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ORIGINAL ARTICLE

Preoperative computed tomography morphological characteristics of displaced femoral neck fractures

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ABSTRACT

Objectives: This study aims to investigate the morphological classification of preoperative computed tomography (CT) in patients with femoral neck fracture treated by hollow nail.

Patients and methods: Between January 2014 and December 2021, a total of 34 patients (23 males, 11 females; mean age: 51.97±11.80 years; range, 18 to 85 years) with displaced femoral neck fracture according to Garden classification (Stage III-IV) were included in this study. The preoperative CT data of the patients with femoral neck fractures treated with a hollow screw were collected. According to the morphological characteristics of femoral neck fracture, the slope angle of CT, three-dimensional reconstruction, the lateral upward angle of coronal position, the opening angle, the head-back tilt angle and the head backward distance ratio in horizontal position were measured.

Results: According to the study of CT morphology, femoral neck fracture was classified into varus separated type 1, varus separated type 2, and valgus impacted type. The mean slope angle was 52.95°±10.36°, the mean lateral upward angle was 15.45°±5.59°, the mean head-back tilt angle was 33.89°±11.20°, the mean head backward distance ratio was 0.822±0.114, and the mean forward opening angle was 23.82°±6.11° in varus separated type 1. The mean slope angle was 65.72°±3.36°, the mean head-back tilt angle was 18.44°±5.18°, and the mean head backward distance ratio was 0.460±0.181 in varus separated type 2. The mean head-back tilt angle was 18.65°±12.54° and the mean head backward distance ratio was 0.362 in valgus impacted type. For varus separation type, the proportion of male patients (93.75%), high-energy injuries (56.25%), and Garden type 4 fractures (87.50%) was higher than that of valgus impacted type (38.89%, 11.11%, and 5.56%, respectively), indicating a statistically significant difference ($p<0.01$). The amount of intraoperative blood loss, head-back tilt angle, and backward distance ratio of patients with varus separation were higher than those of patients with valgus impaction, indicating a statistically significant difference ($p<0.01$).

Conclusion: The morphology of preoperative CT of femoral neck fracture treated with hollow screw can be divided into varus separated type and valgus impacted type. This fracture classification can guide the intraoperative reduction and improve the quality of reduction. The functional exercise is reasonably guided by evaluating prognosis according to the classification characteristics.

Keywords: Femoral neck fracture, hollow screw, valgus, varus.

Femoral neck fracture is a common fracture of the limbs, accounting for approximately 4.5% of systemic fractures.[1] Surgical treatment of femoral neck fracture includes open reduction and internal fixation, femoral head replacement, and total hip replacement.[2] Due to poor biomechanical stability and failure to bear weight early after surgery, patients may have refracture, internal fixation failure, and ischemic necrosis of the femoral head.[3] In particular, once the femoral head necrosis occurs, it would be an irreversible complication and, therefore, the femoral head ischemic necrosis is also known as the deathless cancer.[4]

Currently, the prognosis is usually evaluated according to different types of femoral neck fractures. Clinically, there are many classification methods for femoral neck fracture, such as classification according to the anatomical position of the fracture

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line, Pauwels classification according to the angle of the fracture line, and Garden classification according to the degree of fracture displacement.[5] Various fracture classifications require preoperative standard X-ray imaging data for accurate judgment.[6] However, for patients with femoral neck fracture, due to the pain and the affected limb flexion and external rotation deformity, it is difficult to take a relatively standard anteroposterior (AP) radiograph of pelvis or AP and lateral radiograph of hip joint before surgery. Additionally, due to the interference of two-dimensional X-ray overlapping images, it is often difficult for orthopedic surgeons to accurately identify the fracture type, which cannot improve the quality of intraoperative fracture reduction, and also cannot reasonably guide patients to functional exercise through an accurate postoperative evaluation.[7]

Compared to ordinary X-ray, computed tomography (CT) examination is without position limitation.[8] In addition, there are few reports regarding the CT morphological characteristics and classification of femoral neck fractures in the literature. In the present study, we aimed to roughly classify the fractures according to the preoperative CT morphological characteristics of the displaced femoral neck fracture and to guide the intraoperative reduction and improve the reduction quality, evaluate the prognosis according to the classification characteristics, and reasonably guide the patients' functional exercise.

PATIENTS AND METHODS

The retrospective study was conducted at BeiJing ShiJingshan Hospital, Department of Orthpedics between January 2014 and December 2021. A total of 34 patients (23 males, 11 females; mean age: 51.97±11.80 years; range, 18 to 85 years) with displaced femoral neck fracture (Garden classification: Stage III-IV[9]) were included. Nineteen patients were Garden Stage III and 15 patients were Garden Stage IV. There were 12 patients with a left-sided fracture and 22 patients with a right-sided fracture. The causes of injury included 11 cases of high-energy injury (n=6 car accident injury, n=high-altitude fall injury) and 23 cases of low-energy injury (ordinary fall injury). Exclusion criteria were as follows: *(i)* hip dysplasia or rheumatoid arthritis; *(ii)* hip valgus deformity; *(iii)* ischemic necrosis of the femoral head; *(iv)* old femoral neck fracture or pathological fracture; and *(v)* long-term alcohol abuse or hormone use.

We performed CT imaging without position restriction than the ordinary X-ray as our routine preoperative imaging examination and, therefore, patients could have the routine CT examination in the natural stretching state of both lower limbs before surgery. Three-dimensional (3D) reconstruction was performed based on CT data (some earlier cases reconstruction assisted with MIMICS® version 17.0 software [Materialise HQ, Leuven, Belgium]). The

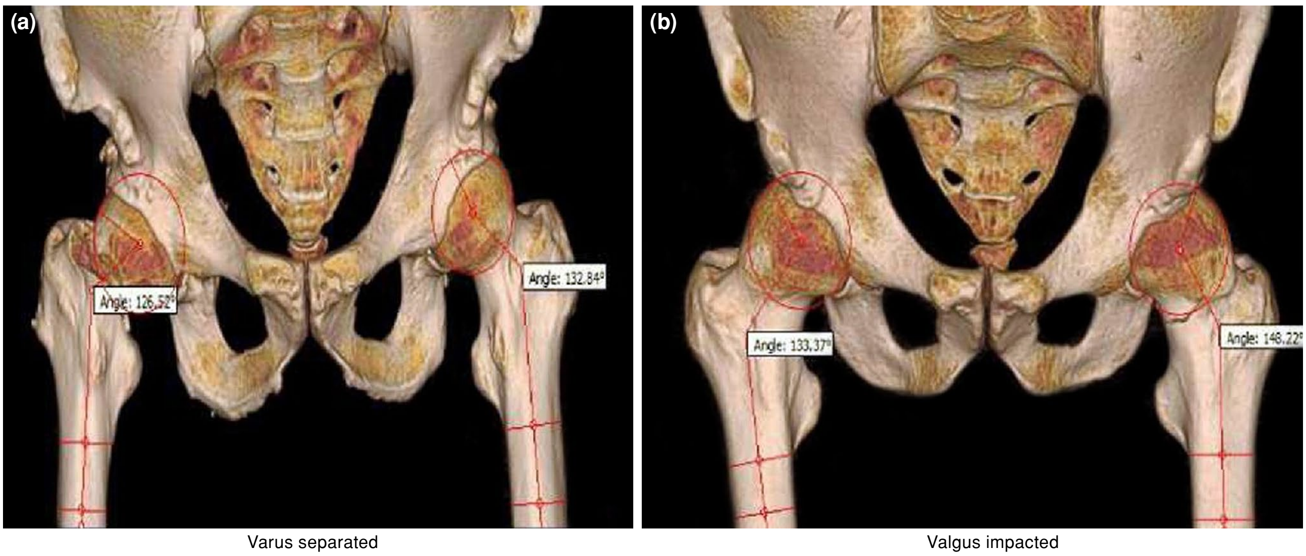


FIGURE 1. Preoperative computed tomography classification of displaced femoral neck fractures. **(a)** varus separated type: fracture displacement with neck-shaft angle less than the healthy side. **(b)** valgus impacted type: fracture displacement with neck-shaft angle greater than the healthy side.

Varus separated type 1 | Varus separated type 2 | Varus separated type 2 (Beak fracture)

FIGURE 2. Computed tomography morphological characteristics of varus separation type 1. **(a)** Varus separated type 1: The broken ends showed anterolateral superior varus and angulation deformity. **(b)** Varus separated type 2: The fracture end was parallel. **(c)** Varus separated type 2 (Beak fracture).

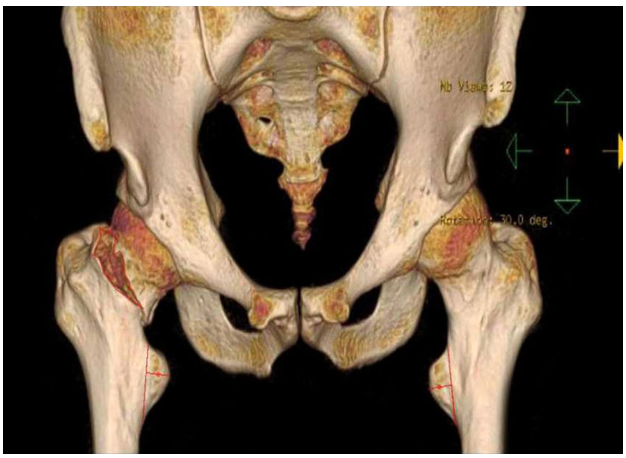
position of the 3D-reconstructed image was adjusted to the AP image of the affected side and the healthy side to compare the neck-shaft angle.

Classification of femoral neck fractures

According to the size of neck-shaft angle, the patients were divided into varus separation type (fracture displacement with neck-shaft angle less than the healthy side) and valgus impacted type (fracture displacement with neck-shaft angle greater than the healthy side) (Figure 1). The varus separation type was also divided into type 1 (the broken ends showed anterolateral superior varus and angulation deformity) and type 2 (the fracture end was parallel or beak-like) (Figure 2).

Measurement of 3D reconstruction data

Varus separation type: This fracture type has fracture displacement with neck-shaft angle smaller than the healthy side and can be divided into two types. Type 1 patients present the forward, lateral upward openings on the 3D reconstructed images. With Digimizer Image Analysis Software (MedCalc Software Ltd., Ostend, Belgium), the opening area, circumference, maximum diameter and basal length of bilateral lesser trochanter can be measured and the mean value can be calculated. The ratio of the perimeter and the longest diameter to this mean is defined as the perimeter ratio and the longest diameter ratio (Figure 3). Given the position limitation during fracture, it is difficult to take AP projection of the affected hip joint. The Pauwels angles are mostly difficult to be accurately measured. Therefore, according to the anatomical characteristics of the femur itself, the slope angle can more accurately reflect the characteristics of the fracture, that is, the angle formed by the fracture section and the vertical axis of the femoral shaft (Figure 4). The Pauwels angles are mostly difficult to be accurately measured. Therefore, according



Measurement	Area	Perimeter	Length	Angle	Radius	Unit
Area	1140.192	196.186	82.098			px
Length			62.780			px
Length			62.466			px
Perpendicular			27.032	174.226		px
Perpendicular			27.190	7.712		px

FIGURE 3. Perimeter ratio/maximum diameter ratio. The ratio of the perimeter and the longest diameter to this mean is defined as the perimeter ratio and the longest diameter ratio.

Area: Open area; Perimeter; Length (first column): the longest diameter; Length (second and third columns): the length of the small trochanter base on both sides.

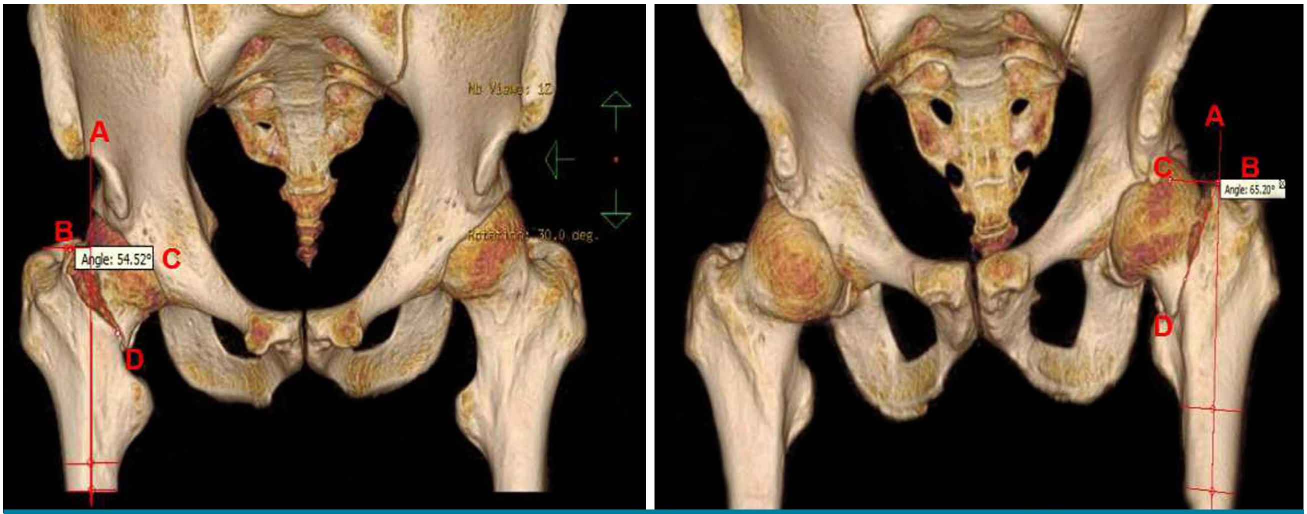


FIGURE 4. Angle of varus separation type 1 slope.
a: Longitudinal axis of femoral shaft. **b:** The highest point outside the fracture. **d:** The lowest point in side and below the fracture. **b, c:** Vertical line the of longitudinal axis of the femoral shaft. **c, d, b:** Slope angle formed by the section of the femoral neck fracture and the vertical line of the femoral shaft.

to the anatomical characteristics of the femur itself, the slope angle can more accurately reflect the characteristics of the fracture, that is, the angle formed by the fracture section and the vertical axis of the femoral shaft (Figure 4). The broken ends of type 2 are almost parallel, and the slope angle can be measured using Digimizer software.

Valgus impacted type: The patients had a displaced fracture with a larger neck-shaft angle than the healthy side. It was difficult to accurately measure the slope angle due to the impacted fracture.

Data measurement of coronal section

Varus separation type: The fracture in the coronal position presents the lateral upward opening of type 1. The image with the largest opening above the anterior in the coronal position was selected and measured by Digimizer software (Figure 5a). The upper coronal fracture of the affected limb was almost parallel. The upper coronal fracture end of the affected limb was almost parallel. The broken ends of type 2 in the coronal position were almost parallel (Figure 5b).

Valgus impacted type: The patients with this type showed outer upper incarceration in the coronal position without lateral upward opening angle (Figure 5c).

Horizontal data measurement

Varus separation type: The varus separation type 1 has a forward opening at the horizontal level, with

FIGURE 5. Coronal computed tomography morphological characteristics displaced femoral neck fracture. **(a)** varus separated type 1. **(b)** varus separated type 2. **(c)** valgus impacted type

FIGURE 6. Computed tomography horizontal anterior opening angle of varus separation type 1.
∠a, c, b: The front opening angle.

a backward head. The front opening is indicated by the forward opening angle ∠acb (Figure 6) and is measured by the Digimizer software. Head backward tilt is indicated by head-back tilt angle and distance ratio. The angle of the femoral neck axis (a) and the femoral head axis (b) indicates the head-back tilt angle. The greater the angle, the greater the backward inclination. The ratio of the distance between the femoral head center (c) and the femoral neck axis (a) and the femoral head radius indicates the backward tilt distance ratio. The larger the ratio, the greater the head backward inclination. The broken ends of the type 2 are almost parallel, without obvious opening angle. The measurements of head-back tilt angle and backward tilt distance ratio remain unchanged (Figure 7).

Valgus impacted type: This type presents head backward in the horizontal position. Head-back tilt angle and backward tilt distance ratio are measured by the Digimizer software.

Statistical analysis

Statistical analysis was performed using the SPSS version 17.0 software (SPSS Inc., Chicago, IL, USA). Data were expressed in mean ± standard deviation (SD) or number and frequency. The chi-square test and the independent sample t-test were performed. *P* values of <0.05 and <0.01 were considered statistically significant and statistically extremely significant, respectively.

RESULTS

Measurement data

Of a total of 34 patients, 12 had varus separation type 1, four had varus separation type 2, and 18 had Valgus impacted type (Table I). Of 12 cases with varus separation type 1, three (25%) were left-sided and nine (75%) were right-sided cases. Four cases had a low-energy injury (50%) and four cases had a high-energy injury (50%). The mean operation time was 88.75±8.10 (range, 75 to 100) min. The mean amount of intraoperative blood loss was 42.5±9.89 (range, 30 to 55) mL. One case (8.33%) had Garden type 3 fracture, while 11 cases (91.67%) had Garden type 4 fracture. The mean slope angle was 52.95°±10.36° (range, 67.86° to 34.06°). The mean perimeter ratio was 2.69±0.63 (range, 1.940 to 4.145). The mean maximum diameter ratio was 1.08±0.23 (range, 0.774 to 1.52). The mean lateral upward opening angle was 15.45°±5.59° (range, 12.49° to 35.99°). The mean head-back tilt angle was 33.89°±11.20° (range, 15.62° to 54.22°). The mean head-backward distance ratio was 0.822±0.114 (range, 0.598 to 0.997). The largest forward opening

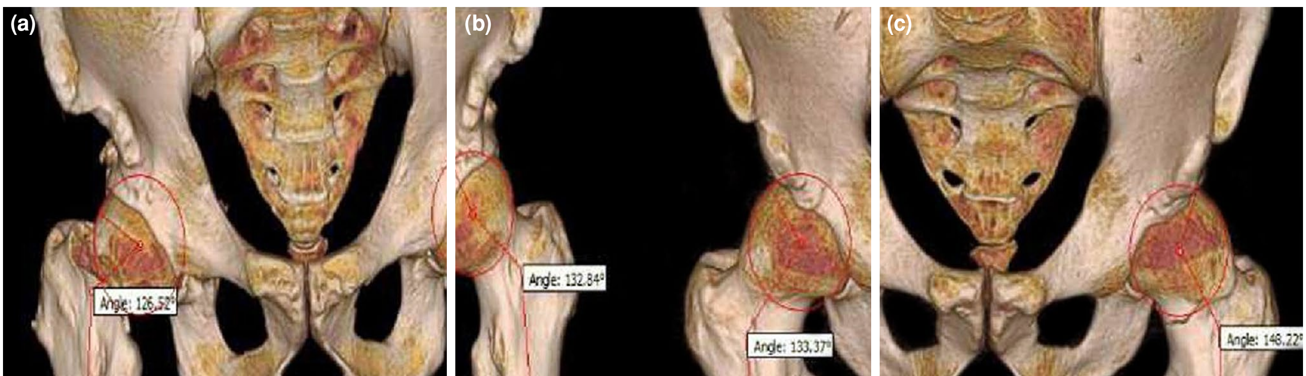


FIGURE 7. Head dip Angle/distance ratio horizontal computed tomography displaced femoral neck fracture. **(a)** femoral neck axis. **(b)** femoral head axis, the included Angle of the two axes is head-back tilt angle. **(c)** the ratio of the distance from C to axis A and the radius the femoral head to the center of the femoral head, as the ratio of the backward tilt distance of the femoral head.

TABLE I
Measurement results

	Total (n=34)			Varus separated type 1 (n=12)			Varus separated type 2 (n=4)			Valgus impacted type (n=18)		
Factor	n	%	Mean±SD	n	%	Mean±SD	n	%	Mean±SD	n	%	Mean±SD
Age (year)			51.97±11.80			47.67±11.63			58±3.92			53.5±12.48
Sex												
Males	21	61.76		11	91.67		4	100		7	38.89	
Females	12	38.24		1	8.34		0	0		11	61.11	
Side												
Left	13	38.24		3	25.00		3	75.00		7	38.89	
Right	21	61.76		9	75.00		1	25.00		11	61.11	
Injury mechanism (energy)												
Low	23	67.65		6	50.00		1	25.00		16	88.89	
High	11	32.35		6	50.00		3	75.00		2	11.11	
Time of operation (min)			90.29±9.12			88.75±8.10			97.50±6.45			89.72±10.21
Hemorrhage (mL)			40.74±12.50			42.5±9.89			62.5±9.29			34.72±8.48
Garden type												
3	19	55.89		1	8.33		1	25.00		17	94.44	
4	15	44.12		11	91.67		3	75.00		1	5.56	
Slope angle			56.14±10.69			52.95±10.36			65.72±3.36			-
Perimeter ratio			-			2.69±0.63			-			-
Max diameter ratio			-			1.08±0.23			-			-
Lateral upward opening angle						15.45°±5.59			0°			
Head-back tilt angle			25.82°±14.95°			39.04°±11.20°			18.44°±5.18°			18.65°±12.54°
Backward tilt distance ratio			0.542±0.173			0.822±0.114			0.460±0.181			0.362±0.195
Forward opening angle			-			23.82°±6.11°			-			-

SD: Standard deviation.

TABLE II
Comparative study of varus separation type and valgus impacted type

Factor	Total (n=34)			Varus separated type (n=16)			Valgus impacted (n=18)					
	n	%	Mean±SD	n	%	Mean±SD	n	%	Mean±SD	*p*	χ^2	t value
Age (year)			51.97±11.80			50.25±11.12			53.5±12.48	0.431		0.797
Sex										0.004	8.356	
Males	21	61.76		15	93.75		7	38.89				
Females	12	38.24		1	6.25		11	61.11				
Side										0.943	0.007	
Left	13	38.24		6	37.50		7	38.89				
Right	21	61.76		10	62.50		11	61.11				
Injury mechanism (energy)										0.005	7.886	
Low energy	23	67.65		7	43.75		16	88.89				
High energy	11	32.35		9	56.25		2	11.11				
Time of operation (min)			90.29±9.12			90.94±8.00			89.72±10.21	0.909		0.115
Hemorrhage (mL)			40.74±12.50			42.5±9.89			34.72±8.48	0.003		3.425
Garden type										0.000	23.071	
3	19	55.89		2	12.50		17	94.44				
4	15	44.12		14	87.50		1	5.56				
3D reconstruction data												
Slope angle			-			56.14°±3.37			-			
Data in the coronal section												
Lateral upward opening angle			-			15.45°±5.59°			-			
Data in the horizontal section												
Head-back tilt angle			25.82°±14.95°			33.89°±13.50°			18.65°±12.54°	0.020		3.412
Backward tilt distance ratio			0.542±0.173			0.732 ±0.204			0.362±0.195	0.000		5.32

SD: Standard deviation.

TABLE III
Compared with the sex, side, trauma mechanism and classification

Factor	Total (n=34)			Varus separated type (n=16)			Valgus impacted (n=18)				
	n	%	Mean±SD	n	%	Mean±SD	n	%	Mean±SD	*p*	χ^2
Age (year)			51.97±12.29			47.67±11.63			53.5±12.48	0.208	
Sex										0.004	8.356
Males	18	60.00		11	91.67		7	38.89			
Females	12	40.00		1	8.34		11	61.11			
Side										0.429	0.625
Left	10	33.33		3	25.00		7	38.89			
Right	20	66.67		9	75.00		11	61.11			
Injury mechanism (energy)										0.018	5.568
Low energy	24	80.00		6	50.00		16	88.89			
High energy	6	20.00		6	50.00		2	11.11			
Time of operation (min)			89.33±7.938			88.75±7.424			89.72±10.214	0.779	-0.283
Hemorrhage (mL)			37.83±9.71			42.5±9.89			34.72±8.48	0.029	2.303
Garden type										0.000	22.245
3	18	60.00		1	83.33		17	94.44			
4	12	40.00		11	91.97		1	5.56			
3D reconstruction data											
Slope angle			52.95°±10.36			52.95°±10.36°			-		
Data in the coronal section											
Lateral upward opening angle			15.45°±5.59			15.45°±5.59°			-		
Data in the horizontal section											
Head-back tilt angle			27.58°±16.45°			39.04°±11.20°			18.65°±12.54°	0.000	4.548
Backward tilt distance ratio			0.546±0.284			0.822±0.114			0.362±0.195	0.000	7.202

SD: Standard deviation.

angle was 23.82°±6.11° (range, 10.05° to 48.18°). Of the patients with varus separation type 2, one (25%) had a low-energy injury and three (75%) had a high-energy injury. The mean operation time was 97.50±6.45 (range, 90 to 105) min. The mean amount of intraoperative blood loss was 62.5±9.29 (range, 50 to 70) mL. One case (25%) had Garden type 3 fracture and three cases (75%) had Garden type 4 fracture. The mean slope angle was 65.72°±3.36° (range, 61.51° to 69.53°). The mean head-back tilt angle was 18.44°±5.18° (range, 12.74° to 22.10°). The mean head-backward distance ratio was 0.460±0.181 (range, 0.342 to 0.726). Of the patients with valgus impacted type, seven (38.89%) had left-sided and 11 (61.11%) had right-sided cases: Sixteen cases (88.89%) had a low-energy injury, while two cases (11.11%) had a high-energy injury. The mean operation time was 89.72±10.21 (range, 75 to 105) min. The mean amount of intraoperative blood loss was 34.72±8.48 (range, 20 to 50) mL. Seventeen cases (94.44%) had Garden type 3 fracture, while one case (5.56%) had Garden type 4 fracture. The mean head-back tilt angle was 18.65°±12.54° (range, 0° to 41.39°). The mean head-backward distance ratio was 0.362±0.195 (range, 0 to 0.989).

Statistical analysis results

For varus separation type, the proportion of male patients (93.75%), high-energy injuries (56.25%), and Garden type 4 fractures (87.50%) was higher than that of valgus impacted type (38.89%, 11.11%, and 5.56%, respectively). The difference was significantly significant ($p<0.01$). Head-back tilt angle of varus separation type patients in the horizontal section was greater than that of the valgus impacted type with a statistically significant difference ($p<0.05$). The amount of intraoperative blood loss and backward tilt distance ratio of horizontal section of varus separation type were greater than that of valgus impacted type with a significant difference ($p<0.01$). However, there was no statistically significant difference in sides or operation time between the two groups (Table II).

For varus separation type 1, the proportion of male patients (91.67%), high-energy injuries (50%), and Garden type 4 fractures (91.97%) was higher than that of valgus impacted type (38.89%, 11.11%, and 5.56%, respectively). The difference was statistically significant. The head-back tilt angle and backward tilt distance ratio of varus separation type 1 patients were greater than those of valgus impacted type with a significant difference ($p<0.01$). The amount of intraoperative blood loss in varus separation type 1 patients was greater than valgus impacted type. The difference was statistically significant ($p<0.05$). However, there was no statistically significant difference in sides or operation time between the two groups (Table III).

DISCUSSION

In the study of preoperative CT scans in patients with femoral neck fractures treated with hallow screw, we obtained the following findings: *(i)* In the 3D reconstruction, the femoral neck of varus separation type 1 had the forward, lateral upward opening, the femoral head was backward or accompanied with rotation, and the impacted angle deformity of the internal bone cortex. The average slope angle of the vertical axis of the proximal femur and the fracture section was 52.95°. The broken ends of the type 2 fracture were almost parallel or accompanied by a sheet-shaped split of the inner inferior edge of the femoral neck, with a beak-like change. The femoral head was backward to tilt or with rotation, or accompanied by the internal and lower displacement, the inner and lower cortex separation and displacement. The average slope angle was 65.72°, and the broken ends were unstable. For valgus impacted type, the broken end was incarcerated, and the inner lower cortex was discontinuous; however, there was no obvious angulated opening deformity. *(ii)* In the coronal position, patients with varus separation type 1 have the lateral upward opening deformity, and the average maximum lateral upward opening angle was 15.45°, and the internal lower part was impacted into the angle, with some support, but unstable. The broken ends of the type 2 fracture were almost parallel. The inner inferior cortex was discontinuous or accompanied with an inward inferior displacement of the femoral head with unstable support. For valgus impacted type, the broken end was incarcerated, shortening and abduction. The inner and lower bone cortex was not continuous, but the alignment was basically satisfactory. *(iii)* At the horizontal level, varus separation type 1 had the forward opening deformity, the average forward opening angle was 23.82°, and the head backward tilt displacement was obvious. The broken ends of the type 2 fracture were almost parallel and the head was backward. The patients of valgus impacted type showed the characteristics of head backward and fracture insertion in the horizontal position. Taken together, in the 3D, coronal and horizontal levels, the varus separation type showed more obvious displacement and opening deformity compared to the valgus impacted type. Meanwhile, at the horizontal level, both the head-back tilt angle and the backward tilt distance ratio of varus separation type were significantly greater than that of valgus impacted type, indicating that the varus separation type is mostly caused by multiplane complex violent injury.

In our study, varus separation type was often common in men and due to high-energy injury, while valgus impacted type was common in women and due to low-energy injury, which may be due to less exercise and a higher incidence of osteoporosis in women, particularly in postmenopausal women. Therefore, women tend to have femoral neck fractures in low-energy injuries, while male femoral neck fractures mostly occur in high-energy injuries, accompanied by rotational violence, such as car accident injuries, and high falling injuries. In Garden type, the proportion of Garden type 4 in the varus separation type was significantly higher than in the valgus impacted type. Varus separation type (average slope angle 56.14°) is mostly seen in Pauwels abduction type and Garden type 4. This also reflects from the side that the risk of severe fracture of varus separation type is significantly higher than of valgus impacted type. In addition, the present study showed that the intraoperative bleeding volume of the varus separation type was significantly greater than the valgus impacted type. The femoral neck fracture was an intracapsular fracture. Varus separation fracture is more severe than valgus impacted type, with separation and rotation deformity of femoral head, and more bleeding. The broken ends were impacted in valgus impacted type with limited bleeding volume.

The current study showed that the patients with femoral neck fractures had widespread head-back tilt at horizonal level of CT, which may be associated with the anatomical characteristics of the presence of femoral neck anteversion. Due to the presence of anteversion, when the external force acts on the femoral neck, the femoral head receives the reaction force of the front wall of the acetabulum, resulting in the posterior displacement of the femoral neck during the fracture. When the patient's femoral neck is subjected to low-energy injury, mainly by single plane vertical stress (such as falling, bed falling injury in the elderly with severe osteoporosis or postmenopausal osteoporosis woman), the femoral head is tilted backward and the neck-shaft angle is turned outside, showing changes of valgus impacted type. When the femoral neck is subjected to high-energy injuries, mainly by compound rotation stress (such as car accident injury, high falling injury), the femoral head is tilted back and accompanied by rotation, and the neck-shaft angle is inverted with changes of varus separation type. In this study, men (91.67%), high-energy injuries (50%), and Garden type 4 fractures (91.97%) had a statistically significantly higher incidence than patients with valgus impacted type. The head-back tilt angle and backward tilt distance ratio at the horizontal section of varus separation type were larger than that of the valgus impacted type with a significant difference. This finding indicates that, in patients with varus separation type, men and high-energy injuries had a significantly higher incidence than those of valgus impacted type. In addition, the varus separation fracture has large displacement and serious injury, which leads to more difficult preoperative closed reduction. The complex rotational displacement of the femoral head needs to be corrected, and it is difficult to accurately confirm its reduction quality in two-dimensional C-arm fluoroscopy and, therefore, open reduction needs to be performed in certain patients. Domestic scholars' researches on the risk factors of ischemic necrosis of the femoral head caused by femoral neck fracture patients have shown that, according to the results of logistic multivariate analysis, the risk factors are fracture type, reduction, and fixation quality.[10,11] Therefore, clinically, patients with varus separation type of femoral neck fracture may be more prone to ischemic necrosis of the femoral head. Of note, there was no significant difference in the operation time, suggesting that the differently classified fractures may affect the reduction time rather than the operation time after the completion of the reduction.

Furthermore, according to the study of the femoral head blood supply anatomy, the blood supply of the femoral head is mainly from the deep branch of the medial femoral circumflex artery. The deep branch of the medial femoral circumflex artery and the ascending branch of the lateral femoral circumflex artery form the basilar arterial circle outside the joint capsule at the base of the femoral neck. The femoral head receives blood supply from branches of the arteries circle including the anterior, posterior, medial and lateral ascending cervical arteries. Among them, the lateral ascending cervical artery supplies two-third or three-quarters blood of the femoral head, including that of the weight-bearing area, and the medial ascending cervical artery supplies one-third or one-quarter blood of the femoral head.[12] The displaced femoral neck fracture of type Pauwels III seriously damages the blood supply of the femoral head, resulting in a non-healing fracture and ischemic necrosis of the femoral head.[13,14] The varus separation type can be seen as displaced (Garden type 4) Pauwels III. The lateral separation and displacement severely disrupt the blood supply to the lateral ascending cervical artery. Due to the limited number of cases and the short time of follow-up, this study did not involve the statistically significant differences of the ischemic necrosis of the femoral head and the varus separation type 1 and type 2.

Considering that it is difficult to take standard AP radiograph of pelvis in fracture patients, the Pauwels angle is difficult to measure accurately. According to the anatomical characteristics of the femur itself, we designed the slope angle which could more accurately reflect the characteristics of the fracture, that is, the angle formed by the fracture section and the vertical axis of the femoral shaft. The most accurate measurement method of slope angle is to use MIMICS® software to cut the femoral head imaging and retain the broken ends. In this study, as a preliminary study, the relatively simple Digimizer software has some errors. Also, the valgus impacted type cannot be accurately measured due to the impacted part. However, there were few cases of varus separation type 2 cases in this study and, therefore, correlation studies were limited to varus separation type 1 patients.

In conclusion, through the study of the preoperative fracture classification of femoral neck fracture treated with hallow screw, we found that the fracture classification was simple, with a wide coverage and high accuracy of the prognosis assessment, which could improve the quality of preoperative reduction, guide the way of hollow screw fixation, and reasonably guide the functional exercise according to the prognosis assessment. This study also provides a basis for the next in-depth study of the fracture CT characteristics of femoral neck fractures (excluding Garden type 2) in large samples (including all surgical and conservatively treated patients).

Ethics Committee Approval: The study protocol was approved by the BeiJing ShiJingshan Hospital Ethics Committee (date: 12.12.2020, no: LSKYD2022-21). The study was conducted in accordance with the principles of the Declaration of Helsinki.

Patient Consent for Publication: A written informed consent was obtained from each patient.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

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