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The association between anterior femoroacetabular impingement and femoral neck fractures

An observational study

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Abstract

The impact between acetabulum and femoral neck is another possible mechanism of femoral neck fracture.

Direct trauma of the greater trochanter may not be able to fully explain the mechanism underlying femoral neck fracture. In this study, we sought to investigate whether anterior femoroacetabular impingement are associated with femoral neck fractures.

A total of 36 patients with femoral neck fracture who had undergone total hip arthroplasty or hemiarthroplasty were included in this study. These patients were divided into 2 groups: labrum tear group and normal labrum group. Patients' age, gender, body mass index, muscle injury, injury pattern, trauma severity, femoral head-neck offset, femoral head-neck ratio, Cam deformity alpha angle, acetabular anteversion, femoral head diameter, acetabular index, cortical index, hip axis length, and neck stem angle were recorded and analyzed. SPSS 18.0 software was used for statistical analyses.

According to intraoperative findings, 22 patients exhibited a labrum tear. Magnetic resonance imaging examination revealed bone contusion on the anterolateral margin of the acetabulum with muscle damage surrounding the hip. Among 14 cases without a labrum tear, no bone contusion and obvious muscle injury were found on the anterolateral margin of the acetabulum. Notably, muscle injury, injury pattern, trauma severity and femoral head-neck offset differed significantly ($P < .05$) between labrum tear and normal labrum groups.

Previous studies have focused more on direct lateral trauma. In this study, the impact between acetabulum and femoral neck is another possible mechanism besides lateral impact. Specifically, the abnormal anatomy of the hip, such as femoral head-neck offset, may promote the fracturing process.

Abbreviations: 3D = three-dimensional, AI = acetabular index, BMI = body mass index, CI = cortical index, CT = computed tomography, HAL = hip axis length, MRI = magnetic resonance imaging, NSA = neck stem angle.

Keywords: acetabular anteversion, acetabulum labrum, cam, falls, hip fracture, hip impingement

1. Introduction

Femoral neck fracture is one of the serious health problems that affect patients with advanced age. Previous studies have suggested that femoral neck fragility fractures in the elderly are related to direct trauma imposed by lateral falls.[1–3] Three-dimensional finite element models reveal that direct trauma to the greater trochanter is a leading cause of femoral neck fracture. Longitudinal compression forces can lead to a pathological fracture in the weak zone of anterolateral femoral neck, and subsequently progress to a complete fracture of the femoral neck.[4–6] However, in some cases, the greater trochanter does not directly suffer from trauma following fall accidents. In fact, some fracture cases are not associated with falls. Moreover, the existing literature has failed to explain the mechanism underlying the occurrence of femoral neck fracture. We hypothesized that there may be different mechanisms involved in the etiology of femoral neck fracture.

In certain injury cases, the patients did not fall laterally, but rather fall forward or simply twist without actually falling, which were met in our cases. Hence, the injury pattern may be an important determinant of femoral neck fracture. Some studies have noted that long-term exercise in patients with hip impingement can lead to stress fractures in the femoral neck,[7] and these impacts occur at flexion position and internal rotation.

Tokyay et al[8] point out that acetabular morphology can predict the types of proximal femoral fractures among elderly patients. A previous study has identified proximal femoral morphology as a major predisposing risk factor for proximal femoral fractures.[9] Considering that both hip dysplasia and injury position can result in stress fractures, we sought to investigate whether femoral neck fractures are associated with anterior femoroacetabular impingement, on account of hip anatomy indexes and injury pattern.

2. Methods

2.1. Patient information

A total of 36 out of 74 patients (10 males and 26 females) with a history of femoral neck fractures for less than 4 weeks were recruited from February 2017 to February 2018. Patient's data were collected from the medical record system in September 2018. All patients underwent total hip arthroplasty or hemiarthroplasty due to their age, fracture displacement and/or geriatric fracture. The mean age of the included patients was 72.8 years (range 50–89 years). Meanwhile, 38 patients were excluded due to:

(1) previous history of hip pain;
(2) previous history of hip surgery;
(3) hip dysplasia;
(4) femoral head osteonecrosis;
(5) hip osteoarthritis;
(6) history of femoral neck fractures for more than 4 weeks; and
(7) not able to communicate normally.

Ethical approval was obtained from the Ethics Committee of the First Affiliated Hospital of Army Medical University (People's Liberation Army) before the research commences, and written informed consent was given by all participants.

Only the selected patients underwent magnetic resonance imaging (MRI) examination, while all the patients underwent computed tomography (CT) examination routinely at the time of admission with ethical approval, and our hospital equipped with these imaging devices. No obvious history of trauma, distal thigh pain and knee injury were observed in each patient. Patients' age, gender, body mass index (BMI), muscle injury, injury pattern, trauma severity, femoral head-neck offset, femoral head-neck ratio, Cam deformity alpha angle, 1/14, 3/14, 5/14, 7/14 and femoral head center anteversion on the affected side, femoral head diameter, acetabular index (AI), cortical index (CI), hip axis length (HAL), and neck stem angle (NSA) were recorded.

Previous literature suggests that the hyperplasia of granulation tissue and hemosiderin macrophages can be found in patients with acute soft tissue injury.[10] To assess the changes in the hyperplasia of granulation tissue and hemosiderin macrophages, all samples with injured labrums were sent to biopsy. The patients were classified into 2 groups.

(1) Labrum tear group (n = 22), with the presence of hemorrhage and hematoma in local area of the injured labrums as well as the hyperplasia of granulation tissue and hemosiderin macrophages.
(2) Normal labrum group (n = 14), in which the labrums were not injured or no hyperplasia of granulation tissue and hemosiderin macrophages.

2.2. Analysis of injury pattern and trauma severity

Both injury pattern and trauma severity were determined according to the self-reported injury histories, and further confirmed by reviewing the surveillance records and videos obtained legally from the place where a patient was injured. The location of bone contusion and muscle injury around the hip were observed by MRI examination. According to previous literature, the signal intensity of edema can last for at least 4 weeks following muscle injury,[11] and all the patients had a history of this symptom for less than 4 weeks.

Among the patients who fell sideways, direct trauma of the greater trochanter resulted in a compression type stress fracture of femoral neck. Considering 15-degree anteversion of the femoral neck, the injury pattern of cases without a labrum tear was possibly a posterolateral fall, while the injury pattern of cases with a labrum tear was likely an anterolateral or lateral fall. The injury patterns of all patients were recorded from patient's medical history, and the differences were compared between the 2 groups. High-energy refers to traffic injury, falling injury, etc. Therefore, it may be necessary to explain that generally speaking, the damage of the selected cases was low-energy, and there is a difference between relatively low-energy and relatively high-energy traumas. Relatively low-energy trauma was defined as a lateral fall that occurred during walking; while relatively high-energy trauma was a fall characterized by additional acceleration, such as slip, fall from heights, trip, traffic injury, fall and get hurt by heavy objects at the same time.

2.3. Evaluation of hip anatomy indexes

The affected femoral neck could not be observed due to the fracture. Therefore, alpha angle (Fig. 1A), femoral head-neck offset (Fig. 1B) and femoral head-neck ratio (Fig. 1B) were determined through a clear lateral view of the contralateral femur.[12] AI, HAL, and NSA were measured through anterior-posterior radiographs of the contralateral hip (Fig. 1C), while CI was of the ipsilateral femur (Fig. 1D). Cam deformities often affect the bilateral hip.[13] Nonetheless, our results demonstrated no significant differences in the diameters of bilateral femoral head and bilateral acetabular anteversion based on 3D reconstruction. Tokyay et al[14] have assessed the contralateral hip data of patients with femoral neck fracture to reflect the affected side. Hence, the affected sides of our patients were evaluated by observing the contralateral hip.

The anteversion of the bilateral acetabulum was measured at five different angles in a 3-dimensional (3D) reconstruction of the pelvis. Thin-layer CT scanning with a slice thickness of 1.0 mm was performed on the bilateral acetabulum at a scan range between the entire pelvis and proximal 200 mm of the femur. The scan data were stored in DICOM format, and then imported into MIMICS 14.0 for reconstructing and generating STL files of the pelvis and femur. Unigraphics NX 11.0 software was used to import the 3D reconstructed STL files, in order to establish the coordinate system and place the pelvis completely in a neutral position. According to Tannast et al,[15,16] the superior margin of the acetabulum was set at the same level for both sides in an anteroposterior position (Fig. 2A), and the angle from the anterosuperior margin line of sacral promontory to the superior margin of pubic symphysis and horizontal line was set at 60° in a lateral position (Fig. 2B). The acetabulum was divided into 14 parts from top to bottom, and the 5 different angles were defined as follows: 1/14, 3/14, 5/14, 7/14 and the femoral head center (Fig. 2C). The anteversion angle A of the acetabulum was measured, as well as contralateral anteversion angle B (Fig. 2D).
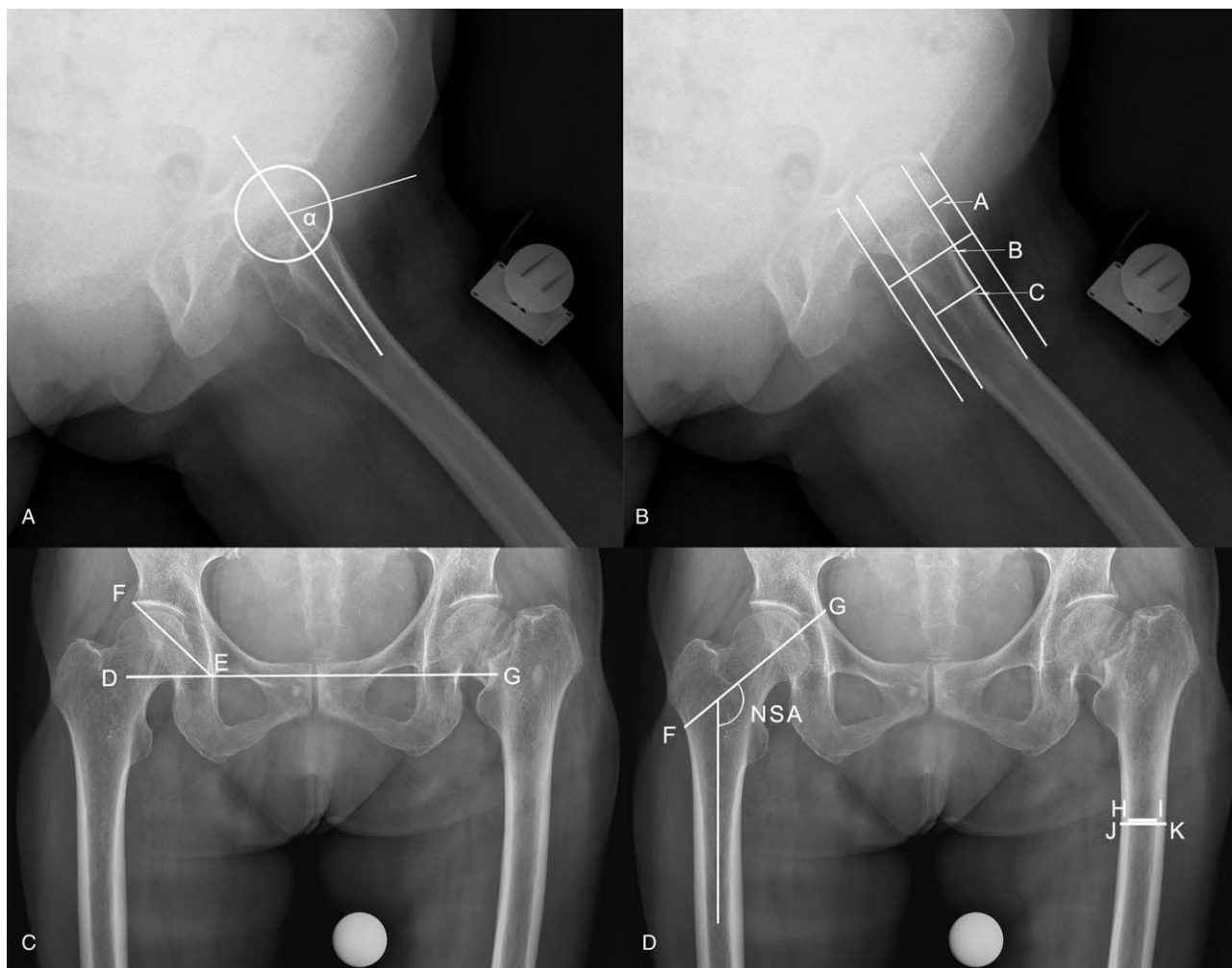
Figure 1. Identification of cam deformity through α angle (A) and femoral head-neck offset and ratio (B) at the contralateral hip, where A is the femoral head-neck offset between 2 lateral lines (outer head vs line from lateral neck parallel to head-neck center), B is the femoral head width, C is the neck width at narrowest point, and B/C is the ratio of femoral head-neck. Acetabular index = the DEF angle (C). Cortical index = (outer diameter [J-K]) minus the intramedullary canal diameter (inner diameter [H-I]) to the (outer diameter [J-K]) approximately 2 cm below minor trochanter; hip axis length = the length along the femoral neck axis from the lateral aspect of the greater trochanter to the inner pelvic rim; and NSA = the angle between femur mid-cervical axis and mid-shaft axis (D). NSA = neck stem angle.

2.4. Statistical analysis

The Fisher exact test and *t* test were used to compare the differences in clinical features (age, gender, BMI, muscle injury, injury pattern and trauma severity) and radiographic variables (femoral head-neck offset, femoral head-neck ratio, Cam deformity alpha angle, acetabular anteversion, femoral head diameter, AI, CI, HAL and NSA) between labrum tear and normal labrum groups. All statistical analyses were performed using SPSS version 18.0 software (IBM Corp., Armonk NY). *P* value of less than .05 was considered statistically significant.

3. Results

3.1. Factors of the injury mechanism

The results of preoperative MRI showed an obvious bone contusion signal on the anterolateral margin of the acetabulum (Fig. 3A). It was found that 6 cases with bone contusion exhibited a labrum tear (Fig. 3B) located on the anterolateral margin of the acetabulum. Extensive amounts of granulation tissue (Fig. 3C)

and hemosiderin macrophages (Fig. 3D) were observed in the torn labrum biopsy samples. Among cases without a labrum tear, no bone contusion was found on the anterolateral margin of the acetabulum, and no granulation tissue or hemosiderin macrophages were detected.

In addition, we noted the occurrence of labrum injury and muscle injury, and found that the short external rotators (Fig. 4A) and adductors (Fig. 4B) manifested an obvious sign of edema in labrum tear cases. However, muscle damage was not obvious in patients with an intact labrum (Fig. 4C and D). As shown in Table 1, muscle and labral injuries were significantly different between labrum tear group and normal labrum group.

Based on fall injury data, we found that the injury pattern of cases without a labrum tear was mainly posterolateral, while that of cases with a labrum tear was primarily non-posterolateral. Data on the injury conditions of all patients were collected through the past medical history. A total of 9 out of 14 cases with relatively high-energy trauma were identified in untorn labrum group, including 1 case of falling off a bike, 3 cases of slip, 1 case of fall and get hurt by heavy objects at the
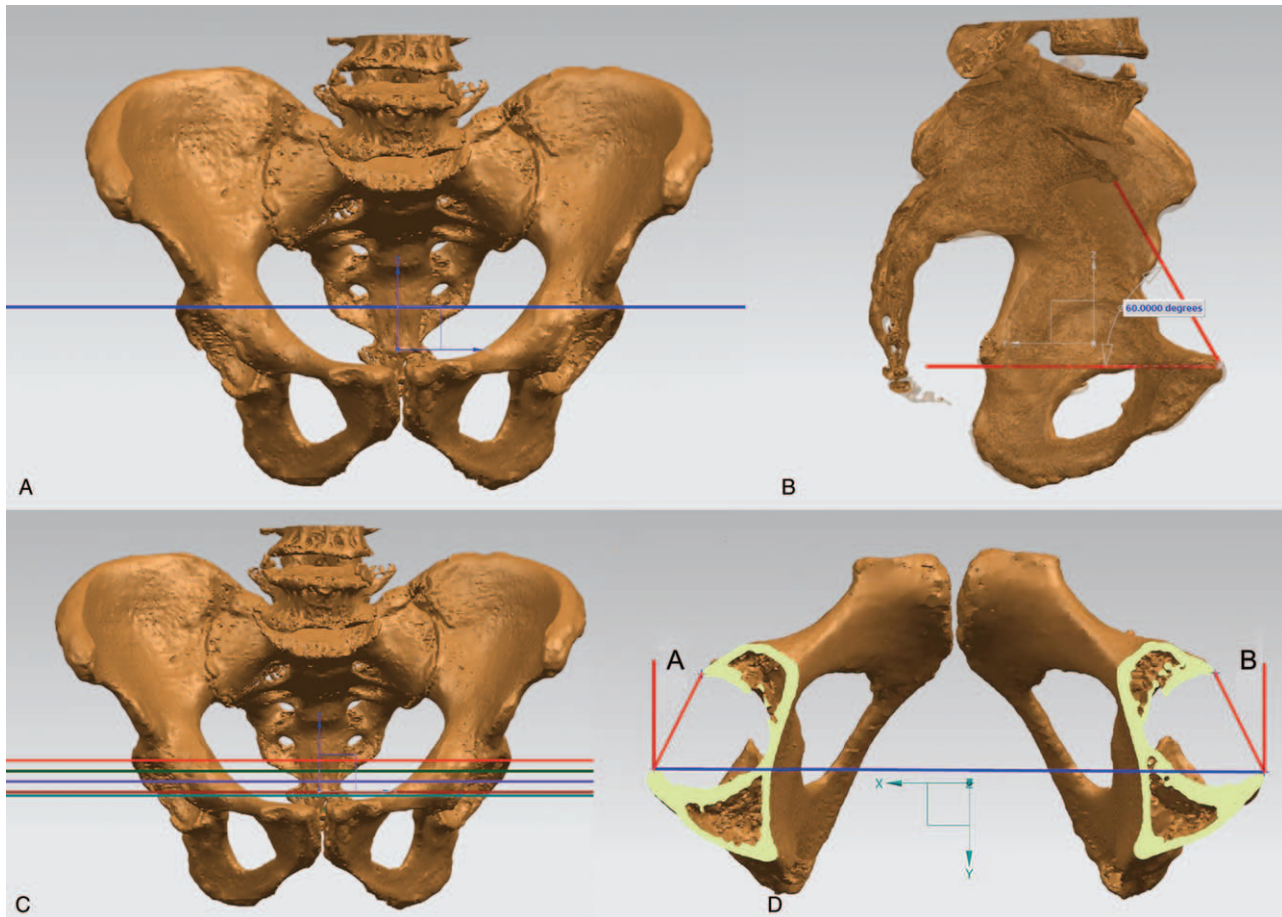
Figure 2. Anterolateral margin of the bilateral acetabulum at the same horizontal line (A). The angle between the anterolateral margin line of the sacral promontory to the superior margin of the pubic symphysis and the horizontal line was set to 60° (B). The acetabulum was divided into 14 parts from top to bottom, and 5 different levels were defined as follows: 1/14, 3/14, 5/14, 7/14 and the femoral head center (C). The anteversion angles of the acetabulum (angle A and angle B) were measured at transverse position (D).

same time, 1 case of falling down from a parallel bar, and 2 cases of trip. Meanwhile, 3 out of 22 cases with relatively high-energy trauma were identified in labrum tear group, all of which corresponded to a fall downstairs. Table 2 shows the underlying relationship between age group and trauma severity. It was noteworthy that the severity of traumatic injury in patients with labrum tear was significantly lower than those with normal labrum (Table 1).

3.2. Hip anatomy indexes

There were no statistically significant differences between labrum tear and normal labrum groups with respect to gender, BMI, femoral head-neck ratio, Cam deformity alpha angle, femoral head diameter, AI, HAL and NSA. On the contrary, age, femoral head-neck offset and CI were significantly associated with labrum tear (Table 1). Notably, the smaller the femoral head-neck offset, the higher the incidence of labrum tear. Besides, there were no statistically significant differences for the 5 angles of acetabular anteversion between the 2 groups. However, the mean acetabular anteversion values at the 5 angles were smaller in labrum tear group compared to untorn labrum group, and the greater differences were observed at 1/14 and 3/14 angles (Fig. 5).

4. Discussion

In the present study, acetabular contusions were less likely to occur if the broken end was in contact with the acetabular margin after a fracture, due to the presence of low stress. The broken ends of the femoral neck were closer to the posterior margin of the acetabulum, but the posterior margin of the labrum was intact. Preoperative and intraoperative observations indicated that the fracture end of the femoral neck had no contact with the acetabulum margin. All the labrum tears were located on the anterosuperior edge of the acetabulum, and their positions were consistent with those of acetabulum bone contusions. Therefore, these findings suggest that the labrum tear is not formed by the broken end.

MRI examination revealed that the labrum tear group displayed significant muscle injuries around the hips, including damages to the short external rotators, obturator externus, pectineus and adductor brevis. When an injury occurs at internal rotation and flexion position, femoroacetabular impingement may be presented. Short external rotation muscle and joint capsule restrict the internal rotation of the hip and prevent further dislocation of the femoral head, obturator externus and adductors magnus,[17,18] while gluteus medius restricts the greater trochanter. Both muscles and joint capsule are equivalent
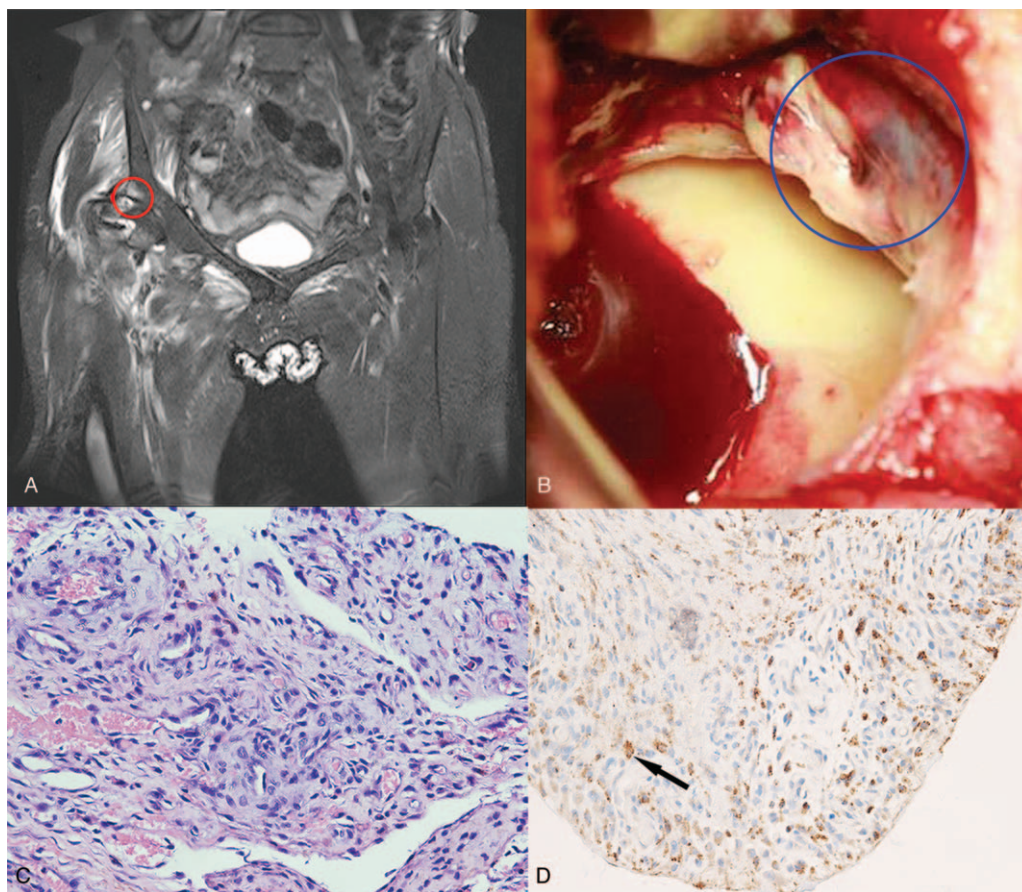
Figure 3. Bone marrow edema (red circle) in the anterolateral margin of the acetabulum observed during MRI examination (A). The anterolateral labrum tear with blood stasis (blue circle) was found during surgical operation (B). Hyperplastic granulation tissue was observed in the torn labrum biopsy (C). Hematoxylin and eosin staining, 400×. A large amount of hemosiderin macrophages (black arrow) were found in the torn labrum biopsy (D). Hematoxylin and eosin staining, 400×.

to one end of a lever, and the anterolateral margin of the acetabulum is similar to the fulcrum of the lever, where the femoral neck is located; while the affected limb is equivalent to the other end of the lever. When an external force acts on the affected limb, the more distal the external force is on the lever, the greater the stress borne on the femoral neck. Patients with normal labrum exhibited no traction in the muscles around the hip or impingement on the hip, and thus, there is no apparent damage on the soft tissues surrounding the hip. The injury pattern of patients without a labrum tear was primarily posterolateral, while the injury pattern of patients with a labrum tear was primarily anterolateral or lateral, suggesting that patients with a labrum tear may have suffered anterior impingement of the hip. In line with our hypothesis, the severity of trauma in labrum tear group was lower than that in untorn labrum group. The most likely explanation is that the injuries in labrum tear group may be due to lever force, whereas those in untorn labrum group may be caused by direct stress. Theoretically, lever is more effective in view of its lower stress (force).

The mean age of the patients in labrum tear group were older, but osteoarthritis cases were excluded and labrum tear cases with no hemosiderin deposition and granulation tissue were classified as normal labrum group. Therefore, age exerts no significant effect on the results of this study. To eliminate the impact of bone mineral density, we compared the CI values in the 2 groups, as the

value of dual-energy x-ray absorptiometry (DEXA) scan was not assessed in our study group. Notably, statistically significant difference was found between the 2 groups in terms of CI values. The CI value of labrum tear group was higher, indicating that the patients with a labrum tear exhibit better bone quality. Moreover, less stress was imposed for the fracture in labrum tear group, suggesting the possibility of anterior femoroacetabular impingement. Previous studies have demonstrated that the smaller the diameter of femoral head, the higher the incidence of femoroacetabular impingement,[19] while the larger the offset and ratio of femoral head-neck, the lower the incidence of hip impingement.[20–22] In addition, the offset of femoral head-neck was reduced in labrum tear group compared to untorn labrum group. Thus, smaller femoral head-neck offset correspond to a high likelihood that the femoral neck fracture is caused by anterior impingement. The measurement results after 3D reconstruction showed that there were no differences between the 2 groups with regard to the acetabular anteversion of both hips and the acetabular anteversion of the affected side. However, a significant difference was found in the mean acetabular anteversion between the 2 groups, with the largest differences observed at 1/14 and 3/14 angles, where it was more susceptible to the impingement between head-neck and acetabulum.

It is believed that there might be at least 2 injury mechanisms underlying femoral neck fracture. One is the common typical
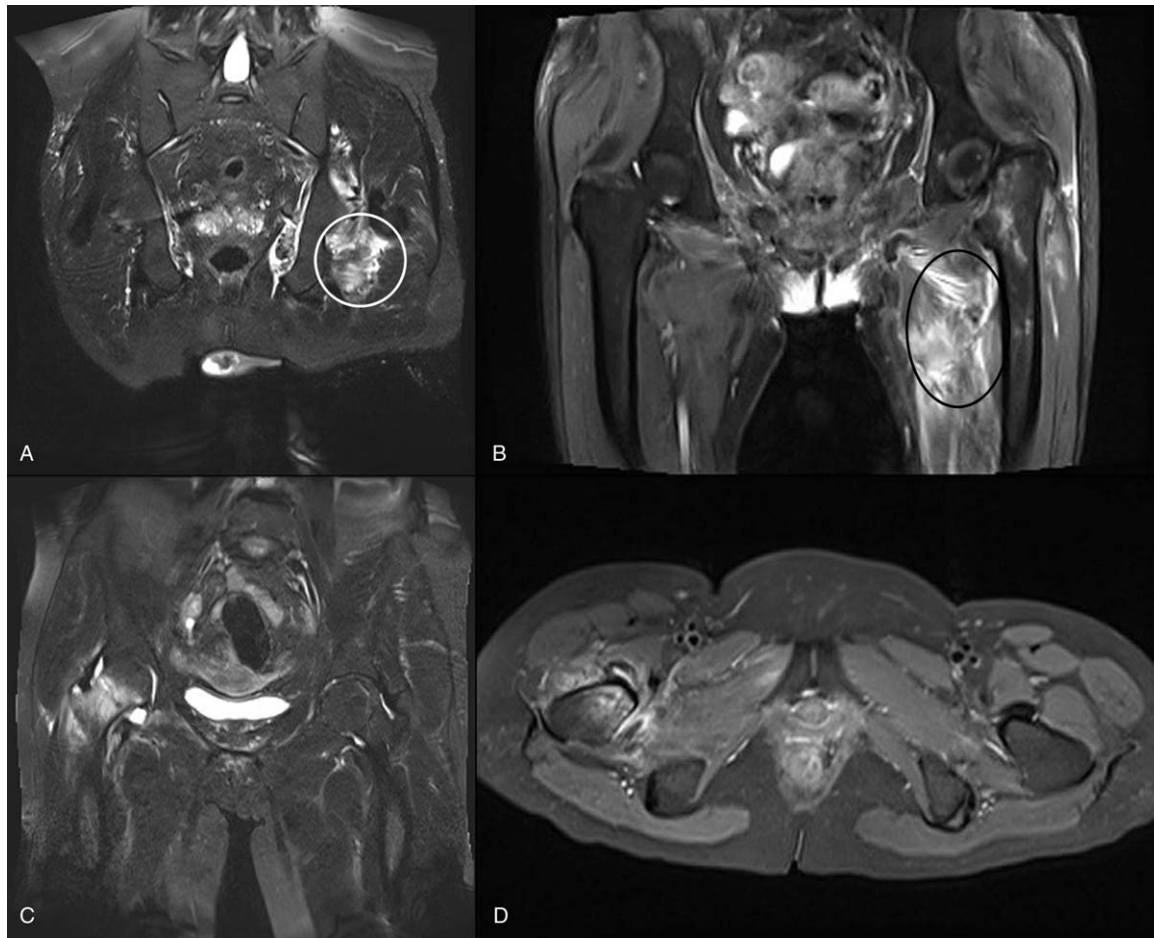
Figure 4. Short external rotator muscle injury (white circle) was found in cases with a labrum tear (A). Adductor muscle injury (black circle) was found in cases with a labrum tear (B). No apparent muscle injury was observed in cases without a labrum tear (C and D).

sideways fall, in which femoral neck fracture of is attributed by direct trauma to the greater trochanter; the other is femoroacetabular impingement. These 2 types of injury mechanisms are totally different with respect to the physiological anteversion of femoral neck. In particular, the former occurs in a posterolateral position without femoroacetabular impingement, while the latter involves a fall pattern of lateral or anterolateral, as the affected

limb should be in the position of flexion and internal rotation. Further reviewing the surveillance videos supported our hypothesis. For this type of injury, we observed that corresponding injury to the muscles around the hip, and femoroacetabular impingement could result in an acetabular labrum tear and bone contusion on the anterolateral margin of the acetabulum. These findings were verified by MRI examination and intraoperative findings. Besides, it is believed that the abnormal anatomy of the hip, such as femoral head-neck offset may promote femoroacetabular impingement. Previous studies have reported that the use of hip protectors[23,24] or specific training can reduce the incidence of hip fracture.[25–27] Thus, novel solutions for preventing femoral neck fracture should be discovered by elucidating the injury mechanisms, which also confers protection against injuries.

Table 1

Relationships between labrum tear and various parameters.

Parameters	Labrum Tear	Normal Labrum	P value
Age (yr)	76.1 ± 9.9	67.7 ± 10.4	.02
Muscle injury/no muscle injury	22/0	1/13	<.001
Posterolateral fall/non-posterolateral fall	7/14	10/4	.04
Severe trauma/general trauma	3/19	9/5	.003
Femoral head-neck offset (mm)	6.1 ± 1.7	7.3 ± 1.0	.03
Femoral head-neck ratio	1.41 ± 0.08	1.46 ± 0.08	.08
Cam (°)	46.8 ± 10	44 ± 5.3	.34
AI (°)	35.9 ± 3.8	36.3 ± 4.5	.79
CI	0.45 ± 0.06	0.40 ± 0.06	.03
HAL (mm)	114 ± 8.4	115.8 ± 8.9	.54
NSA (°)	132.7 ± 5.6	133.5 ± 5.6	.71

AI = acetabular index, CI = cortical index, HAL = hip axis length, NSA = neck stem angle.

Table 2

Age range and trauma severity.

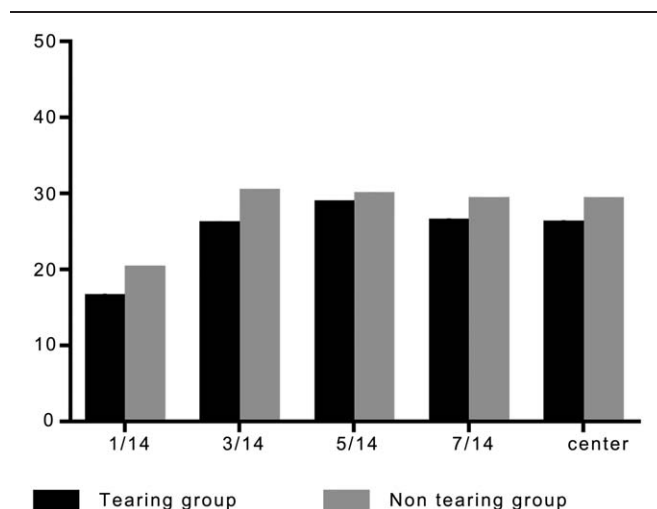| Trauma severity	Age (yr)			
	50~59	60~69	70~79	80~89
Low-energy	2	5	8	9
High-energy	2	4	3	3

Figure 5. Differences in the mean acetabular anteversion of the affected sides between labrum tear and normal labrum groups.

Although this research has reached its aims, there were some unavoidable limitations. Cam deformity was not significantly associated with labrum tear, probably due to the sample size in this study, and the use of contralateral femoral neck data for the comparison. Considering the relatively small sample size and a potentially large variance, no significant difference was noted for the acetabular anteversion between the 2 groups. Regression analysis was performed on all variables, which exerted low power due to the small number of subjects enrolled. Additionally, there was a limitation in the grouping method regarding the presence of labrum tear. Therefore, further well-designed case-control studies with larger sample size are warranted to confirm our findings.

5. Conclusions

The current mechanism is still worthy of further study. Previous studies have focused more on direct lateral trauma. In this study, the impact between acetabulum and femoral neck is another possible mechanism besides lateral impact. Furthermore, the abnormal anatomy of the hip, such as femoral head-neck offset, may promote the fracturing process.

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