


## CLINICAL ARTICLE

# Association between Weitbrecht's Retinaculum Injury and Femoral Head Necrosis in Femoral Neck Fractures

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**Objective:** To investigate associations between femoral head necrosis (FHN) and injury to the retinaculum of Weitbrecht in patients with femoral neck fractures who had undergone initial trials of either closed reduction or direct open reduction.

**Methods:** This prospective observational study included 110 patients with displaced femoral neck fractures admitted to the Sixth People's Hospital Affiliated to Shanghai Jiaotong University and Shanghai Tongji Hospital between January 2008 and May 2017. Among these, 25 patients underwent initial closed reductions, and 85 patients underwent an open reduction directly. Watson-Jones anterolateral approach was used during the surgery for injury to the retinaculum of Weitbrecht, and FHN was assessed as a surgical outcome. The severity of injury to the retinaculum of Weitbrecht was evaluated using a scoring system developed by our surgical team. Follow-up was at least 24 months.

**Results:** The initial closed reduction treatment group had significantly higher total scores of injury to the retinaculum of Weitbrecht ( $6.24 \pm 2.20$  vs  $4.62 \pm 2.12$ ,  $p = 0.009$ ) compared to the open reduction group. High total scores were significantly associated with initial trials of closed reduction treatment, especially for the broken and released injury to the superior and anterior retinacula (both  $p = 0.01$ ). Twenty-six patients experienced FHN postoperatively, with mean onset time of  $19.42 \pm 3.87$  months. FHN was significantly associated with the severity of injury to the retinaculum of Weitbrecht ( $p < 0.001$ ) at the superior, anterior, and inferior retinacula. FHN was significantly associated with injury to the retinaculum of Weitbrecht in females.

**Conclusions:** Femoral neck displacement in patients treated initially with closed reduction is associated with subsequent injury to the retinaculum of Weitbrecht, which may lead to FHN. Severity of injury to the retinaculum of Weitbrecht may be used as a biomarker to evaluate bone necrosis in patients with femoral neck fractures.

**Key words:** Closed reduction; Femoral head necrosis; Osteonecrosis; Femoral neck fracture; Retinaculum of Weitbrecht

## Introduction

Younger adults (aged 18–60 years) with femoral neck fractures are mainly treated with closed reduction and internal fixation, except for the small number of patients for whom closed reduction failed and open reduction was required.<sup>1,2</sup> However, insufficient fracture reduction significantly

increases the risk of reoperation.<sup>3</sup> In younger adults with comminuted fractures, open reduction and internal fixation has been suggested for better recovery, showing that anatomical reduction improves the prognosis of fractures.

The retinacular arteries are the major blood supply to the femoral head, and injuries to these arteries may lead to

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femoral head necrosis (FHN) in patients with femoral neck fractures. Previous reports have shown that avascular FHN was associated with fracture displacement and quality of reduction.<sup>4,5</sup> Therefore, it is essential to evaluate the degree of injury to the femoral head blood supply after femoral neck fracture and maintain the blood supply as much as possible during surgery.

The three retinacula of Weitbrecht are the lateral, anterior, and medial retinacula, as depicted in the original drawings published by Anseroff in 1929.<sup>6</sup> Many studies have addressed the blood supply to the femoral head and the anatomy of the retinacula of Weitbrecht. However, no detailed reports have been published about the feature of attachment of the retinacula of Weitbrecht to the surface of the femoral neck. The anatomical characteristics of two fixed ends with relatively loose middle pieces for the retinaculum of Weitbrecht may reduce injury caused by fracture displacement. The fibers are dense but small blood vessels are relatively rare compared with the lateral and medial retinacula in the anterior retinaculum. The anterior retinaculum has compact fibrous structures composed of several layers of dense fibers. Directions of fibers in the adjacent layers vary, and various layers are connected with only a few fibers.<sup>7</sup>

In the femoral head, the connection between the fibrous layer of the superior and anterior retinacula is tight, while the inferior retinaculum is connected to the femur on both ends without connecting to the bone in the middle. The subordinate arteries of the superior and inferior circumflex femoral arteries branch out as they run through the inside of the capsule at the base of femoral neck.<sup>8,9</sup> These new arteries are divided into more branches in the femoral neck and femoral head, along with the spread of the retinaculum of Weitbrecht, and are known collectively as retinacular arteries.<sup>6,10-12</sup> The retinaculum of Weitbrecht is a bridge between the ring-shaped basilar arteries and the nutrient artery (nutrient foramina) of the femoral head. Retinacular arteries are the main blood source in the femoral head.<sup>6,7,13</sup> Lateral and medial circumflex femoral arteries branch from the joint capsule at the base of the femoral neck when passing through the retinaculum of Weitbrecht to the femoral neck and head. Both femoral neck fractures and injury to the retinaculum of Weitbrecht may injure the retinacular arteries because of the proximity.<sup>7,14</sup> Maruenda *et al.* further confirmed the idea that FHN depends on vascular damage at the time of fracture.<sup>15</sup>

Femoral neck fracture results in distortion and/or compression of the retinaculum of Weitbrecht and disrupts the blood supply, which finally leads to avascular FHN.<sup>16</sup> Not all patients with femoral neck fracture were well-recovered after the initial trial of closed reduction, and repeated closed reductions have been reported to aggravate blood vessel injuries in the retinaculum of Weitbrecht.<sup>16</sup> The main purposes of this study were to investigate the association between injury to the retinaculum of Weitbrecht, initial trials of

closed reduction, and FHN in patients with femoral neck fractures.

## Patients and Methods

### Patients

Patients with displaced femoral neck fractures who underwent open reduction and internal fixation at the Sixth People's Hospital Affiliated to Shanghai Jiaotong University and Shanghai Tongji Hospital between January 2008 and May 2017 were prospectively enrolled. Inclusion criteria were: (1) age over 18 years; (2) active outdoors before injury; (3) displaced femoral neck fracture (Garden grade III or IV); (4) internal fixation performed by the same team; (5) open reduction and internal fixation; (6) follow-up longer than 24 months or FHN found during follow-up. Exclusion criteria were: (1) presence of systemic chronic diseases, long use of steroids, alcoholism, or any mental or neuromuscular disorder; (2) no displaced FHN, or FHN treated with closed reduction and internal fixation or arthroplasty; (3) pathological fracture.

### Ethical Considerations

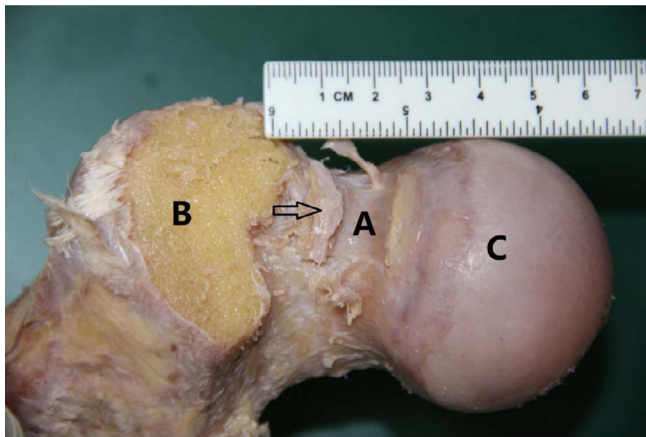
The study protocol was approved by the Ethics Committee of Shanghai Tongji Hospital (K-2014-023), and the Ethics Committee of Shanghai Sixth People's Hospital (2019-KY-037).

### Surgical Procedure

The Watson-Jones anterolateral approach was used to help with the observation and protection of the superior, inferior, and anterior retinacula of Weitbrecht during surgery.

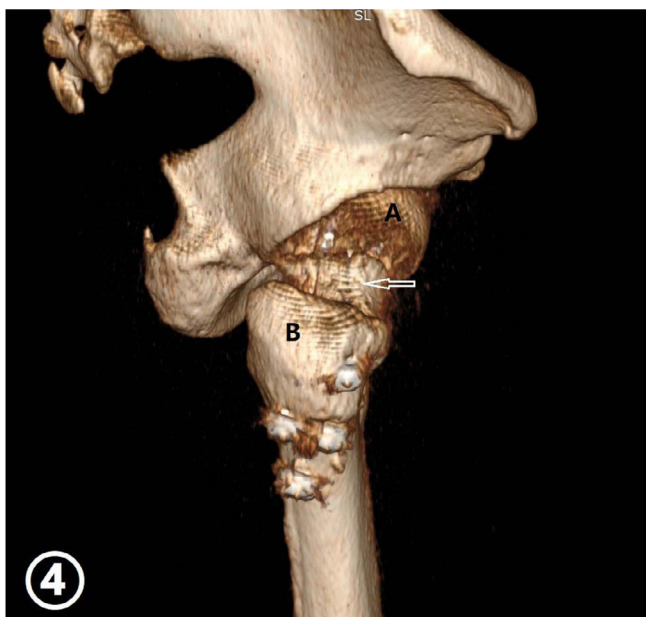
The surgical methods used in this study are listed as follows:

1. Damage of the superior and inferior retinaculum of Weitbrecht was monitored by internal or external rotation of the hip joint.
2. Watson-Jones incisions were created in front of the joint capsule in cases with exposure and cutting of the joint capsule.
3. Joint capsule was cut along the longitudinal axis and transversely at the proximal end of the femoral neck, and a T-shape cut was made to reveal the fracture end.
4. Two 2.5-mm Kirschner wires were inserted into the edge of the femoral head cartilage to control the rotation of the femoral head as a control stick.
5. All fracture ends had bone defects to some extent and had bone grafts in the bone defect area. Autogenous iliac bone grafting was used for those with larger bone defects, and allogeneic cancellous bone grafting was used for those with smaller defects. Injury to the retinaculum of Weitbrecht with avulsion of bone flakes of the femoral head was sutured with silk thread and repaired under direct vision to maintain its consistency and to avoid free bone flakes inside the joint capsule (Figures 1-3).



**FIGURE 1** Top view of the back of the femoral neck. (A) The superior retinaculum. (B) The greater trochanteris removed horizontally from the femoral neck. (C) Femoral head. The arrow points to the junction of the joint capsule and the superior retinaculum

6. Internal fixation options: dynamic hip screws were used in 26 cases; three cannulated screws were used in 60 cases; four cannulated screws were used in 22 cases; proximal femoral locking plates were used in two cases.



**FIGURE 2** Three-dimensional CT image of femoral neck after open reduction and internal fixation. It can be seen that the sutured bone fragments fit well, and the suture line is indicated by the arrow. (A) Femoral head. (B) Greater trochanter

### **Identification of Femoral Head Necrosis (FHN)**

Clinical symptoms and computed tomography (CT) images were used to judge FHN. After internal fixation, if the patient felt increasing pain at the hip joint in the operated side after previously being painless, femoral head necrosis was highly suspected and CT scanning was required. Traumatic FHN was identified when spot-like bone density changes within the femoral head were shown in CT images. If no changes were observed in bone density, CT imaging was performed again after 1 month. FHN was confirmed when pain in the hip joint was increased or no relief and uneven bone density within the femoral head was observed in CT images. There cording of data started from the appearance of clinical symptoms.

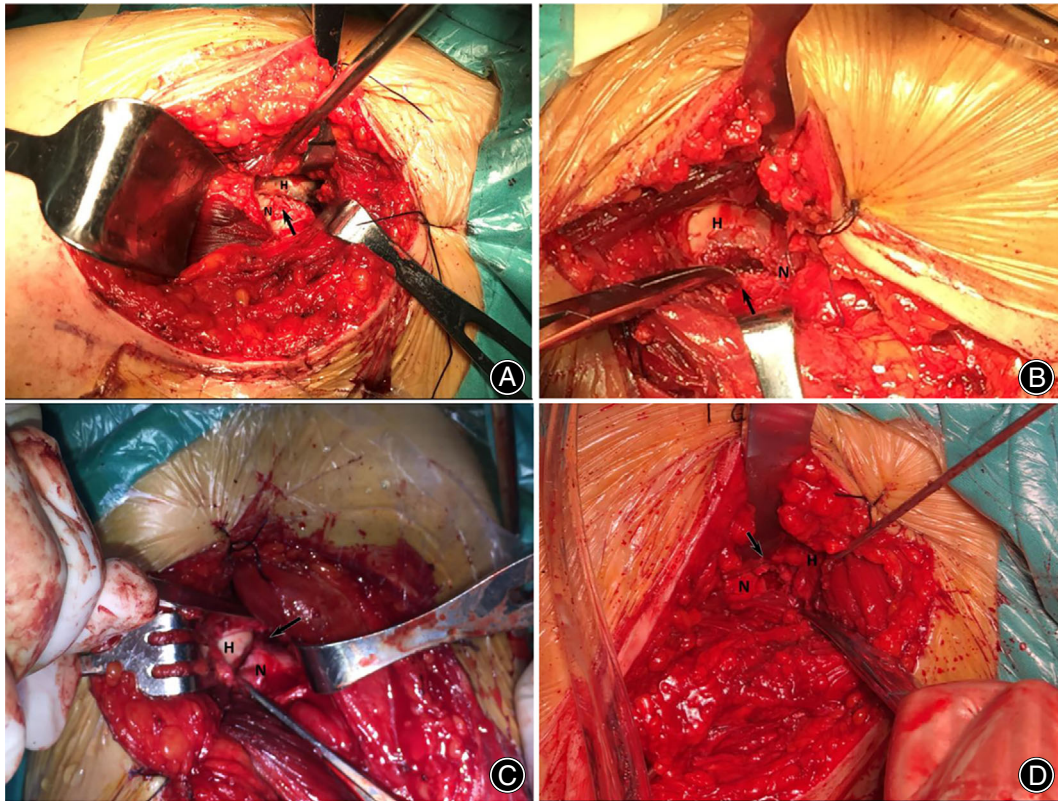
### **Scoring the Severity of Injury to the Retinaculum of Weitbrecht**

Our surgical team has developed a scoring system to examine the severity of injury to the retinaculum of Weitbrecht based on immediate and direct vision during surgery.<sup>7</sup> The degree of injury is scored by four levels: 0, the retinaculum is not damaged; 1, the retinaculum is bleeding; 2, the retinaculum is broken and attached to the bone; 3, the retinaculum is broken and released. In the present study, the highest score was 9 when all retinacula were broken. The scoring of retinacular injury was performed alternately by three or four well-trained physicians who were involved in performing the surgeries.

### **Statistical Analysis**

Continuous variables are expressed as mean  $\pm$  standard deviation (mean  $\pm$  SD) and tested by Mann-Whitney U test. Categorical variables are expressed as counts (percentage), and chi-squared tests or Fisher's exact tests were conducted to determine differences between variables. Logistic regression analyses were performed to estimate associations between closed reduction with Weitbrecht's retinaculum injury scores and the association between FHN with closed reduction and Weitbrecht's retinaculum injury scores. Univariate regression analysis was performed with and without adjusting for age, sex, side of fracture, and fixation material.

A multivariate model was applied to analyze the total score of Weitbrecht's retinaculum injury and the severity of three sections (lateral, anterior, and medial) of the retinaculum of Weitbrecht after adjusting for age, gender, side of fracture, and fixation material. Results are presented as odds ratios (ORs) with corresponding 95% confidence intervals (95% CI) and *p*-values. All *P* values were two-sided and a *p*-value of  $<0.05$  was considered statistically significant. All statistical analyses were performed using IBM SPSS statistical software version 22 for Windows (IBM Corp., Armonk, New York, USA).



**FIGURE 3** Representative images showing the completely tom (A) anterior, (B) superior, and (C) inferior retinaculum of Weitbrecht, and the partially tom (D) inferior retinaculum of Weitbrecht during surgery. The torn retinaculum of Weitbrecht is indicated by the black arrow. H, femoral head; N, femoral neck

## Results

### Characteristics of Patients

A total of 110 patients with displaced femoral neck fractures were included. The mean age was  $43.2 \pm 12.8$  years and the majority were male (64.5%). Demographic characteristics, fracture characteristics, and the severity of injury to the retinaculum of Weitbrecht are summarized in Table 1. Among them, 25 (22.7%) patients were switched to open reduction after failed initial trials of closed reduction based on general principles of treatment for femoral head fracture, and 85 (77.3%) underwent open reduction directly. Patients who underwent initial closed reduction were significantly older ( $48.5 \pm 13$  vs  $41.6 \pm 12.4$ ,  $p = 0.018$ ) and with a higher percentage of females (12/71 vs 13/39,  $p = 0.049$ ) compared to those without. Fracture types of femoral neck among all patients were identified as OTA/AO 31-B1.3, B2.2 or B2.3. A total of 26 patients had FHN during follow-up, with a mean time to FHN of  $19.42 \pm 3.87$  months.

The total scores of injury to the retinaculum of Weitbrecht were significantly higher in patients with initial closed reduction treatment than in those without ( $6.24 \pm 2.20$  vs  $4.62 \pm 2.12$ ,  $p = 0.009$ ), as well as in patients with FHN ( $7.3 \pm 1.4$  vs  $4.3 \pm 1.9$ ,  $p < 0.001$ ) than in those without. Injury severity in the retinaculum of Weitbrecht, i.e., superior, anterior, and inferior retinacula, were also

significantly higher in patients who underwent initial closed reduction than in those without (superior:  $2.28 \pm 0.84$  vs  $1.81 \pm 0.71$ ,  $p = 0.01$ ; anterior:  $2.16 \pm 0.94$  vs  $1.61 \pm 0.90$ ,  $p = 0.008$ ; inferior:  $1.80 \pm 0.87$  vs  $1.20 \pm 0.91$ ,  $p = 0.001$ ). Similarly, the injury severity of the retinaculum of Weitbrecht was significantly higher in patients with FHN than in those without FHN (superior:  $2.46 \pm 0.65$  vs  $1.75 \pm 0.73$ ,  $p < 0.001$ ; anterior:  $2.65 \pm 0.56$  vs  $1.45 \pm 0.84$ ,  $p < 0.001$ ; inferior:  $2.23 \pm 0.65$  vs  $1.06 \pm 0.83$ ,  $p < 0.001$ ).

### Association between Injury to the Retinaculum of Weitbrecht and Initial Trials of Closed Reduction

To clarify the association between injury to the retinaculum of Weitbrecht and initial closed reduction treatments, analysis was conducted using Model I (univariate analysis for each variable), II (univariate analysis for each variable after adjusting for age and sex), and III (univariate analysis for each variable after adjusting for age, sex, side of fracture, and fixation material) (Table 2). The results showed that initial closed reduction was significantly associated with the total scores of injury to the retinaculum of Weitbrecht ( $p = 0.002$  in Model I,  $p = 0.001$  in Model II and III), especially with broken and released injuries in the superior and anterior retinaculum of Weitbrecht in all three models (all  $p < 0.01$ ).

TABLE 1 Characteristics of patients

Variables	Total	Initial closed reduction			Femoral head necrosis		
		No	Yes	p-value	No	Yes	p-value
No of patients	110	85	25		84	26	
Age	43.2 ± 12.8	41.6 ± 12.4	48.5 ± 13.0	<b>0.018</b>	43.5 ± 12.9	42.1 ± 12.7	0.618
Sex				<b>0.049</b>			0.714
Male	71 (64.5)	59 (69.4)	12 (48)		55 (65.5)	16 (61.5)	
Female	39 (35.5)	26 (30.6)	13 (52)		29 (34.5)	10 (38.5)	
Smoke, yes (%)	17 (15.5)	11 (12.9)	6 (24)	0.179	15 (17.9)	2 (7.7)	0.351
Diabetes mellitus, yes (%)	8 (7.3)	4 (4.7)	4 (16)	0.077	6 (7.1)	2 (7.7)	1.000
Hypertension, yes (%)	9 (8.2)	5 (5.9)	4 (16)	0.205	5 (6)	4 (15.4)	0.211
Side of fracture				0.617			0.876
Left	62 (56.4)	49 (57.6)	13 (52)		47 (56.0)	15 (57.7)	
Right	48 (43.6)	36 (42.4)	12 (48)		37 (44.0)	11 (42.3)	
Pauwels type, III (%)	110 (100)	85 (100)	25 (100)	n/a	84 (100)	26 (100)	n/a
Fixation material				0.574			0.816
Cannulated bone screw (3-pieces)	60 (54.5)	48 (56.5)	12 (48)		47 (56)	13 (50)	
Cannulated bone screw (4-pieces)	22 (20)	17 (20)	5 (20)		17 (20.2)	5 (19.2)	
DHS	26 (23.6)	18 (21.2)	8 (32)		18 (21.4)	8 (30.8)	
PFP	2 (1.8)	2 (2.4)	0 (0)		2 (2.4)	0 (0)	
Weitbrecht's retinaculum injury, total scores	4.99 ± 2.23	4.62 ± 2.12	6.24 ± 2.20	<b>0.009</b>	4.3 ± 1.9	7.3 ± 1.4	<b>&lt;0.001</b>
Superior Weitbrecht's retinaculum	1.92 ± 0.77	1.81 ± 0.71	2.28 ± 0.84	<b>0.010</b>	1.75 ± 0.73	2.46 ± 0.65	<b>&lt;0.001</b>
1, Bleeding	37	31 (36.5)	6 (24)		35 (41.7)	2 (7.7)	
2, Broken and attached to the bone	45	39 (45.9)	6 (24)		35 (41.7)	10 (38.5)	
3, Broken and released	28	15 (17.6)	13 (52)		14 (16.7)	14 (53.8)	
Anterior Weitbrecht's retinaculum	1.74 ± 0.93	1.61 ± 0.90	2.16 ± 0.94	<b>0.008</b>	1.45 ± 0.84	2.65 ± 0.56	<b>&lt;0.001</b>
0, No injury	7 (6.4)	6 (7.1)	1 (4.0)		7 (8.3)	0 (0)	
1, Bleeding	45 (40.9)	39 (45.9)	6 (24.0)		44 (52.4)	1 (3.8)	
2, Broken and attached to the bone	28 (25.5)	22 (25.9)	6 (24.0)		21 (25.0)	7 (26.9)	
3, Broken and released	30 (27.3)	18 (21.2)	12 (48.0)		12 (14.3)	18 (69.2)	
Inferior Weitbrecht's retinaculum	1.34 ± 0.93	1.20 ± 0.91	1.80 ± 0.87	<b>0.001</b>	1.06 ± 0.83	2.23 ± 0.65	<b>&lt;0.001</b>
0, No injury	21 (19.1)	21 (24.7)	0 (0)		21 (25.0)	0 (0)	
1, Bleeding	45 (40.9)	33 (38.8)	12 (48.0)		42 (50.0)	3 (11.5)	
2, Broken and attached to the bone	30 (27.3)	24 (28.2)	6 (24.0)		16 (19.0)	14 (53.8)	
3, Broken and released	14 (12.7)	7 (8.2)	7 (28.0)		5 (6.0)	9 (34.6)	
Follow-up time, months	36.66 ± 14.53 (11 to 77)	38.02 ± 14.51 (11 to 77)	32.04 ± 13.91 (15 to 61)	0.070	42 ± 12.28 (19 to 77)	19.42 ± 3.87 (11 to 30)	<b>&lt;0.001</b>
Having complication	3 (2.7)	1 (1.2)	2 (8.0)	0.129	3 (3.6)	0 (0)	n/a
Femoral head necrosis				0.099			
No	84 (76.4)	68 (80)	16 (64)				
Yes	26 (23.6)	17 (20)	9 (36)				

Data are presented as n (%) for categorical variables and as mean ± SD for continuous variables, and mean ± SD (range: min. to max.) for follow-up time.; Data were compared using Pearson chi-squared test/or Fisher's exact test for categorical variables; Mann-Whitney U test for other continuous data.; n/a, not assessed.; **Bold** value indicated significance ( $p < 0.05$ ).

### Association between FHN and Injury to the Retinaculum of Weitbrecht

Associations between FHN and the severity of injury to the retinaculum of Weitbrecht are shown in Table 3. FHN was significantly associated with total scores in all three models mentioned above (all  $p < 0.001$ ). According to the severity of injury, FHN was significantly associated with “broken and attached to the bone” and “broken and released” injuries in all retinacula of Weitbrecht in the three models.

The association between FHN and injury to the retinaculum of Weitbrecht was examined in patients with or without initial trials of closed reduction treatment (Table S1). For patients without initial closed reduction treatment

(i.e., patients who underwent open reduction directly), only “broken and attached to the bone” injury in the inferior retinaculum of Weitbrecht was significantly associated with FHN (OR: 10, 95% CI: 1.03–97.50,  $p = 0.048$ ). Among patients with initial closed reduction treatment, FHN was significantly associated with the total score of injury to the retinaculum of Weitbrecht (OR: 2.94, 95% CI: 1.83–4.70,  $p < 0.01$ ). Moreover, FHN was significantly associated with “broken and attached to the bone” injury in the anterior retinaculum (OR: 11.18, 95% CI: 1.21–103.10,  $p = 0.033$ ) and inferior retinaculum (OR: 22.86, 95% CI: 2.66–196.11,  $p = 0.004$ ) of Weitbrecht as well as with “broken and released” injury in all three retinacula of Weitbrecht (all  $p \leq 0.001$ ).

**TABLE 2 Relationship of Weitbrecht's retinaculum injury and initial trials of closed reduction**

Variables	Model I		Model II		Model III	
	OR (95% CI)	p-value	adj. OR (95% CI)	p-value	adj. OR (95% CI)	p-value
Weitbrecht's retinaculum injury, total scores	1.40 (1.13, 1.74)	<b>0.002</b>	1.55 (1.20, 2.00)	<b>0.001</b>	1.52 (1.18, 1.98)	<b>0.001</b>
Superior Weitbrecht's retinaculum						
1, Bleeding	Reference		Reference		Reference	
2, Broken and attached to the bone	0.80 (0.23, 2.71)	0.714	1.06 (0.29, 3.93)	0.927	1.06 (0.28, 4.01)	0.927
3, Broken and released	4.48 (1.42, 14.10)	<b>0.01</b>	9.24 (2.27, 37.62)	<b>0.002</b>	9.09 (2.10, 39.33)	<b>0.003</b>
Anterior Weitbrecht's retinaculum						
0, No injury	1.08 (0.11, 10.64)	0.945	1.37 (0.12, 15.01)	0.799	1.52 (0.13, 17.80)	0.739
1, Bleeding	Reference		Reference		Reference	
2, Broken and attached to the bone	1.77 (0.51, 6.16)	0.368	1.54 (0.40, 5.92)	0.532	1.68 (0.42, 6.64)	0.459
3, Broken and released	4.33 (1.40, 13.39)	<b>0.011</b>	7.17 (2.03, 25.35)	<b>0.002</b>	6.77 (1.87, 24.42)	<b>0.003</b>
Inferior Weitbrecht's retinaculum						
0, No injury	ND	n/a	ND	n/a	ND	n/a
1, Bleeding	Reference		Reference		Reference	
2, Broken and attached to the bone	0.69 (0.23, 2.09)	0.509	0.68 (0.21, 2.20)	0.517	0.62 (0.19, 2.05)	0.433
3, Broken and released	2.75 (0.80, 9.49)	0.109	3.15 (0.83, 11.89)	0.091	2.85 (0.74, 10.91)	0.126

Results are presented as odd ratio with corresponding 95% confidence intervals (95% CI) and p-value.; Model I: univariate analysis for each variable.; Model II: univariate analysis for each variable adjusting with age and sex.; Model III: univariate analysis for each variable adjusting with age, sex, side of fracture, and fixation material.; Abbreviations: adj., adjusted; OR, odds ratio; CI., confidence intervals; ND, not derived; n/a, not available.; Bold value indicated significance ( $p < 0.05$ ).

### Associations between FHN and Severity of Injury to the Retinaculum of Weitbrecht Stratified by Gender, Age, and Follow-up Time

We further examined the associations between FHN and severity of injury to the retinaculum of Weitbrecht stratified by gender, age, and follow-up time (Table 4). The total scores were highly associated with both female (OR: 3.070, 95% CI: 1.518–6.207) and male (OR: 2.013, 95% CI: 1.419–

2.856) genders and remained associated after adjusting for age (female, OR: 3.105, 95% CI: 1.496–6.444; male, OR: 2.067, 95% CI: 1.434–2.980). However, only female gender was highly associated with total scores after adjusting for age, side of fracture, and fixation material (OR: 6.424, 95% CI: 1.511–27.318). FHN was highly associated with severity of injury to the retinaculum of Weitbrecht in adult patients younger than 60 years (OR: 2.118, 95% CI: 1.553–2.889) and

**TABLE 3 The association of femoral head necrosis and Weitbrecht's retinaculum injury**

Variables	Model I		Model II		Model III	
	OR (95% CI)	p-value	adj. OR1 (95% CI)	p-value	adj. OR2 (95% CI)	p-value
Closed reduction, yes vs. no	2.25 (0.85, 5.96)	0.103	2.51 (0.89, 7.08)	0.081	2.34 (0.82, 6.69)	0.112
Weitbrecht's retinaculum injury, total scores	2.26 (1.65, 3.09)	<b>&lt;0.001</b>	2.30 (1.66, 3.19)	<b>&lt;0.001</b>	2.37 (1.68, 3.36)	<b>&lt;0.001</b>
Superior Weitbrecht's retinaculum						
1, Bleeding	Reference		Reference		Reference	
2, Broken and attached to the bone	0.20 (0.04, 0.98)	<b>0.047</b>	5.14 (1.04, 25.41)	<b>0.045</b>	4.88 (0.98, 24.33)	0.053
3, Broken and released	3.50 (1.26, 9.72)	<b>0.016</b>	18.64 (3.59, 96.77)	<b>&lt;0.001</b>	14.10 (3.18, 91.85)	<b>0.001</b>
Anterior Weitbrecht's retinaculum						
0, No injury	ND	n/a	ND	n/a	ND	n/a
1, Bleeding	Reference		Reference		Reference	
2, Broken and attached to the bone	14.67 (1.69, 127.03)	<b>0.015</b>	14.48 (1.67, 125.70)	<b>0.015</b>	15.39 (1.74, 135.97)	<b>0.014</b>
3, Broken and released	66 (7.98, 545.70)	<b>&lt;0.001</b>	69.08 (8.23, 579.56)	<b>&lt;0.001</b>	78.04 (8.92, 683.07)	<b>&lt;0.001</b>
Inferior Weitbrecht's retinaculum						
0, No injury	ND	n/a	ND	n/a	ND	n/a
1, Bleeding	Reference		Reference		Reference	
2, Broken and attached to the bone	12.25 (3.10, 48.38)	<b>&lt;0.001</b>	12.45 (3.13, 49.49)	<b>&lt;0.001</b>	12.59 (3.12, 50.74)	<b>&lt;0.001</b>
3, Broken and released	25.20 (5.08, 125.09)	<b>&lt;0.001</b>	25.30 (5.08, 125.92)	<b>&lt;0.001</b>	26.07 (5.11, 132.96)	<b>&lt;0.001</b>

Results are presented as odds ratio with corresponding 95% confidence intervals (95% CI) and p-value.; Model I: univariate analysis for each variable.; Model II: univariate analysis for each variable adjusting with age and sex.; Model III: univariate analysis for each variable adjusting with age, sex, side of fracture, and fixation material.; Abbreviations: adj., adjusted; OR, odds ratio; CI., confidence intervals; ND, not derived; n/a, not available.; Bold value indicated significance ( $p < 0.05$ ).

**TABLE 4** The association of femoral head necrosis and Weitbrecht's retinaculum injury stratified by gender, age, and follow-up

subgroup	Model 1 OR (95% CI)	Model 2 OR (95% CI)	Model 3 OR (95% CI)
<b>Gender</b>			
<b>Female</b>			
Closed reduction, yes vs no	1.481 (0.334–6.572)	1.749 (0.370–8.272)	2.307 (0.435–12.238)
Weitbrecht's retinaculum injury, total scores	<b>3.070 (1.518–6.207)</b>	<b>3.105 (1.496–6.444)</b>	<b>6.424 (1.511–27.318)</b>
<b>Male</b>			
Closed reduction, yes vs no	3.117 (0.831–11.685)	3.364 (0.851–13.293)	3.941 (0.931–16.674)
Weitbrecht's retinaculum injury, total scores	<b>2.013 (1.419–2.856)</b>	<b>2.067 (1.434–2.980)</b>	2.092 (0.474–9.234)
<b>Age</b>			
<b>≥60 years</b>			
Closed reduction, yes vs no	NA	NA	NA
Weitbrecht's retinaculum injury, total scores	NA	NA	NA
<b>&lt;60 years</b>			
Closed reduction, yes vs no	2.824 (0.964–8.268)	NA	2.801 (0.952–8.237)
Weitbrecht's retinaculum injury, total scores	<b>2.118 (1.553–2.889)</b>	NA	2.208 (1.586–3.074)
<b>Follow-up time</b>			
<b>&gt;2 years</b>			
Closed reduction, yes vs no	2.357 (0.200–27.833)	1.045 (0.943–1.157)	2.981 (0.191–46.448)
Weitbrecht's retinaculum injury, total scores	<b>2.234 (1.185–4.210)</b>	1.077 (0.950–1.222)	10.003 (0.645–155.052)
<b>≤2 years</b>			
Closed reduction, yes vs no	0.533 (0.063–4.531)	1.091 (0.974–1.223)	0.159 (0.004–5.825)
Weitbrecht's retinaculum injury, total scores	0.196 (0.030–1.291)	0.211 (0.027–1.841)	NA
Results are presented as odds ratio with corresponding 95% confidence intervals (95% CI) and p-value.; Model I: univariate analysis for each variable.; Model II: univariate analysis for each variable adjusting with age.; Model III: univariate analysis for each variable adjusting with age, side of fracture, and fixation material; In age subgroup, the adjustment excluded age.; Abbreviations: adj., adjusted; OR, odds ratio; CI., confidence intervals; ND, not derived; n/a, not available.; Bold value indicated significance ( $p < 0.05$ ).			

in follow-up longer than 2 years (OR: 2.234, 95% CI: 1.185–4.210).

## Discussion

In the present study, patients with femoral fractures who underwent closed reduction treatment experienced severe injury to the retinaculum of Weitbrecht, especially at the sites of the superior and anterior retinacula, which probably occurred because the rich blood supply at these sites was highly susceptible.<sup>17</sup> FHN was also significantly associated with the severity of injury to the retinaculum of Weitbrecht in the three anatomical substructures.

### Associations between Internal Fixation, the Retinaculum of Weitbrecht, and FHN

In the present study, we demonstrated that injury to the retinaculum of Weitbrecht was significantly associated with FHN, which appears to be attributed to the disruption of blood supply during surgery. Repeated closed reductions are likely to aggravate blood vessel injury in the retinacula of Weitbrecht, while direct open reduction may protect the retinacula during surgery, reducing the risk of further injury.<sup>16</sup> The present results are also consistent with our previous findings that an increase in intracapsular pressure after femoral neck fracture may lead to twisted blood vessels and smaller blood vessel lumen, which may in turn reduce the blood flow.<sup>18</sup> In addition, it increases the risk of damage to the superior retinaculum of Weitbrecht.<sup>18</sup>

Clinical evidence has suggested that the incidence of avascular necrosis of the femoral head is associated with fracture displacement and the quality of reduction.<sup>4</sup> Toh *et al.* indicated that the prognostic factors for avascular FHN after femoral neck fracture included age, fracture displacement, and fracture reduction.<sup>5</sup> Femoral neck fracture often leads to distortion or compression of the retinaculum of Weitbrecht, which implies that the main blood supply to the retinaculum of Weitbrecht will be diminished or even completely blocked, and may further lead to avascular FHN.<sup>16</sup> Because the retinaculum of Weitbrecht acts as a bridge for blood supply to the femoral head, the intraoperative procedures and protection of the retinaculum of Weitbrecht are particularly important in preventing FHN after femoral neck fracture. Our previous study showed that the blood supply to the femoral head is mainly through the superior retinaculum of Weitbrecht.<sup>19</sup> In the femoral neck fracture, the superior retinaculum of Weitbrecht with the medial femoral circumflex artery may be damaged, resulting in reduced blood supply to the femoral head. A reduction in blood supply increases the risk of avascular necrosis of the femoral head.<sup>20</sup>

### Considerations for Treating Femoral Neck Fracture

Trueta and Harrison indicated that the quality of reduction or fracture fixation may contribute to FHN.<sup>9</sup> Although internal fixation is the standard treatment for Garden III and IV fractures, controversy remains regarding the model of fixation and the approaches used.<sup>19</sup> Indeed, for younger adults

(aged <60 years) internal fixation is preferred in treating femoral neck fractures. However, these reports suggest that joint replacement rather than internal fixation would be a better choice for older adult patients (>60 years) with fracture displacement. Nevertheless, for younger adult patients, evaluation of the disruption of blood flow is required. In the present study, we demonstrated that injury to the retinaculum of Weitbrecht is highly associated with closed reduction and FHN. Thus, the occurrence of FHN should be assessed for younger patients with femoral neck fractures in the future.

To date, Smith-Peterson and Watson-Jones incisions have been used regularly in clinical surgery for patients with femoral neck fractures.<sup>21</sup> Overall, both are similar regarding the extent of hip cavity and procedures of fracture reduction. Nevertheless, in our own experience, the Watson-Jones approach is more advantageous because the incisions are created at the front of the joint capsule, which contributes to the ease of operation. In addition, the retinaculum of Weitbrecht (especially the superior part) has a lower risk of injury, because the degree of damage in fracture displacement can be monitored directly. Moreover, the Watson-Jones incision also facilitates bone grafting for lateral bone defects.

Similarly, the present study suggests that the risk of FHN is positively associated with injury to the retinaculum of Weitbrecht, including the superior, anterior, and inferior retinacula. However, the Smith-Petersen incision will better reveal the inferior retinaculum of the femoral neck than the superior retinaculum, although it is likely to damage the superior retinaculum during surgery. The Watson-Jones incision reveals the superior retinaculum of the femoral neck, which will protect the superior retinaculum under direct visual surveillance. Thus, we suggest that the Watson-Jones incision might be the better choice for protecting the retinaculum of Weitbrecht during surgery. Nevertheless, familiarity with the anatomy of the retinaculum of Weitbrecht is far more important than the choice of the incision method.

Another aspect of the present study is that different degrees of bone defects were noted in all patients with femoral neck fractures. To the best of our knowledge, such prevalence of bone defects has not been noted or reported in previous studies. Severe bone defects usually lead to avascular FHN, which is of clinical importance and should be handled with care. In the present study, we used bone grafting to deal with bone defects, which appears to be an advantageous strategy because none of the patients exhibited complications of nonunion. Further studies are warranted to confirm the association between the degree of bone defects and the efficacy of surgical interventions.

#### **Classification Systems for Femoral Neck Fracture**

Currently no classification system includes all types of femoral neck fracture. The Garden classification system is generally used to classify the femoral neck/head inferior fracture subtypes, reflecting the status of displacement; Pauwel's classification reflects the degree of shear force at the fracture site

according to the angle between the fracture line and horizontal plane, but it may overlook the status of displacement. All included patients in the present study had obvious displacement and internal fixation and were classified as Garden III or IV. However, some patients also had a larger Pauwels angle. Neither Garden nor Pauwels classifications include all fracture subtypes. Therefore, we used the AO/OTA classification on the premise that all patients had translocated fractures, which include subcapital and transcervical subtypes but without basicervical subtype. A031-B1.3 is a subcapital fracture with displacement, B2.2 is a transcervical subtype with multifragment fracture, and B2.3 is a transcervical subtype with shear fracture. We clarified the lesion status of the supporting zone in the displaced femoral neck fracture.

In the present study, further subgroup analysis was based on gender, age, and follow-up time. After adjusting for age, fracture side, and fixation materials, injury to the retinaculum of Weitbrecht was significantly associated with FHN in females but not in males. The question remains whether injuries to the retinaculum of Weitbrecht in females with femoral neck fractures are more susceptible to FHN.

#### **Limitations**

The present study has several limitations. First, the classification of the injury level of the retinaculum of Weitbrecht is arbitrary, although it is based on the judgment of three or more experienced surgeons. Second, although the current methods allow identifying injury to the retinaculum of Weitbrecht in patients with femoral neck fractures, the injury level was only observable in patients who underwent open reduction. Based on the bone structure, the retinaculum of Weitbrecht is not part of the femoral head, and damage to the blood supply may not be the same between the extravascular and the intravascular structures of the femoral head. Future studies will focus on developing methods, such as using MRI techniques, whereby retinacular injury can be determined with more accuracy, which would help guide management for younger adult patients with femoral neck fracture.

#### **Conclusions**

In patients with displaced femoral neck fractures, closed reduction treatment is associated with subsequent injury to the retinaculum of Weitbrecht, resulting in FHN. The severity of injury to the retinaculum of Weitbrecht may be used as a biomarker to evaluate the risk of bone necrosis in this patient population. Currently no objective indicator is available for surgical procedures for younger adult patients with femoral neck fractures, and further in-depth studies detecting injury to the retinaculum of Weitbrecht will help the determination.

#### **Author Contribution**

Jiong Mei: conception and design; acquisition of data; analysis and interpretation of data; acquisition of data; analysis and interpretation of data; drafting of the manuscript; critical revision of the manuscript; final approval of



the manuscript; guarantor of integrity of the entire study; definition of intellectual content; literature research; clinical studies; obtaining funding; administrative, technical or material support; supervision.

Shuqing Wang: conception and design; acquisition of data; analysis and interpretation of data; acquisition of data; analysis and interpretation of data; drafting of the manuscript; critical revision of the manuscript; final approval of the manuscript; guarantor of integrity of the entire study; definition of intellectual content; literature research; clinical studies.

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### Competing Interests

The authors declare that they have no competing interests.

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### Supporting Information

Additional Supporting Information may be found in the online version of this article on the publisher's web-site:

**Table S1** Univariate analysis of association between femoral head necrosis and Weitbrecht's retinaculum injury in patients with or without initial closed reduction treatment.

## References

- Bhandari M, Devereaux PJ, Tornetta P 3rd, et al. Operative management of displaced femoral neck fractures in elderly patients. An international survey. *J Bone Jt Surg Am Vol.* 2005;87:2122–30.
- Davidovitch RI, Jordan CJ, Egol KA, Vrahas MS. Challenges in the treatment of femoral neck fractures in the nonelderly adult. *J Trauma Acute Care Surg.* 2010;68:236–42.
- Nyholm AM, Palm H, Sandholdt H, Troelsen A, Gromov K. Danish fracture database C. Osteosynthesis with parallel implants in the treatment of femoral neck fractures: minimal effect of implant position on risk of reoperation. *J Bone Jt Surg, Am Vol.* 2018;100:1682–90.
- Wright JG. Evidence-Based Orthopaedics: The Best Answers to Clinical Questions. 1st ed. Philadelphia, PA: Saunders Elsevier; 2009. p. 396–400.
- Toh EM, Sahni V, Acharya A, Denton JS. Management of intracapsular femoral neck fractures in the elderly; is it time to rethink our strategy? *Injury.* 2004;35:125–9.
- Gojda J, Bartonicek J. The retinacula of Weitbrecht in the adult hip. *Surg Radiol Anat.* 2012;34:31–8.
- Mei J, Ni M, Wang G, et al. Association between injury to the retinacula of Weitbrecht and femoral neck fractures: anatomical and clinical observations. *Int J Clin Exp Med.* 2015;8:17674–83.
- Ly TV, Swiontkowski MF. Management of femoral neck fractures in young adults. *Indian J Orthop.* 2008;42:3–12.
- Trueta J, Harrison MH. The normal vascular anatomy of the femoral head in adult man. *J Bone Joint Surg, Br Vol.* 1953;35-B:442–61.
- Gulizar A, Tan W, Yang Y, Liu GY, Huang WH. Anatomic study and clinical significance of the retinacula of femoral neck. *Chin J Clin Anat.* 2012;30:625–8.
- Bartonicek J. Weitbrecht's retinacula of the hip joint. *Acta Chir Orthop Traumatol Cech.* 1990;57:385–91.
- Groves EW. Treatment of fractured neck of the femur with especial regard to the results. *J Bone Jt Surg, Am Vol.* 1930;12:1–11.
- Beaule PE, Campbell P, Lu Z, et al. Vascularity of the arthritic femoral head and hip resurfacing. *J Bone Jt Surg, Am Vol.* 2006;88(Suppl 4):85–96.
- Xiao J, Yang XJ, Xiao XS. DSA observation of hemodynamic response of femoral head with femoral neck fracture during traction: a pilot study. *J Orthop Trauma.* 2012;26:407–13.
- Maruenda JI, Barrios C, Gomar-Sancho F. Intracapsular hip pressure after femoral neck fracture. *Clin Orthop Relat Res.* 1997;340:172–80.
- Arnoldi CC, Lemperg RK. Fracture of the femoral neck. II. Relative importance of primary vascular damage and surgical procedure for the development of necrosis of the femoral head. *Clin Orthop Relat Res.* 1977;340:217–22.
- Dou B, Mei J, Wang Z, Ni M, Jia G, Liu S. Histological observation of the retinacula of Weitbrecht and its clinical significance: a cadaveric study. *Indian J Orthop.* 2018;52:202–8.
- Mei J, Yan F, Ni M, Wang H, Zhang F, Wang Z. Changes in intraarticular pressure on the blood supply in the retinaculum of the femoral neck. *Clin Biomech.* 2019;68:73–9.
- Upadhyay A, Jain P, Mishra P, Maini L, Gautum VK, Dhaon BK. Delayed internal fixation of fractures of the neck of the femur in young adults. A prospective, randomised study comparing closed and open reduction. *J Bone Jt Surg, Br Vol.* 2004;86:1035–40.
- Weinlein JC. Fractures and dislocation of the hip. In: Azar FM, Beaty JH, Canale ST, eds. *Campbell's Operative Orthopaedics Thirteenth Edition.* Philadelphia, PA: Elsevier; 2017:281.
- Smith-Petersen MN. A new supra-articular subperiosteal approach to the hip joint. *J Bone Jt Surg, Am Vol.* 1917;15:592–5.