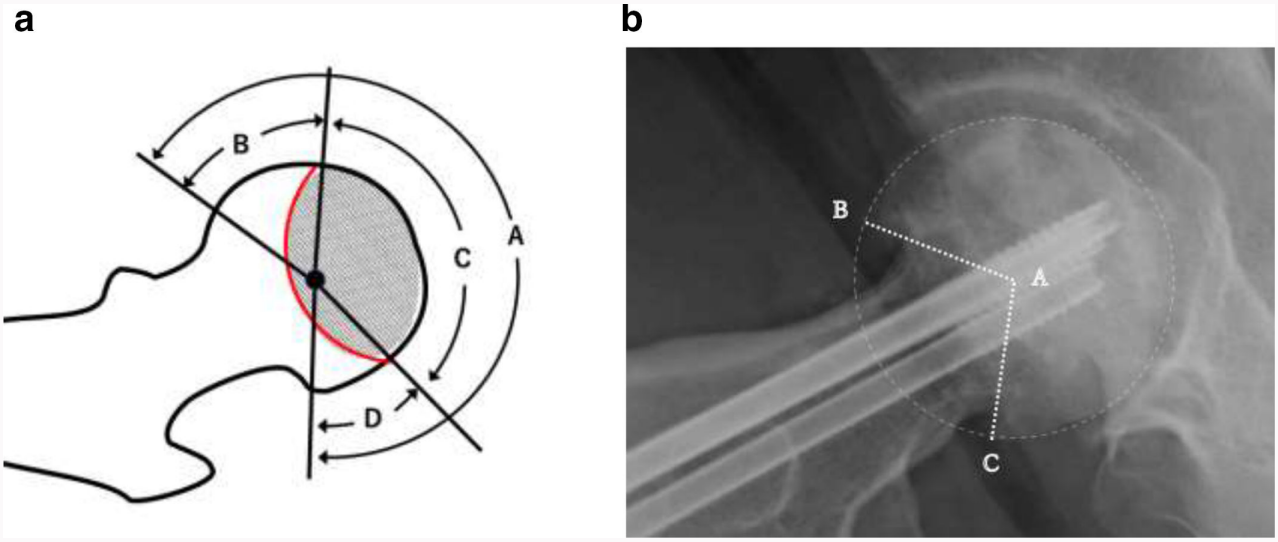

Fig. 1

a) Diagram showing the method for measuring the extent of the viable and necrotic areas of the femoral head on the lateral radiograph (Sugioka view). The ratio of the anterior viable area was calculated by dividing angle B (anterior reference point of the articular surface) by angle A (centre of the femoral head). The ratio of the posterior viable area was calculated by dividing angle D (posterior reference point of the articular surface) by angle A. The ratio of the necrotic area was calculated by dividing angle C (necrotic area from anterior to posterior point of the articular surface) by angle A. b) Evaluation of the articular surface in a case where the margin was unclear due to depression of the fracture. The distal end of the femoral head was used as the reference point for the articular surface.

post-fracture ONFH is approximately 4% to 16%,[1-3] and is higher in young patients.

There are several classifications for ONFH, with the Association Research Circulation Osseous (ARCO) classification[4] and Japanese Investigation Committee classification[5] being determined by the extent and localization of the necrotic area. These classifications have been reported to excel in predicting the prognosis of ONFH and are deemed valuable in guiding treatment decisions.[5] Although these classifications focus on sites of necrosis in the coronal plane, several studies have shown that the anteroposterior localization of the necrotic area (sagittal plane) is also associated with the incidence of the collapse of ONFH.[6,7] Another classification described by Kerboul et al[8] has also been used to evaluate lesion size and involves the addition of the two angles measured on anteroposterior and lateral radiographs. These classifications and previous reports suggest the importance of localization in the coronal plane and anteroposterior localization of necrosis.[6,7]

Extensive necrosis poses significant treatment challenges in post-fracture ONFH,[9] and arthroplasty is the optimal choice in older patients.[10] Joint preservation procedures, such as core decompression, cell therapy, and osteotomy, are preferred in younger patients due to the risk of revision with arthroplasty in the long term.[11,12] In these joint preservation procedures, the correlation between preoperative stages and treatment outcomes has been documented, enhancing the utility of these classifications in guiding treatment decisions.[5,13,14] Furthermore, some authors have reported that necrotic areas in the coronal plane, along with the anteroposterior plane, are also important in determining the indication of appropriate joint preservation procedures.[5,13,15]

Vascularity of the femoral head is crucial in the discussion of ONFH.[16-18] In patients with FNF, the major vessels to the femoral head are damaged at the time of injury. Several authors have reported revascularization of the femoral head after FNF using selective angiography or bone single-photon emission CT.[18,19] However, considering that residual deformities, such as posterior tilt or valgus impaction, have been reported as unfavourable factors for the occurrence of ONFH and as poor prognostic factors for osteosynthesis outcomes, we speculated that the residual posterior tilt or valgus deformities might influence revascularization, potentially impacting the size and localization of ONFH. Non-traumatic ONFH is commonly found in the anterior portion of the femoral head;[20] however, the anteroposterior localization of the necrotic area in the femoral head following a FNF has not yet been clearly established. We hypothesize that postoperative morphological abnormalities of the femoral head after FNF may affect the localization of the necrotic area by impeding the revascularization of the femoral head. We aim to investigate the association between the posterior tilt angle (PTA) and the anteroposterior location of the necrotic area of the femoral head.

Methods

Patients

This retrospective study was approved by the institutional review board of Showa University Hospital, Yokohama, Japan (no. 3478), and the requirement for informed consent was waived due to the retrospective nature of the study. We reviewed the records of patients aged < 55 years who were diagnosed with post-fracture ONFH between January 2000 and April 2022 at Showa University Hospital and two of its affiliated hospitals. All patients were symptomatic. The ARCO classification for ONFH was applied,[4] and stage 1 patients were excluded as the extent of necrosis of their femoral head was difficult to define only with radiographs. Stage 4 patients were also excluded because the presence of osteosclerosis

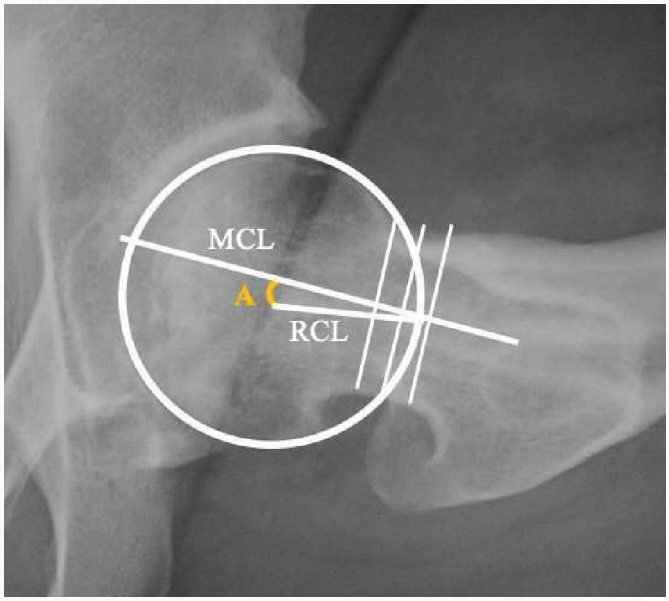

Fig. 2
The posterior tilt angle (angle A) was measured with Palm's method on the lateral radiograph (Sugioka view). Angle A was measured between two lines, the mid-collum line (MCL) and the radius collum line (RCL). The middle of the collum (femoral neck) is determined by drawing three perpendicular lines across the narrowest part of the collum with 5 mm between each line. The RCL is drawn from the middle of the femoral head to the intersection of the MCL and the caput circle.

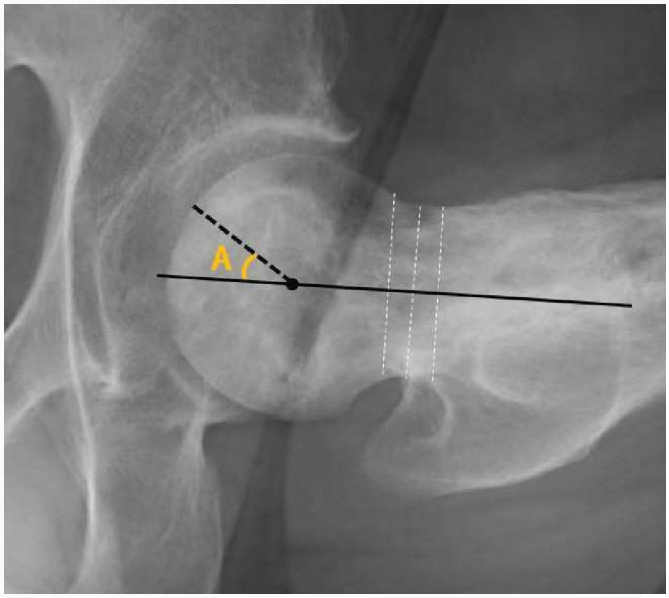

Fig. 3
Measurement of the anterior necrotic angle (angle A). Angle A was measured between two lines, the radius collum line (RCL) and a line passing from the centre of the femoral head to the anterior boundary of the necrotic area. The solid line indicates the RCL, and the dotted line indicates a line passing from the centre of the femoral head to the anterior boundary of the necrotic area.

and osteophytes due to secondary osteoarthritis obscured the extent of necrosis.

Radiological assessment

A lateral hip radiological image (Sugioka view) was used for the measurement. The Sugioka view is taken in precisely 90° of flexion and 45° of abduction and with neutral rotation, allowing a longer view of the femoral neck and an accurate lateral view of the femoral head.[21] The ratio of the anterior and posterior viable and necrotic areas was measured on the articular surface, using the centre of the femoral head as the reference point (Figure 1).[13] The articular surface was defined by setting the borderlines of the femoral head and neck as the anterior and posterior margins. If the margin was unclear due to depression of the fracture, the distal end of the femoral head was used as the reference point for the articular surface (Figure 1b).

The PTA was measured between the mid-collum line (MCL) and the radius collum line (RCL) (Figure 2).[22] The direction of the tilt was defined as follows: when the head was tilted posteriorly or anteriorly from the femoral neck axis, the tilting angle was signed positive or negative, respectively. Two board-certified orthopaedic surgeons (MN, TA) independently measured all parameters using ImageJ software (National Institutes of Health, USA),[23] and they were blinded to each other's measurements. The average values of two raters were used for the analysis. The data were also used to assess inter-rater reliability, and one of the raters measured the PTA and ratio of necrosis and viable areas over a six-week interval to assess the intrarater reliability. Interclass correlation coefficients (ICCs) were calculated for the inter-/intrarater reliabilities of these parameters. ICCs were interpreted as excellent (> 0.90), good (0.75 to 0.89), moderate (0.50 to 0.74), and poor (< 0.50).[24]

Regarding the prognosis of ONFH, Kubo et al[6] revealed that the anterior necrotic angle (ANA), which is measured at the midline of the femoral neck axis and a line passing from the centre of the femoral head to the anterior boundary of the necrotic area, is associated with the collapse of ONFH in patients with extensive necrosis if the angle exceeds 67°. Therefore, we investigated the correlation between ANA and PTA. In this study, the femoral neck axis was often tilted due to the FNF, and the ANA was measured as the angle between the RCL and the anterior boundary of the necrotic area (Figure 3). To evaluate the cut-off point for PTA, a receiver operating characteristic (ROC) curve was used.

Statistical analysis

Patient characteristics were described using frequencies and percentages for categorical variables, and means with standard deviations (SDs) or medians and interquartile ranges (IQRs) for continuous variables. The relationship between PTA and the ratio of the necrotic, anterior viable, and posterior viable areas was examined using Spearman's rank correlation analysis. All statistical analyses were performed using JMP Pro 15 for Mac (SAS Institute, USA) and R software v. 4.0.3 (R Foundation for Statistical Computing, Austria). Statistical significance was defined as $p < 0.05$.

Results

The data on 83 hips from 83 patients were reviewed, and 65 hips in 65 patients (38 males and 27 females; mean age 32.6 years (SD 12.2)) were included in the final analysis. On evaluating the necrosis on the coronal plane according to the ARCO classification, type 1 was found in two hips, type 2 in 26

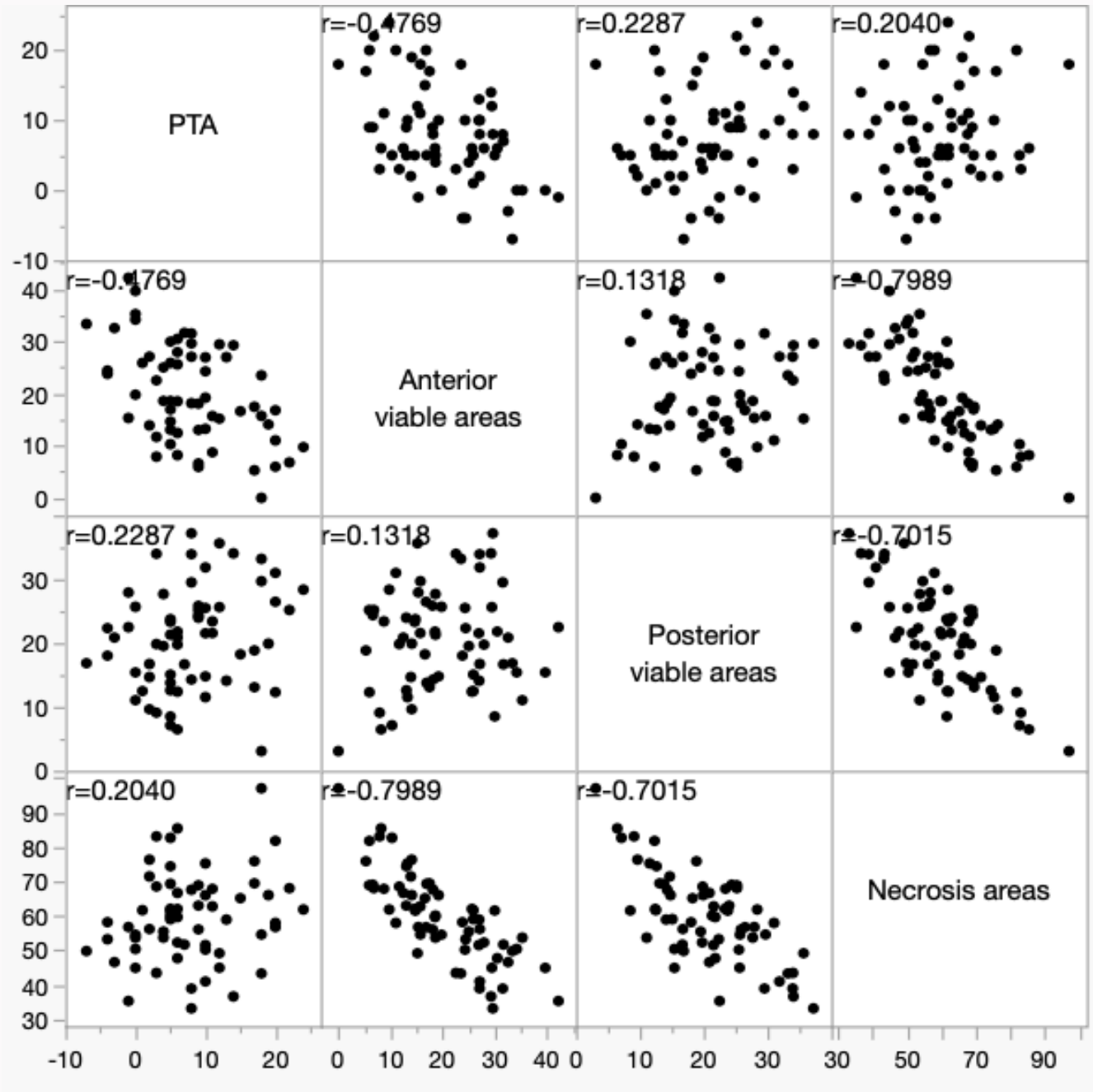

Fig. 4
Scatter plots of Spearman's rank correlation coefficient between the posterior tilt angle and the necrotic or viable areas.

Table I. Interclass correlation coefficients for inter- and intrarater reliabilities of posterior tilt angle, anterior viable area, necrotic area, and posterior viable area.

Variable	Inter-rater reliability	Intrarater reliability
	ICC (95% CI)	ICC (95% CI)
Posterior tilt angle	0.870 (0.796 to 0.919)	0.621 (0.512 to 0.785)
Anterior viable area	0.787 (0.665 to 0.861)	0.867 (0.791 to 0.918)
Posterior viable area	0.667 (0.506 to 0.783)	0.623 (0.488 to 0.752)
Necrosis area	0.699 (0.550 to 0.805)	0.734 (0.5797 to 0.829)

CI, confidence interval; ICC, intraclass correlation coefficient.

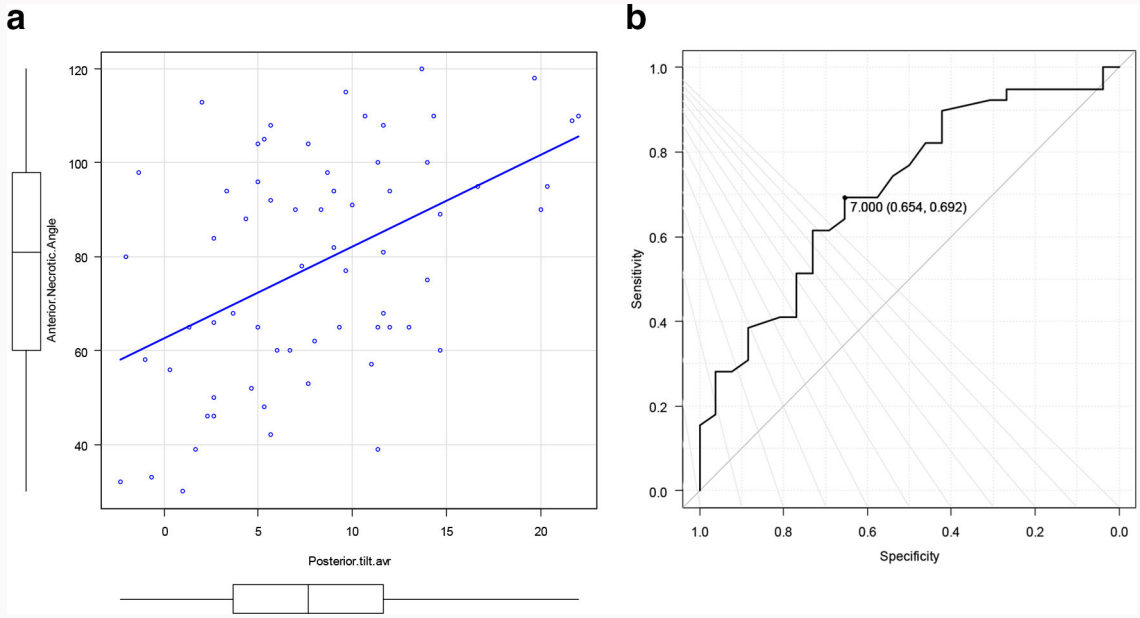

Fig. 5

a) Scatter plots of Spearman's rank correlation coefficient between the anterior necrotic angle (ANA) and the posterior tilt angle (PTA). b) Receiver operating characteristic curve of the PTA for the prediction of ANA > 67° (area under the curve 0.713; 95% confidence interval 0.585 to 0.840).

hips, and type 3 in 37 hips. The median PTA was 6.0° (IQR 3 to 11.5). The mean ratios of the anterior viable area, necrotic area, and posterior viable area were 19.9% (SD 9.3%), 59.5% (SD 12.9%), and 20.6% (SD 7.8%), respectively.

All ICCs for inter- and intrarater reliability ranged from moderate to good (Table I). Spearman's rank correlation analysis showed a negative correlation between the PTA and the ratio of the anterior viable area (rho −0.477; p = 0.001). However, there was no significant correlation between the PTA and the ratios of the necrotic area (rho 0.204, p = 0.132) or posterior viable areas (rho 0.229; p = 0.067) (Figure 4). The median ANA was 81.0° (IQR 90 to 98), and a positive correlation was found between the ANA and PTA (rho 0.473; p < 0.001) (Figure 5a). ROC analysis indicated that the cut-off point for the ANA > 67° was 7 ° (area under the curve 0.713; 95% confidence interval (CI) 0.585 to 0.840) (Figure 5b).

Discussion

In this study, we found a negative correlation between postoperative PTA and the anterior viable areas in post-fracture ONFH on lateral hip radiological images in the Sugioka view. There is no gold standard for measuring PTA, and previous reports have mainly used Garden's alignment index and Palm's method.[25-27] Our PTA measurement results were comparable to those of previous reports.[26]

We used the Sugioka view, which is suitable for observing the femoral head and evaluating necrotic areas,[21] and is commonly used in the pre- and postoperative evaluation of transtrochanteric rotational osteotomies.[13,15,21] As previously mentioned, we also used Palm's method, and the ICCs of our measurements were deemed good and satisfactory.

Many studies have investigated the risk factors for the occurrence of ONFH after FNF.[11,28,29] Poor reduction quality at the initial fracture surgery is considered one of the risk factors for traumatic ONFH.[25,30] However, little attention has been paid to the association between postoperative residual morphological abnormalities due to poor reduction quality and the location of necrosis. We found a positive correlation between the ANA and PTA. A greater ANA increases the risk of the collapse of ONFH, suggesting that residual PTA after FNF – in other words, poor reduction quality at the initial fracture surgery – could affect the prognosis of ONFH.[6] Considering our results, we suggest that the PTA should be within 7° at the initial surgery.

Some studies have reported on the relationship between the loading area and the development and progression of necrosis in pre-clinical models, as well as the finite element analysis (FEA) of ONFH.[31,32] In addition, several FEA studies have investigated changes in the loading direction on the femoral head after FNF.[33,34] Using a 3D model, Zhang et al[34] demonstrated that stress distribution on the femoral head after FNF moved medially, thereby potentially changing the non-loading area of the femoral head into the loading area after FNF, which leads to a femoral head collapse. The authors also observed that fracture edge instability hinders revascularization of the femoral head, and this change in revascularization resulted in delayed fracture healing of the trabecular bone and, ultimately, femoral head collapse.

Femoral osteotomy also changes the load-bearing area of the femoral head.[35,36] Kim et al[36] reported the results of valgus flexion femoral osteotomy for Perthes' disease. They concluded that the anterior part of the head shifted away from the loading area, and the direction of loading moved toward the posterior part of the femoral head owing to the flexion osteotomy, resulting in spheronization of the femoral head in the long term due to remodelling. The residual posterior tilt and valgus impaction of the femoral head after FNFs can be approximated from the postoperative state of valgus extension femoral osteotomy. In other words, the residual posterior tilt to the femoral neck axis is similar to the positional relationship between the femoral head and the acetabulum after femoral

extension osteotomy, and the valgus impaction is similar to that after valgus osteotomy. The postoperative state after femoral extension osteotomy, which is approximated as the residual posterior tilt of the femoral head, is assumed to be the opposite of the postoperative condition after femoral flexion osteotomy, in which the load is concentrated on the anterior part of the femoral head. In other words, the load is considered to be concentrated in the anterior part of the femoral head due to the residual posterior tilt of the femoral head.

Applying the previous study findings to the interpretation of our results, it can be said that greater mechanical load will be applied to the anterior portions of the femoral head if the PTA becomes greater, and this loading shift likely impairs revascularization of the anterior part of the femoral head and eventually reduces the anterior viable area. However, we did not observe a correlation between the proportion of necrotic areas and posterior tilt. While the extent of the necrotic area may not necessarily align with the degree of posterior tilt, taking into account previous reports associating a smaller anterior viable area with a higher risk of collapse, a residual posterior tilt suggests an increased risk of a diminished anterior viable area, leading to collapse.

Limitations

This study had several limitations. First, it was a retrospective study with a small sample size, and only limited outcome data were available due to the retrospective nature of the study. The number of young patients with femoral neck fractures is significantly lower compared to older individuals, and considering that the occurrence of post-traumatic femoral head osteonecrosis is in the range of 4% to 16% among these cases, collecting a substantial number of cases was challenging. These issues should be addressed in future larger studies. Second, this study included only symptomatic patients, and did not include patients with ARCO classification stage 1 or small necrotic areas without symptoms. However, small asymptomatic necrotic lesions are unlikely to be a clinical issue.[37] Third, although this study investigated residual deformity after internal fixation, the fracture type at the time of injury (such as the Garden classification, mechanism of injury, information about implants, and the location of implants used for fracture fixation), and post-treatment methods such as weightbearing, were unknown due to data availability issues.[25,38] These variables are well-established risk factors for post-traumatic ONFH.[27-30] Many patients visited our hospital for treatment after ONFH had occurred, making it impossible to obtain radiographs at the time of injury in all patients. Fourth, this study was conducted using radiographs, the ICC of the posterior viable area was relatively low, and the partial overlap of the femoral head with the acetabulum wall could have interfered with necrosis assessment. Further studies using CT and MRI are needed to resolve these limitations.[39]

In conclusion, the results demonstrated a negative correlation between PTA and anterior viable areas. Furthermore, the postoperative residual posterior tilt after FNF could impact the location of ONFH.

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Data sharing

The data that support the findings of this study are available from the corresponding author (MN) upon reasonable request

Ethical review statement

This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Ethics Committee of Showa University Hospital (no. 3478). The requirement for informed consent was waived due to the retrospective nature of the study.

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