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CLINICAL ARTICLE

The Significance of Evaluating the Femoral Head Blood Supply after Femoral Neck Fracture: A New Classification for Femoral Neck Fractures

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Abstract

Objective: To compare a new classification with the Garden classification by exploring their relationships with vascular injury.

Methods: This retrospective study enrolled 73 patients with subcapital femoral neck fracture from July 2015 to November 2018, including 32 males and 41 females with an average age of 47.2 years. All patients were classified by the Garden classification using anteroposterior X-ray imaging and by a new classification system based on three-dimensional CT imaging. The blood supply of the affected femoral head in these patients was evaluated based on DSA images. Correlations between the two classifications and the degree of vascular injury were assessed.

Results: The results of the DSA examination indicated that eight patients had no retinacular vessel injury, 20 patients had one retinacular vessel injury, 35 patients had two retinacular vessel injuries, and 10 patients had three retinacular vessel injuries. The degree of vascular injury was used to match the two fracture classifications. Forty-nine Garden classifications (Type I-IV: 8, 12, 23, 6, respectively, 67.12%) and 66 new classifications (Type I-IV: 8, 20, 32, 6, respectively, 90.41%) corresponded to the degree of vascular injury ($p < 0.05$). The Garden classification showed moderate reliability, and the new classification showed near perfect agreement (Interobserver agreement of $k = 0.564$ [0.01] in Garden classification *vs*. Garden classification $k = 0.902$ [0.01] for the five observers).

Conclusions: The new classification system can accurately describe the degree of fracture displacement and judge the extent of vascular injury.

Key words: classification; digital substraction angiography; femeral neck fracture; retinacular vessel; three-dimensional CT

Introduction

Femoral neck fracture (FNF) is one of the most common bone and joint injuries in the clinic. The most common and serious complication is femoral head necrosis[1–4]. The main cause of traumatic femoral head necrosis is the destruction of the femoral head blood supply. The femoral head is supplied by three groups of blood vessels: the superior, inferior, and anterior retinacular arteries. When femoral neck fractures occur, some of the blood vessels are usually damaged, which leads to avascular necrosis of the femoral head. The greater the displacement degree of fracture, the more severe the degree of vascular injury. In recent years, great progress has been made in the field of artificial joint replacement technology; however, for younger patients with higher hip activity requirements, the current strategy tends toward native hip joint preservation[5,6]. Therefore, it is very

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Received 25 March 2021; accepted 25 January 2022

Orthopaedic Surgery

important to judge the prognosis and guide the treatment according to the different types of FNF. To date, the classification method proposed by Garden in 1961[7] remains the most commonly used method for classifying FNFs. Garden[7] considered the differences between type III and type IV FNFs to lie in the completeness of the superior retinaculum vessel, as this can be used to judge the degree of retinacular vascular damage. However, this classification method is based only on anteroposterior (AP) X-ray images, which are unable to provide a stereoscopic evaluation. Additionally, several authors believe that Garden's classification is easily affected by the subjective judgment of the radiologist, which makes it unreliable, and advise a simplified two-classification system for intracapsular hip fractures, dividing them into nondisplaced and displaced fractures[8–11]. The practical significance of such a "displacement degree-based" classification is to indirectly infer the damage to the femoral head and neck blood supply according to the degree of fracture displacement shown on X-ray imaging to judge the prognosis of the femoral neck fracture and develop a treatment strategy, especially for displaced fractures. Whether this simplified two-classification system can achieve this effect, especially in displaced femoral neck fracture cases, or whether further classification of the displaced femoral neck fracture (as Garden III and IV) is unnecessary remains unknown. CT can be used to observe the degree of fracture displacement from a three-dimensional perspective. Because the retinacula are all attached to the femoral neck surface, accurate judgment of the degree of fracture displacement can lead to an indirect inference of the damage to the retinacular blood vessels. In addition, previous studies have shown that the main source of blood supply to the femoral head includes the retinacular arterial system, round ligament arterial system, and intramedullary arterial system[12,13]. The primary blood supply source of the femoral head is the retinacular arterial system[13–15]. In traumatic femoral head necrosis, it is generally accepted that some factors, such as femoral neck fracture displacement and intracapsular hematoma, cause damage from the main arterial blood supply to the femoral head (the retinacular vascular system and the intramedullary vascular system), eventually resulting in bone necrosis[1,16]. The application of digital subtraction angiography (DSA) in orthopaedics clinics provides a more effective technology to further understand the state of the blood supply of the femoral head after FNF. Highly selective digital silhouette angiography (DSA) can objectively reflect the patency of the femoral head retinacular artery system. In recent years, many doctors have begun to evaluate the blood supply of the femoral head with preoperative DSA. However, because DSA is an invasive examination, it has high requirements on equipment conditions and operating environments and is expensive and has therefore not experienced widespread use. Is it possible to combine the new advances in anatomical research with new imaging technology to make a more comprehensive analysis and more reliable classification for femoral neck fracture? To clarify the influence of the spatial relationship of fracture displacement on the femoral head retinacular arterial system, in this study, 73 patients with femoral neck fracture hospitalized in our department between July 2015 and November 2018 were classified with a combination of X-ray and three-dimensional CT images. DSA was used to evaluate the extent of vascular injury to clarify the following three points: i) Is it possible to use three-dimensional CT images to form a classification system for describing the three-dimensional displacement of fractures? ii) Compared with Garden classification, can this new classification system improve the consistency among observers and thus be more reliable? ii) Can the new classification system better describe the degree of retinacular arterial system injury?

Materials and Methods

General Data

From July 2015 to November 2018, 73 patients with subcapital femoral neck fracture were enrolled.

Inclusion criteria were as follows: (i) aged between 18 and 60 years; ii) relatively good physical condition that can afford surgery or invasive examination.Exclusion criteria were as follows: (i) patients with severe complex disease or injury (life-threatening conditions such as heart failure, shock, multiple organ failure, etc.); ii) refused to accept preoperative DSA examination.

A total of 32 males and 41 females with an average age of 47.2 years (19–59 years) were enrolled. Thirty fractures were on the left side and 43 were on the right side, including 19 that had been caused by traffic accidents, 24 by falling from a height, and 31 by falling down. From the incident to the operation, the mean delay was 2.9 days (range, 1–5 days).

Classification Based on Anteroposterior (AP) X-Ray Imaging and CT Imaging

We performed X-ray and three-dimensional CT examinations on the 73 FNF patients and analyzed the direction and extent of fracture displacement. All of them were femoral neck subcapital fractures that could be classified according to the Garden classification based on anteroposterior (AP) imaging[7]. After that, by including coronal and transverse plane CT imaging, the direction and extent of fracture displacement on the coronal and transverse plane were both analyzed and classified.

The observer group consisted of five orthopaedic trauma surgeons. They were asked to classify the fractures independently according to the Garden classification based on anteroposterior (AP) X-ray imaging. Then, according to the patient's three-dimensional CT images, they described and recorded the displacement of fracture in coronal and transverse plane.

Evaluating the Blood Supply by DSA Examination

The DSA examination was completed within 12–24 h after hospitalization. The blood supply of the affected femoral head in these patients was evaluated based on DSA images.

We used "affected" and "unaffected" to evaluate the damage the femoral head retinacular arteries on the affected side on DSA. With DSA imaging, when contrast agent passes through retinacular vessels, an "unaffected" vessel should develop in an intact manner, without interruption or blurring, and should eventually enter the femoral head. Otherwise, the vessel was regarded as "affected."

Surgery (Close/Open Reduction and Internal Fixation or THA)

For the choice of the patient's surgical plan, we followed the following principles: for nondisplaced fractures (based on X-ray and CT) we usually chose closed reduction and internal fixation; for displaced fractures, we performed open reduction and internal fixation or THA according to the patient's age, physical condition, DSA results, etc.

Statistical Analysis

Statistical analysis was performed by calculating the Cohen kappa value using SPSS 21.0 statistical software for intraobserver reliability. To calculate the multirater kappa for the interobserver agreement, Fleiss' statistical method was used[*]. We interpreted the kappa value coefficient according to the guidelines proposed by Landis and Koch: less than 0.00, poor reliability; 0.00–0.20, slight reliability; 0.21–0.40, fair reliability; 0.41–0.60, moderate reliability; 0.61–0.80, substantial agreement; and 0.81–1.00, almost perfect agreement[†].

Results

Observation and Classification of the Femoral Neck Fracture Based on CT, X-Ray, and DSA Examinations

Based on the coronal and transverse plane CT imaging, according to the three-dimensional direction of fracture displacement, all 73 fractures in this study could be roughly classified into the following four types, which we collectively named the new classification (Figure 1).

Type I: Complete-incomplete fracture without displacement.

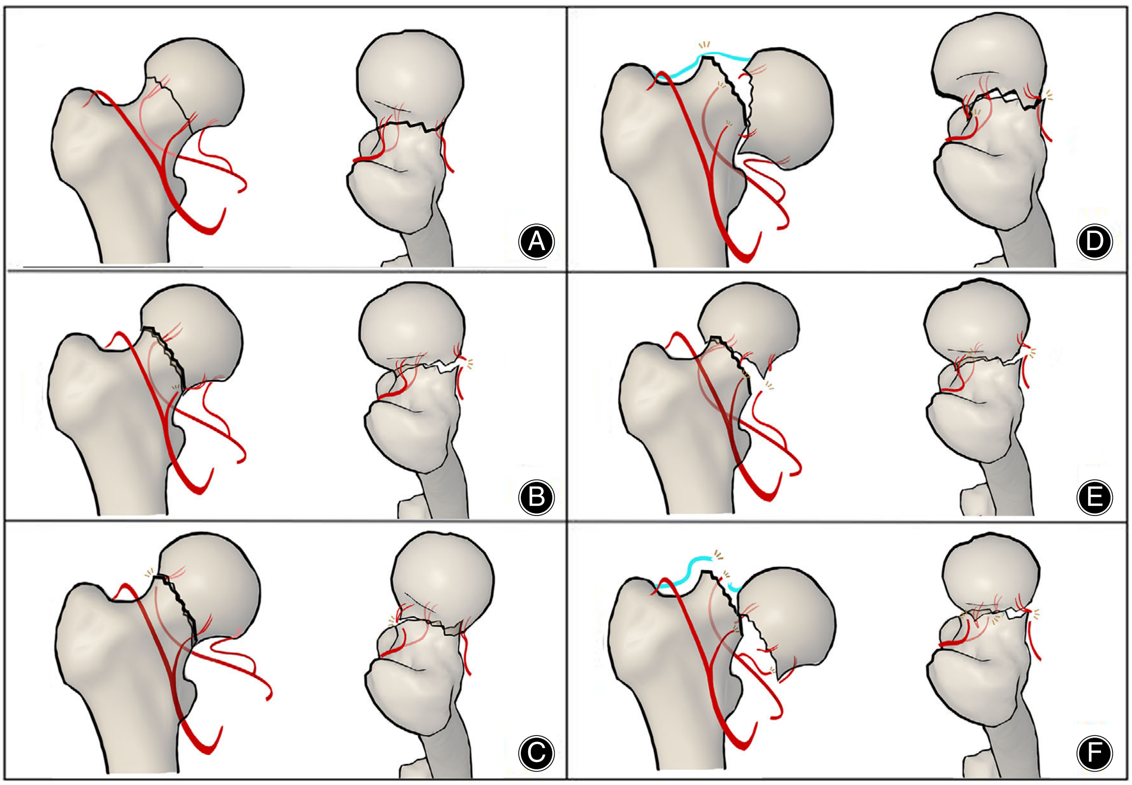

Fig. 1 (A–F) correspond to the new classification types I, IIa, IIb, IIIa, IIIb, and IV, respectively. (A) Type I, complete fracture without displacement. (B) Type IIa: A well-aligned fracture on anteroposterior X-ray imaging but with significant anterior tilting angular displacement on transverse CT imaging. (C) Type IIb: A well-aligned fracture on anteroposterior X-ray imaging but with significant posterior tilting angular displacement on transverse CT imaging. This type was rare in the present study. (D) Type IIIa: Significant displacement on anteroposterior X-ray imaging, usually accompanied by angular deformity and rotational displacement on transverse CT imaging. Type IIIa: The proximal femur is displaced upward with femoral head abduction. (E) Type IIIb: Significant displacement on anteroposterior X-ray imaging, usually accompanied by angular deformity and rotational displacement on transverse CT imaging. The upper end of the femoral head/neck is inserted with femoral head adduction. This type was rare in the present study. (F) Type IV: Complete displacement on anteroposterior X-ray imaging (floating femoral head), accompanied by angular deformity and rotational displacement on transverse CT imaging.

In this type, no obvious displacement or rotation on the CT transverse planes could be observed. It includes all Garden Type I and some Garden Type II fractures.

Type II: A well-aligned fracture on coronal CT imaging but with significant anterior (Type IIa)/posterior (Type IIb) tilting angular displacement on transverse CT imaging.

Type III: Significant displacement on coronal CT imaging, usually accompanied by angular deformity and rotational displacement on transverse CT imaging. This can be divided into two subtypes:

1. Type IIIa: The proximal femur is displaced upward with femoral head abduction.
2. Type IIIb: The upper end of the femoral head/neck is inserted with femoral head adduction.

Type IV: Complete displacement on coronal CT imaging (floating femoral head), accompanied by angular deformity and rotational displacement on transverse CT imaging.

According to this new classification, eight patients had type I, 23 patients had type II, 36 patients had type III, and six patients had type IV fractures. The new classification showed an interobserver agreement of $k = 0.902$ (0.01) for the five observers.

According to the Garden classification based on anteroposterior (AP) X-ray imaging, 15 patients had type I, 19 patients had type II, 28 patients had type III, and 11 patients had type IV fractures. The Garden classification showed an interobserver agreement of $k = 0.564$ (0.01) for the five observers.

The results of the DSA examination indicated that eight patients had no retinacular vessel injury, 20 patients had one retinacular vessel injury, 35 patients had two retinacular vessel injuries, and 10 patients had three retinacular vessel injuries (Figure 2).

The vascular injuries of the different types are shown in Table 1. If the cases with different degrees of vascular injury (no retinacular vascular injury ~3 retinacular vessel injuries, RVI) corresponded to fracture types I to IV, when Garden classification is used, the degree of vascular injury in 49 cases can correspond to DSA results, while when new classification is used, the degree of vascular injury in 66 cases can correspond to DSA results. ($p < 0.05$) (Table 1). It shows that the new classification is more accurate than Garden classification in reflecting vascular injury.

Treatment Outcomes

Among the 73 patients included in this study, 58 underwent one-stage fracture internal fixation. Forty-nine patients were followed up for more than 2 years (average 2.43 years), and patients developed nonunion or osteonecrosis during the follow-up period (Fig. 3).

The majority of nonunion or osteonecrosis cases were type III according to the new classification (Figure 4): seven type III and one type II. According to the Garden classification, the eight cases were equally distributed as type II or type III fractures (Table 2).

Discussion

In this study, 73 patients with FNF were classified by AP X-ray and three-dimensional CT imaging. We classified the fracture displacement displayed on coronal and transverse CT into four types (new classification), analyzed its intraobserver reliability, preoperative DSA was used to evaluate the reliability of this new classification in evaluating the blood supply of femoral head compared to traditional Garden classification, and the following results were obtained.

Comparison of New Classification with Garden Classification

Is it possible to use three-dimensional CT images to form a classification system for describing the three-dimensional displacement of fractures?

In this study, we used coronal and transverse plane CT imaging to classify FNFs into four types (new classification types I~IV, including four subtypes) according to the spatial displacement of the fracture. This new classification system considers both the coronal and transverse plane displacement of the fracture, and all 73 fractures included in this study could be classified into one of the four types. This new classification is to some extent based on the description of the relationship between fracture displacement and vascular injury by Garden classification, on the coronal plane, it eliminates the interference of overlapping projection and adds the evaluation of horizontal plane, so it is more stereoscopic than the description of fracture in Garden classification[7].

Compared with Garden classification, can this new classification system improve the consistency among observers and thus be more reliable?

We assessed the reliability of the Garden classification and the new classification; the Garden classification showed moderate reliability, and the new classification showed near perfect agreement (interobserver agreement of $k = 0.564$ [0.01] in Garden classification *vs.* Garden classification $k = 0.902$ [0.01] for the five observers). The differences may be due to X-ray projection angle and overlapping of projection, some fractures with displacement and embedment in the coronal plane may not show obvious displacement in the AP X-ray imaging. However, this is clearly displayed on CT imaging. Parker *et al.*[10] advocated that the intracapsular fracture of femoral neck should be simply divided into two types: non-displaced and displaced fracture to increase the reliability. However, we did not compare the reliability of this simple classification with the new classification in this study since the results of our study showed that this simple classification was far from sufficient for the evaluation of blood supply of femoral head/neck after FNF.

Can the new classification system better describe the degree of retinacular arterial system injury?

The statistical analysis of the imaging data of the 73 patients in this study showed that compared with Garden classification, the new classification had a better correspondence degree than the Garden classification in estimating

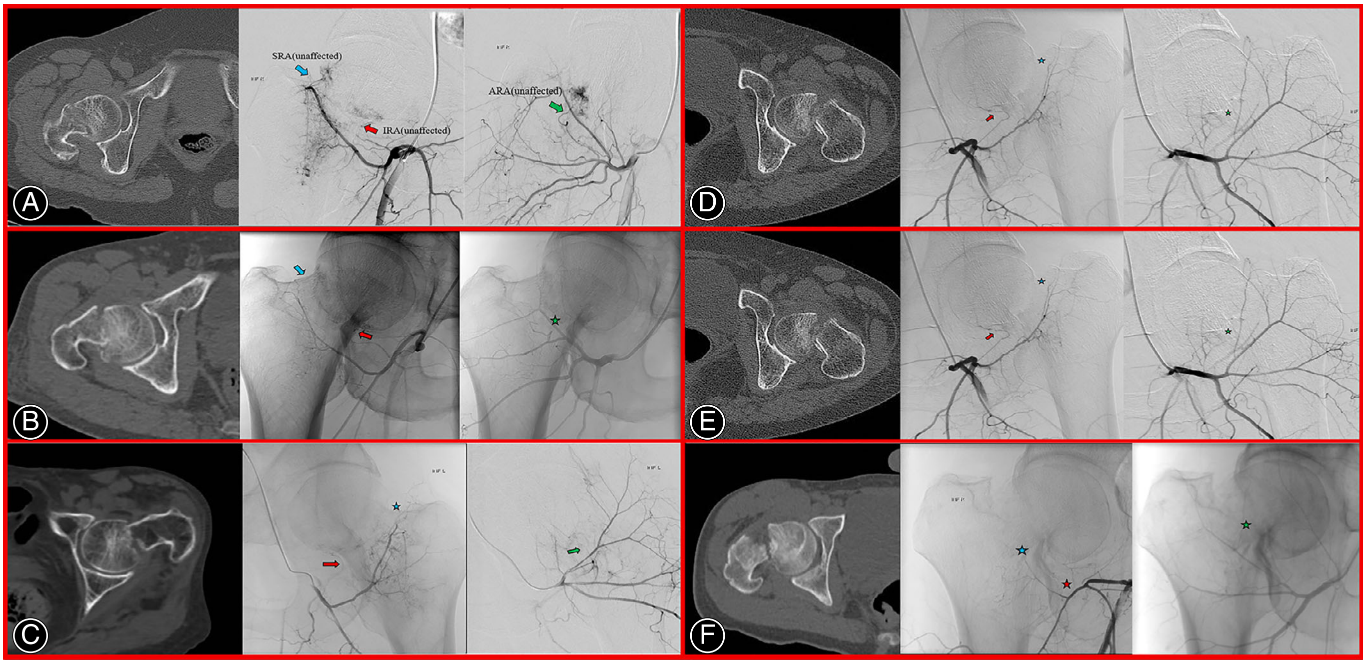

Fig. 2 (A–F) correspond to CT and DSA images of new classifications I, IIa, IIb, IIIa, IIIb, and IV, respectively. (A) A Type I fracture case. The CT scan showed a complete fracture without displacement, and no obvious displacement or rotation on transverse CT imaging could be observed. All three groups of retinacular arteries (the superior retinacular artery (SRA, blue arrow), the inferior retinacular artery (IRA, red arrow), and the anterior retinacular artery (ARA, green arrow) were well-developed on DSA imaging. (B) A Type IIa fracture case. Significant anterior tilting angular displacement could be observed on transverse CT imaging. The superior (blue arrow) and inferior (red arrow) retinacular arteries from MFCA are well-developed on DSA imaging, while the anterior retinacular arteries from LFCA are affected (green star). (C) A Type IIb fracture case in which significant posterior tilting angular displacement could be observed on transverse CT imaging. The inferior (red arrow) and anterior (green arrow) retinacular arteries are well-developed, while the superior retinacular arteries (blue star) are affected on DSA imaging. (D) A Type IIIa fracture case in which significant anterior tilting angular displacement could be observed on transverse CT imaging. The inferior retinacular arteries (red arrow) are well-developed, while the superior (blue star) and anterior (green star) retinacular arteries are affected on DSA imaging. (E) A Type IIIa fracture case in which significant anterior tilting angular and rotation displacement could be observed on transverse CT imaging. The superior retinacular arteries (blue arrow) from the MFCA are well-developed, while the inferior (red star) and anterior (green star) retinacular arteries are affected on DSA imaging. (F) A Type IV fracture case in which significant anterior tilting angular displacement could be observed on transverse CT imaging. The superior (blue star), inferior (red star), and anterior (green star) retinacular arteries are all affected on DSA imaging.

Table 1 The vascular injury of different types

Classification		Case number	Results of the DSA examination			
			no RVI	one RVI	two RVI	three RVI
Garden classification	Type I	15	**8**	7		
	Type II	19		**12**	7	
	Type III	28		1	**23**	4
	Type IV	11			5	**6**
New classification	Type I	8	**8**			
	Type II	23		**20**	3	
	Type III	36			**32**	4
	Type IV	6				**6**
Total		73	8	20	35	10

Bold Values indicate number of Cases that with no vascular affection in type I fracture, with one group of retinacular vessels affected in type II fracture, with two groups of retinacular vessels affected in type III fracture, with all three groups of retinacular vessels affected in type IV fracture.

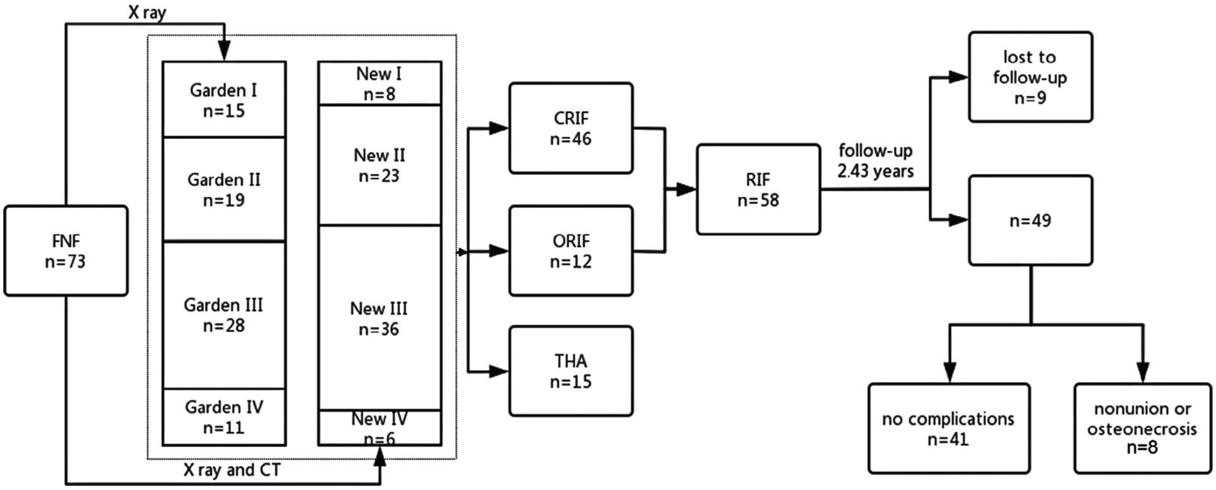

Fig. 3 Treatment outcomes for FNF cases in this study. A flowchart depicting the treatment outcomes for femoral neck fracture. FNF, femoral neck fracture; CRIF, closed reduction and internal fixation; ORIF, open reduction and internal fixation; THA, total hip arthroplasty. Forty-nine patients were followed up for more than 2 years (average 2.43 years), and eight patients developed nonunion or osteonecrosis during the follow-up period.

femoral head vascular injuries (Table 1). In addition, according to the follow-up situation, the prognosis of type II and type III in the new classification is different, but due to the small amount of data, it is impossible to draw accurate statistical conclusions at present (Figure 4) (Table 2). Compared with the Garden classification, the new classification focuses more on the effect of fracture displacement on the retinacular vessels at specific positions, which may mean that combined with the anatomical position of the three retinacular arteries of the femoral head, we could preliminarily analyze the damage to the femoral head blood supply after an FNF by observing its displacement direction. The new classification and Garden classification overlapped in some cases but may not have been completely consistent in others.

In addition, Yang *et al.*[17] used preoperative DSA to evaluate the residual femoral head blood supply in 45 patients and classified them according to the number of retinacular vascular observed in DSA images. After 6~60 months of follow-up, the results showed that the rate of ANFH is negatively related to the visible retreat in acute vascular amount on DSA. The results proved the correlation between preoperative DSA blood supply evaluation and long-term prognosis. In this study, the new classification is superior to Garden classification in the corresponding DSA evaluation, and the new classification relies on noninvasive and low-cost examination, which has obvious advantages over DSA examination.

Analysis of Factors of Blood Supply Injury and Treatment Strategies

The DSA images showed that the anterior retinacular arterial system was the more vulnerable than the superior and inferior retinacular arterial systems, which could be attributed to the weaker tissue structure of the anterior retinaculum and its more restricted space distant from the femoral neck. When a displaced fracture occurs, the displaced fragment and the lateral rotational violence of the femoral head could easily tear the anterior retinacular arterial system. Closed internal fixation can usually achieve good results in new classification type I patients.

The superior retinaculum contains four to six arteries that are important supply arteries for the femoral head. In new type IIa fractures, most of the superior retinacular arteries are unaffected, so for these patients, there is usually a chance to preserve their native hip joint, and few complications will arise. In our study, all of the new type IIa patients presented with good results and no complications for more than 2 years of follow-up.

The superior retinaculum is the hardiest retinacular structure of the femoral head/neck which Gardn[7] mentioned in his article on FNF. Similar to the Garden classification, it is also the key structure for classifying displaced fractures into new type III or IV. This hardy structure makes typical Garden III fractures exhibit abduction displacement of the femoral head and separation of the superior part of the femoral head and neck (new type IIIa), with a certain degree of lateral rotation of the femoral head. Although strong forces tend to separate the femoral head and neck in new classification type IIIa, the tough inferior retinaculum remains intact to some extent and prevents further displacement of the fragment (typical X-ray images show that the trabecular bone of the femoral head exhibits abduction relative to the acetabulum). This mechanism plays an important role in protecting the inferior or superior retinacular arterial system to a certain extent. Meanwhile, there was at least one group with residual retinacular arterial systems among the new type III patients in this study. All of the above results suggest that

Fig. 4 (A,B) A 53-year-old male patient was diagnosed as Type IIIb femoral neck fracture, and the probability of femoral head necrosis was high before operation, but the patient refused to undergo THA. (C) The patient was treated with ORIF, which is an immediate image after surgery. (D) After 16 months of follow-up, necrosis and collapse occurred in the femoral head of the affected side.

in new type III fractures, native hip joint preservation remains possible; for young adult patients with new classification type III fractures, CRIF might be the first consideration. If CRIF cannot achieve a good reduction, ORIF should be considered. However, new type IIIb fractures are rare in the clinic. In this study, three new type IIIb

Table 2 The outcome of the treatment for the patients

Classification		Case number	Surgery			Follow-up
			CRIF	ORIF	THA	
Garden classification	Type I	15	15	0	0	
	Type II	19	17	1	1	4
	Type III	28	7	13	8	4
	Type IV	11	3	2	6	
	total	73	42	16	15	8
New classification	Type I	8	8	0	0	
	Type II	23	22	1	0	1
	Type III	36	12	15	9	7
	Type IV	6	0	0	6	
	Total	73	42	16	15	8

patients were treated with ORIF, and they were followed up for more than 24 months without complications such as osteonecrosis.

Generally, there were no unaffected retinacular arteries in patients with new type IV fractures on DSA imaging in the present study. When an instance of violence tears the superior retinaculum and leads to further, serious displacement of the fracture fragments, irreversible damage could be caused to the superior retinacular arterial system due to the loss of limitation of the superior retinaculum. Additionally, this kind of injury always leads to serious damage to the inferior retinacular arterial systems due to the loss of substantial ligament structure support, which means that in new type IV fractures, there are hardly any opportunities for native hip joint preservation by ORIF. For young patients, vascularized bone flap transplantation or other techniques that can reconstruct the blood supply might be necessary, while for elderly patients, THA is the best choice.

Limitations

There are some limitations in this study. First, the development of retinacular vessels on angiographs can only show the patency of blood vessels but cannot evaluate the true damage to the blood vessels. In cases where the retinacular vessels are not developed during angiography, we suggest that it is more accurate to use the word "affected" instead of "damaged." We believe that when the femoral neck fractures, the types of "affected" vessels could be divided into reversible and irreversible. However, DSA images cannot distinguish between the two. In addition, this study lacks postoperative DSA images, and the results will be more meaningful if we could compare preoperative and postoperative DSA. Second, the sample size of this study was insufficient. We noticed that there were some rare types in the new classification, such as IIb and IIIb. It is impossible to determine the frequency of these types from the current sample size alone. Additionally, the evaluation of retinacular arterial system afflictions needs to be confirmed by a larger sample size. Third, as the overall follow-up time is still short, the long-term result remains to be observed for a long time, which is also a limitation of this study.

Conclusion

We suggest a new classification that combines CT imaging and can more accurately describe fracture displacement to infer the condition of the femoral head blood supply than the Garden classification. The advantage of this new classification is that the blood supply to the femoral head after an FNF could be estimated according to the three-dimensional spatial description of the fracture displacement and the anatomical position of the blood supply of the femoral head.

Conflict of interest

The authors declare that they have no conflicts of interest.

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