RESEARCH ARTICLE

Combined Deflection Angle Classification: A Novel Typing System of Adult Femoral Neck Fracture

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Objective: Femoral neck fracture (FNF) is a common clinical trauma with high mortality and disability rates. Furthermore, its incidence increases exponentially with increasing age. Existing classifications have some disadvantages. Thus, this study aimed to establish a novel typing system for FNF.

Methods: We retrospectively analyzed all adult patients with FNF admitted to our hospital between December 2015 and November 2017 for cannulated screw internal fixation. The study population was divided into the femoral varus offset group (VAR) and the valgus offset group (VAL). The data collected included sex, age, affected side, injury mode, body mass index, complications, pelvic incidence (PI), hip deflection angle (HDA), combined deflection angle (CDA), and neck shaft angle. Statistical analysis was conducted to determine the correlation between complications and deviation angles. A novel typing system was developed and compared with the Garden classification to detect its superiority.

Results: A total of 108 patients were recruited, with 59 patients in the VAR and 49 patients in the VAL groups. The incidence of complications in the VAR group was significantly higher than that in the VAL group ($P < 0.05$). Moreover, there were more male participants in the VAR group. Compared with the VAL group, the VAR group had significantly higher PI, HDA, and CDA ($P < 0.05$). The CDA classification (CDAC) was defined, with CDA as the main criterion and HDA as the supplementary criterion. Furthermore, there was a hierarchical correlation between the actual incidence of complications and the typing level, which was increased in CDAC but not in the Garden classification. This showed that CDAC was more accurate.

Conclusion: A novel typing system, CDAC, for FNF was established, which was more accurate than the Garden classification. We suggest combining CDAC and Garden classifications for the preoperative diagnosis, treatment selection, and prognostic evaluation for patients with FNF.

Key words: Classification; Femoral neck fracture; Hip deflection angle; Pelvic incidence

Introduction

Femoral neck fracture (FNF) is a common clinical trauma with a high mortality and disability rate, and its incidence increases exponentially with age.[1–3] Currently, cannulated screw internal fixation is the treatment of choice in FNF.[4,5] Internal fixation is associated with reduced early mortality, shorter operation time, less trauma and less blood loss, and a low risk of deep infection.[6,7] However, even in the best-case scenarios where correct reduction and fixation have been achieved, post-operative complications may still occur.

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Received 21 April 2022; accepted 19 November 2022

Nonunion and avascular necrosis are the two most frequent complications in the clinical treatment of FNF.[8] Approximately 30% of patients with FNF treated with internal fixation require revision surgery due to serious complications. Revision surgery is known to prolong recovery time and reduce health-related quality of life.[9–11]

The Garden classification and Pauwell classification are the two commonly used clinical classification methods for FNF.[12,13] The Pauwell classification was the first biomechanical typing system for FNF. It was introduced in 1935, based on the angle between the fracture line of the distal fragment and the horizontal line.[14] Since the difficulty of precise angle measurement affects the reliability of the Pauwell classification, it has not been widely used in clinical practice.[15–17] The Garden classification is based on the degree of fracture dislocation. FNF is divided into four types: incomplete fracture (Type I), complete fracture without dislocation (Type II), partial dislocation (Type III), and complete dislocation (Type IV).[12] However, the use of the Garden classification has been controversial in recent years.[8,18] Some scholars believe that the Garden classification has limitations in terms of diagnosing FNF. Additionally, they point out that the degree of femoral head space displacement is an important factor that causes complications.[8,15,19] Therefore, a novel typing system for FNF must be established.

As shown in Fig. S1A,B, the femoral neck has a bidirectional axis. FNF can be anatomically divided into the varus offset type (Fig. S1C) and valgus offset type (Fig. S1D), which have been described in some reports. However, it has not been reported that this is related to the axial displacement of the hip joint (Fig. S1E). Moreover, there is a lack of relevant description and research regarding this matter.[4,13,20] When FNF occurs, the femoral head observed in the pelvic orthophoto and hip axial photo deviates in different directions.

This study aimed: (i) to investigate the correlations of several deviation angles that resulted in complications in patients with FNF; (ii) to establish the "combined deflection angle classification" (CDAC), a novel FNF typing system, based on the combined angle of displacement of the femoral head in the positive and axial position; and (iii) to compare the value of our CDAC with the previous Garden classification in predicting complications. We hypothesized that our typing system might be more accurate in predicting the complications. Additionally, we hypothesized that our typing system would address the gaps in the existing typing systems.

Methods

Study Design

We retrospectively analyzed all adult patients with FNF aged ≥18 years who had been admitted to our hospital between December 2015 and November 2017 for cannulated screw internal fixation. They were divided into the femoral varus offset (VAR) and valgus offset (VAL) groups. These patients were followed up for more than 2 years to monitor if there had been complications, such as osteonecrosis of the femoral head, fracture nonunion, heterotopic ossification, internal fixation failure, and non-complications. This study was approved by the ethics committee of the Luoyang Orthopedic-Traumatological Hospital (Orthopedics Hospital of Henan Province) (Approval No. 2014ZY02094). Informed consent was obtained from the patients.

Initial Selection Criteria

The inclusion criteria were as follows: (i) the patient was definitively diagnosed with FNF and treated with cannulated screw internal fixation; (ii) the patient had standard pelvis orthophoto and affected side hip axial photo or hip computed tomography (the hip axial photo was necessary, whereas the hip computed tomography was used as an auxiliary examination); and (iii) follow-up of the patient was done for more than 2 years, after which final imaging data were obtained.

The exclusion criteria were as follows: (i) the patient suffered from old and pathological fractures; (ii) the patients had complications with fractures in other parts of the body; and (iii) the patient suffered from poliomyelitis and other serious consumptive medical diseases.

Imaging Criteria

The pelvic orthophoto imaging criteria included the naturally stretched out legs that were as wide as the shoulders. The healthy side of the patella should be oriented forward, while the toes of both feet should face each other. Moreover, the healthy side toes of the patients were perpendicular to the pelvic plane and their imaging plane was parallel to the symmetrical plane of the bilateral ilium.

The hip axial photo imaging criteria involved the lying of the patients on their backs with their hips facing upwards. The detector was located on the side above the iliac crest at an angle of approximately 45° to the midsagittal plane of the body. The thigh on the healthy side was raised, while the knee was bent and fixed to keep the body stable. The toes were held perpendicular to the pelvic plane with the assistance of an assistant. The trochanter and tuberosity were overlapping and were located at the middle and back of the femoral neck. The upper edge of the image was extended beyond the iliac crest, whereas the lower edge was extended beyond the greater trochanter. The centerline passed through the middle of the medial femur, perpendicular to the detector, and horizontally into the detector center.

The hip CT imaging criteria involved the same position as that of the pelvic orthophoto.

In consideration of the pain due to the fracture, the patients rested for 15 min. Additionally, potent analgesics, such as tramadol, were injected 20 min before CT.

Radiological Parameters

The data collected and analyzed included the sex, age, affected side, injury mode, body mass index (BMI), complications, pelvic incidence (PI), hip deflection angle (HDA), combined deflection angle (CDA; CDA = PI + HDA), and neck-shaft angle (NSA). The measurement methods for PI, HDA, and CDA are shown in Figs 1 and 2. To reduce the deviation in the measurement results, the average value of any three measurements taken by one physician was taken as the final statistical data. Garden classification was determined by three senior physicians in our research team.

Statistical Methods

Statistical analysis was used to determine the correlation between complications and deviation angles (PI, HDA, and CDA), and a novel CDAC was obtained. The superiority of CDAC was examined by comparing its prediction accuracy to that of the Garden classification. In addition, we explored whether there was a rank correlation between the actual incidence of complications and an increase in the classification level.

Data analysis was performed using the Stata 12 software (StataCorp LP, College Station, TX, USA). The χ^2 test was used for the comparison of count data, while the single-factor analysis of variance was used for the measurement data. $P < 0.05$ indicated that the difference was statistically significant. The range of factors in each group was compared, and a 95% confidence interval (95% CI) was calculated. The key split point was found to provide a basis for the CDAC.

Results

Follow-up Results

Of the 108 recruited patients, 59 underwent VAR, while 49 underwent VAL. Complications occurred in 35 patients (32.41%). These included 27 cases (25.00%) of avascular necrosis, seven cases (6.48%) of fracture nonunion (two cases were combined with internal fixation failure), and one case (0.93%) of severe heterotopic ossification. There were no significant differences in age, affected side, injury mode, BMI, and NSA between the VAR and VAL groups ($P > 0.05$), but the differences in sex, complications, PI, HDA, and CDA were statistically significant ($P < 0.05$). As shown in Table 1, the incidence of complications in the VAR group was significantly higher than that in the VAL group ($P < 0.05$). Additionally, there were more male participants in the VAR group. Compared with the VAL group, the VAR group had

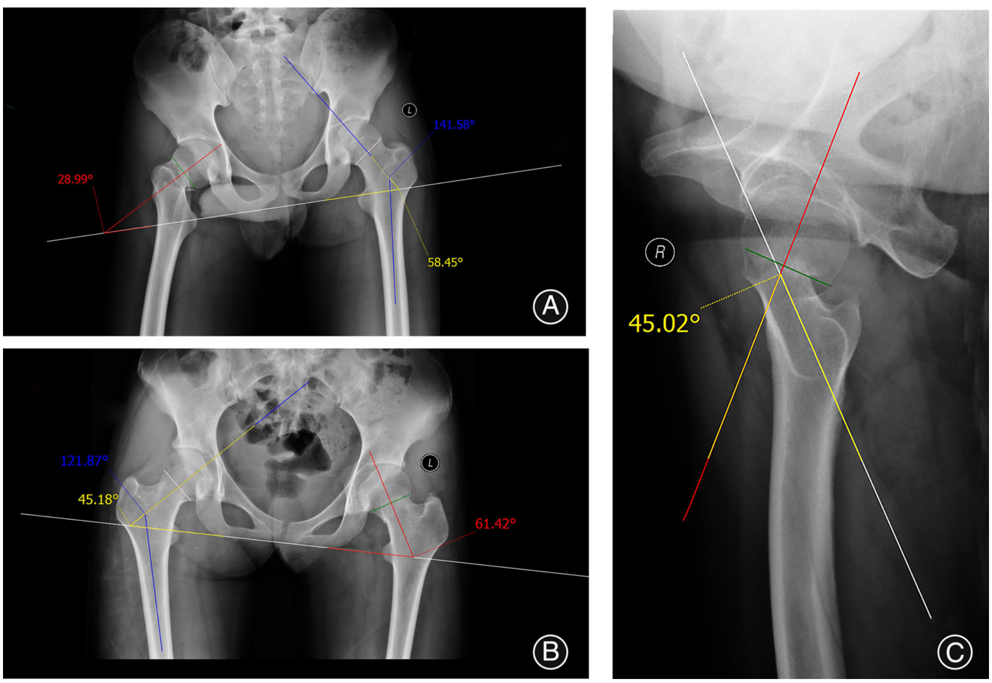

Fig. 1 The schematic diagram of the offset angles. (A) PI of VAR: (i) draw the connecting line of the lowest point of the ischium (white); (ii) draw the connecting line at the junction of the head and neck of the healthy femur head (pink); (iii) draw and measure the NSA, which is 141.58° (blue); (iv) draw the angle between the axis of the healthy femoral neck and the white line, which is 58.45° (yellow); (v) draw the connecting line at the junction of the head and neck of the affected femur head (green); and (vi) draw the angle between the vertical line of the green line and the white line, which is 28.99° (red); thus, PI = 29.46° (58.45°–28.99°). (B) PI of VAL: PI = 16.24° (61.42°–45.18°), and the measurement method is the same as that for the VAR. (C) HDA: (i) draw the axis of femoral head on the pelvis orthophoto (white); (ii) draw the connecting line at the junction of the head and neck of the femur head on the hip axial photo (green); (iii) draw a green vertical line (red); and (iv) the HDA (yellow), which is 45.02° (a backward tilt of the femoral head is defined as positive), is made up by the intersection of the red and the white lines. PI, pelvic incidence, VAR, varus offset, NSA, neck stem angle, and HDA, hip deflection angle.

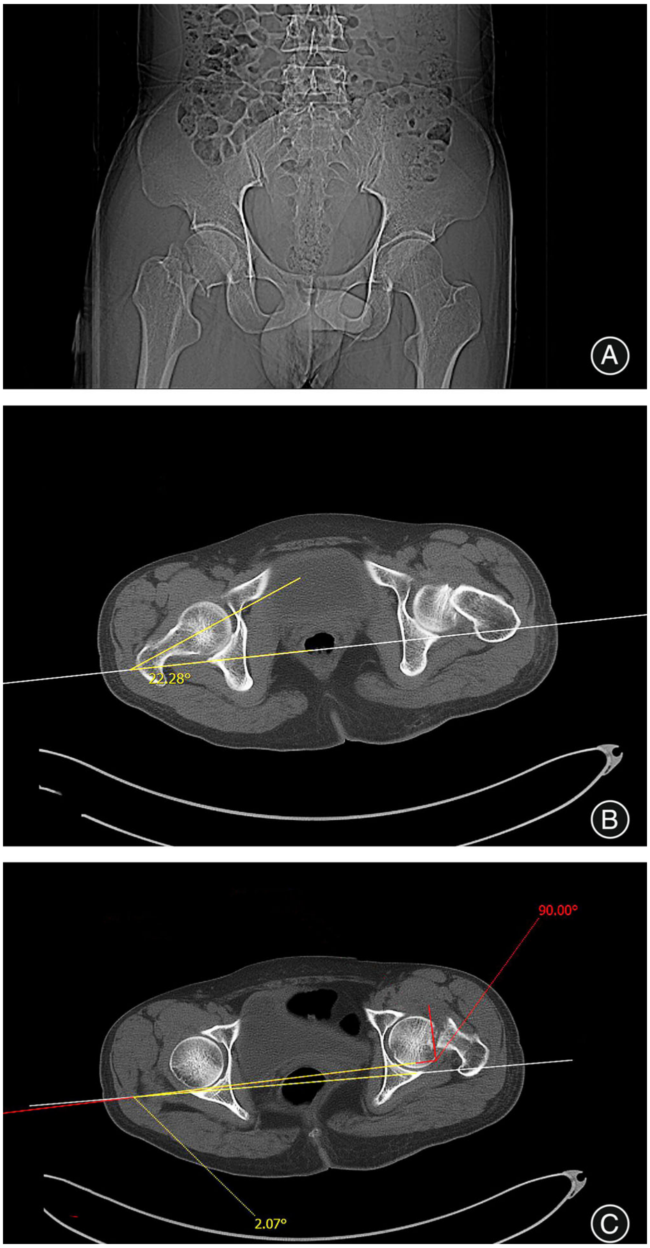

Fig. 2 The schematic diagram of the offset angles in the hip computed tomography. (A) PI can be measured with the general view window of hip computed tomography, and the measurement method is the same as that used for pelvis orthophoto. (B) HDA can also be measured using hip computed tomography. On the computed tomography plane, the plane with complete normal side was found. The connecting line (white) of the posterior edge of the acetabulum was drawn on both sides. The angle (yellow) between the femoral neck axis and the white line was 22.28°. (C) Find the plane with the complete affected side femur head. Draw the connecting line (white) of the posterior edge of the acetabulum on both sides. Draw the axis (red) of the femoral head of the affected side. Measure the angle (yellow) of white and red to be 2.07°. Thus HDA = 24.35° (22.28° + 2.07°). HDA, hip deflection angle; PI, pelvic incidence.

TABLE 1 The follow-up results

Groups	Total	Complications		Gender		Age	Affected side		Injury mode				BMI	Offset angles			
		No	Yes	Male	Female		Left	Right	A	B	C	D		PI	HDA	CDA	NSA
VAR	59	33	26	43	16	42.68 ± 12.61	36	23	11	12	34	2	22.82 ± 2.97	20.90 ± 12.07	36.61 ± 21.49	57.51 ± 25.28	138.51 ± 6.92
VAL	49	40	9	25	24	41.86 ± 12.74	25	24	8	6	33	2	23.07 ± 2.85	11.98 ± 7.40	23.27 ± 18.27	35.26 ± 20.32	137.12 ± 8.26
Total/ Average	108	73	35	68	40	42.31 ± 12.62	61	47	19	18	67	4	22.94 ± 2.90	16.85 ± 11.11	30.56 ± 21.08	47.41 ± 25.60	137.88 ± 7.56
Statistic		$\chi^2 = 8.0717$		$\chi^2 = 5.4858$		$F = 0.11$	$\chi^2 = 1.0883$		$\chi^2 = 1.5762$				$F = 0.19$	$F = 20.34$	$F = 11.79$	$F = 24.71$	$F = 0.90$
P value		0.004		0.019		0.7382	0.297		0.665				0.6606	0.000	0.000	0.000	0.3443

Notes: For injury mode, A: has a traffic collision with a car or an electric car. B: heavy objects are injured or fall from a high altitude. C: injury due to fall. D: falls on a bicycle or an electric vehicle.; Abbreviations: BMI, body mass index; CDA, combined deflection angle; HDA, hip deflection angle; NSA, neck-shaft angle; PI, pelvic incidence; VAL, valgus offset group; VAR, varus offset group.

TABLE 2 Analysis of VAR

Groups	Total	Gender		Age	Affected side		Injury mode				BMI	Offset angles			NSA
		Male	Female		Left	Right	A	B	C	D		PI	HDA	CDA	
NCG	33	26	7	42.51 ± 11.59	17	16	4	9	18	2	22.81 ± 2.58	19.70 ± 12.10	31.52 ± 17.41	51.22 ± 20.23	139.31 ± 7.33
CG	25	16	9	43.80 ± 13.50	18	7	7	3	15	0	22.87 ± 3.52	22.80 ± 12.20	45.44 ± 21.89	68.24 ± 25.90	137.27 ± 6.40
Total/ Average	58	42	16	43.07 ± 12.35	35	23	11	12	33	2	22.84 ± 2.99	21.04 ± 12.04	37.52 ± 20.50	58.56 ± 24.18	138.43 ± 6.96
Statistic		$\chi^2 = 1.5571$		$F = 0.15$	$\chi^2 = 2.4943$		$\chi^2 = 5.0842$				$F = 0.01$	$F = 0.93$	$F = 7.28$	$F = 7.90$	$F = 1.23$
P value		0.212		0.6985	0.114		0.166				0.9393	0.3390	0.009	0.007	0.2726

Notes: This table analyzes the data of 58 cases after excluding the one special case. For injury mode, A: has a traffic collision with a car or an electric car. B: heavy objects are injured or fall from a high altitude. C: injury due to fall. D: falls on a bicycle or an electric vehicle. CG, complications group; NCG, non-complications group; BMI, body mass index; PI, pelvic incidence; HDA, hip deflection angle; CDA, combined deflection angle; NSA, neck-shaft angle.

a larger PI, HDA, and CDA, and the differences were statistically significant ($P < 0.05$). In addition, both hip axial photo and hip computed tomography of the affected side were performed in 26 patients (Figs 1 and 2). The results show that there is no significant difference in the HDA measurement between hip axial photo and hip computed tomography (30.94 ± 17.06 *vs* 30.08 ± 17.04, $P > 0.05$).

Intra-group Analysis

Analysis of the VAR group revealed that there were 25 complications in 59 cases in the VAR group, and one special case was listed and analyzed separately (only this case showed anteversion dislocation of femoral head in HAD, not the other 58 cases). The remaining 58 patients were divided into the complication group and the non-complication group. As shown in Table 2, there were no significant differences between the complication and non-complication groups in terms of sex, age, affected side, injury mode, BMI, PI, and NSA ($P > 0.05$), but the HDA and CDA in the complication group were significantly larger than those in the non-complication group ($P < 0.05$). As shown in Table 3, the 95% CI of HDA and CDA were 36.41°–54.48° and 57.55°–78.94°, respectively, in the complication group and 25.35°–37.70° and 44.05°–58.40°, respectively, in the non-complication group.

Analysis of the VAL group revealed that the 49 cases were divided into two groups: nine cases in the complication group and 40 cases in the non-complication group (all the 49 cases showed no anteversion dislocation of femoral head in HAD). As shown in Table 4, there were no significant differences between the complication and non-complication groups in terms of sex, age, affected side, injury mode, BMI, PI, and NSA ($P > 0.05$), but the HDA and CDA in the complication group were significantly larger than those in the non-complication group ($P < 0.05$). As shown in Table 5, the 95% CI of HDA and CDA were 22.22°–62.73° and 34.17°–81.49°, respectively, in the complication group, and 14.86°–23.05° and 26.01°–34.34°, respectively, in the complication group.

Most importantly, according to the variance of HAD and CDA in the VAR group ($F = 7.28$ and $F = 7.90$, respectively) and in the VAL group ($F = 15.99$ and $F = 18.61$,

TABLE 3 The 95% CI of HDA and CDA in VAR

Groups	HDA		CDA	
	lower limit	upper limit	lower limit	upper limit
NCG	25.35	37.70	44.05	58.40
CG	36.41	54.48	57.55	78.94

Note: CDA, combined deflection angle; CG, complications group; HDA, hip deflection angle; NCG, non-complications group; VAR, varus offset group.

TABLE 4 Analysis of VAL

Groups	Total	Gender		Age	Affected side		Injury mode				BMI	Offset angles			NSA
		Male	Female		Left	Right	A	B	C	D		PI	HDA	CDA	
NCG	40	18	22	43.75 ± 11.56	19	21	8	5	26	1	23.15 ± 2.61	11.22 ± 7.26	18.96 ± 12.80	30.18 ± 13.02	136.83 ± 8.48
CG	9	7	2	33.44 ± 15.03	6	3	0	1	7	1	22.74 ± 3.91	15.36 ± 7.51	42.48 ± 26.35	57.83 ± 30.78	138.44 ± 7.51
Total/ Average	49	25	24	43.07 ± 12.35	25	24	8	6	33	2	23.07 ± 2.85	11.98 ± 7.40	23.27 ± 18.27	35.26 ± 20.32	137.12 ± 8.26
Statistic		$\chi^2 = 3.1587$		$F = 5.23$	$\chi^2 = 1.0800$		$\chi^2 = 3.3035$				$F = 0.14$	$F = 2.36$	$F = 15.99$	$F = 18.61$	$F = 0.28$
P value		0.076		0.0268	0.299		0.347				0.7068	0.1316	0.0002	0.0001	0.6016

Notes: this data includes a case without displacement: female, 44Y, left side fracture, BMI: 23.88, NSA: 134.12, the final result is no complications. It is not culling because the offset angle is 0. For injury mode, A: has a traffic collision with a car or an electric car. B: heavy objects are injured or fall from a high altitude.; Abbreviations: BMI, body mass index; C, injury due to fall; CDA, combined deflection angle; CG, complications group; D, falls on a bicycle or an electric vehicle; HDA, hip deflection angle; NCG, non-complications group; NSA, neck-shaft angle; PI, pelvic incidence; VAL, valgus offset group.

TABLE 5 The 95% CI of HDA and CDA in VAL

Groups	HDA		CDA	
	lower limit	upper limit	lower limit	upper limit
NCG	14.86	23.05	26.01	34.34
CG	22.22	62.73	34.17	81.49

Abbreviations: CDA, combined deflection angle; CG, complications group; HDA, hip deflection angle; NCG, non-complications group; VAL, valgus offset group.

respectively). FNF could be classified with CDA as the main criterion and HDA as the supplementary criterion.

There were also special cases. Besides VAR, there was one case showing anteversion dislocation of femoral head in HDA. Considering that this case was very rare, it was introduced as a special case (Fig. 3) and a special type (Fig. 4).

Illustration of the Combined Deflection Angle Classification

As shown in Fig. 5, based on the combined angle of displacement of the femoral head in the positive and axial position, CDAC was established, which included three main types: combined deflection angle adduction type (ADT), combined deflection angle abduction type (ABT), and combined deflection angle special type (SPT). For ADT, the femoral head was displaced by adduction in the positive position of the pelvis, and was displaced backwards in the axial position of the hip (Fig. 6A,B). For ABT, the femoral head was displaced by abduction in the positive position of the pelvis, and was displaced backwards in the axial position of the hip (Fig. 6C,D). For SPT, the femoral head was displaced by adduction in the positive position of the pelvis, and was displaced forward in the axial position of the hip (Fig. 6E,F).

ADT (Fig. 7): According to the 95% CI of CDA (57.55°–78.94° in the complication group, 44.05°–58.40° in the non-complication group) in VAR, the first main split point was determined as 60°. According to the 95% CI of HDA (36.41°–54.48° in the complication group, 25.35°–37.70° in the non-complication group) in VAR, 35° was defined by the supplementary criterion. Therefore, the second main split point was determined to be 35°. ADT was divided into three subtypes: subtype I (CDA ≤35°), subtype II (35° < CDA ≤60°), and subtype III (CDA > 60°).

ABT (Fig. 8): According to the 95% CI of CDA (34.17°–81.49° in the complication group and 26.01°–34.34° in the non-complication group) in VAL, the first main split point was determined to be 35°. According to the 95% CI of HDA (22.22°–62.73° in the complication group, 14.86°–23.05° in the non-complication group) in VAL, 20° was defined by the supplementary criterion. The second main split point was determined to be 20°. ABT was divided into

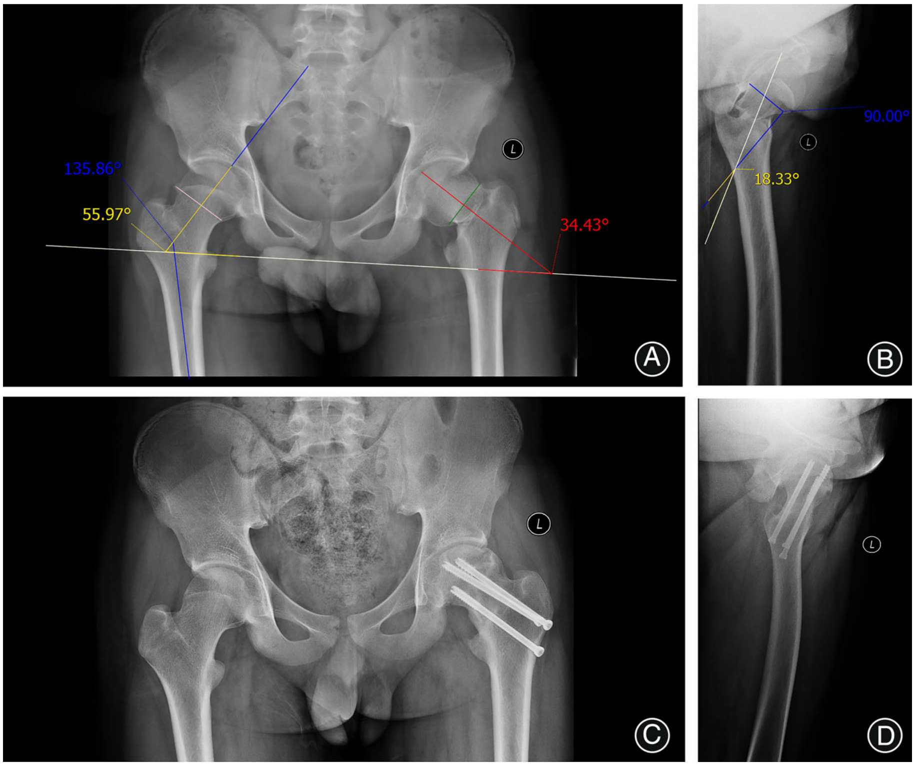

Fig. 3 A special case (A) preoperative pelvis orthophoto, (B) preoperative hip axial photo, (C) pelvis orthophoto 9 months after the operation, and (D) hip axial photo 9 months after the operation. There is one case: male, 20 years old, left side fracture, BMI: 21.97, PI: 21.54°, HDA - 18.33° (anteversion dislocation of femoral head in HDA), CDA 3.21°, NSA 135.86°, necrosis and collapse occurred 9 months after surgery. Osteonecrosis and collapse of the femoral head occurred 9 months after the operation (C,D). Since this type is extremely rare, it is stated separately.

three subtypes: subtype I (CDA ≤20°), subtype II (20° < CDA ≤35°), and subtype III (CDA > 35°).

SPT (Fig. 4): the special type.

The Combined Deflection Angle Classification vs *the Garden Classification*

As shown in Table 6, there was a rank correlation between the actual incidence of complications and the increase in the classification level in CDAC. The classification level was increased. The actual incidences of complications were 11%, 32%, and 56% in ADT, 0%, 8%, and 37% in ABT, and 100% in SPT. The actual incidence of complications in CDAC was ranked as follows: SPT (100%) > ADT Subtype III (56%) > ABT Subtype III (37%) > ADT Subtype II (32%) > ADT Subtype I (11%) > ABT Subtype II (8%) > ABT Subtype I (0%). However, there was no significant difference in the actual incidence of complications between the Garden classification types (Table 7). Therefore, CDAC is deemed as the more accurate predictor of complications.

Discussion

In this study, we found that for both patients with femoral varus offset or valgus offset, the complication group showed significantly higher HDA and CDA values than those of the non-complication group, suggesting a correlation between HDA, CDA, and complications. Therefore, CDAC, a novel FNF typing system, was established based on the combination of HDA and CDA, which was more accurate in predicting complications than the Garden classification.

Complications of FNF

Due to the particularity of the anatomy and physiology of the femoral neck, a variety of complications occur when it is fractured.[21,22] These complications have become obstacles in the treatment and rehabilitation of FNF. Currently, there have been several reports on the complications of FNF. These include studies on non-union, ankylosis, and avascular necrosis of the femoral head. Studies have shown that the incidence of avascular necrosis after internal fixation using cannulated screws is 45%.[21] Since the complications of FNF often occur within 2 years after surgery, it was practical to choose 2 years as the follow-up period in this study.[23,24] Our research shows that the incidence of complications of FNF is 32.41%, whereas that of avascular necrosis is 25%. These figures are consistent with those in most studies.

Femoral head vascular rupture, distortion, and compression caused by femoral neck displacement are significant FNF complications. The blood supply to the femoral head is mainly derived from three systems: intraosseous, scalp, and basal arterial rings.[24] The basilar artery ring system provides the most arterial blood to the femoral head. When FNF occurs, the femoral varus offset can lead to the rupture of the medial femoral circumflex artery (MFCA). A femoral varus offset can squeeze and deform the lateral femoral circumflex artery (LFCA) and MFCA. The greater the offset angle, the higher is the degree of arterial damage. Therefore,

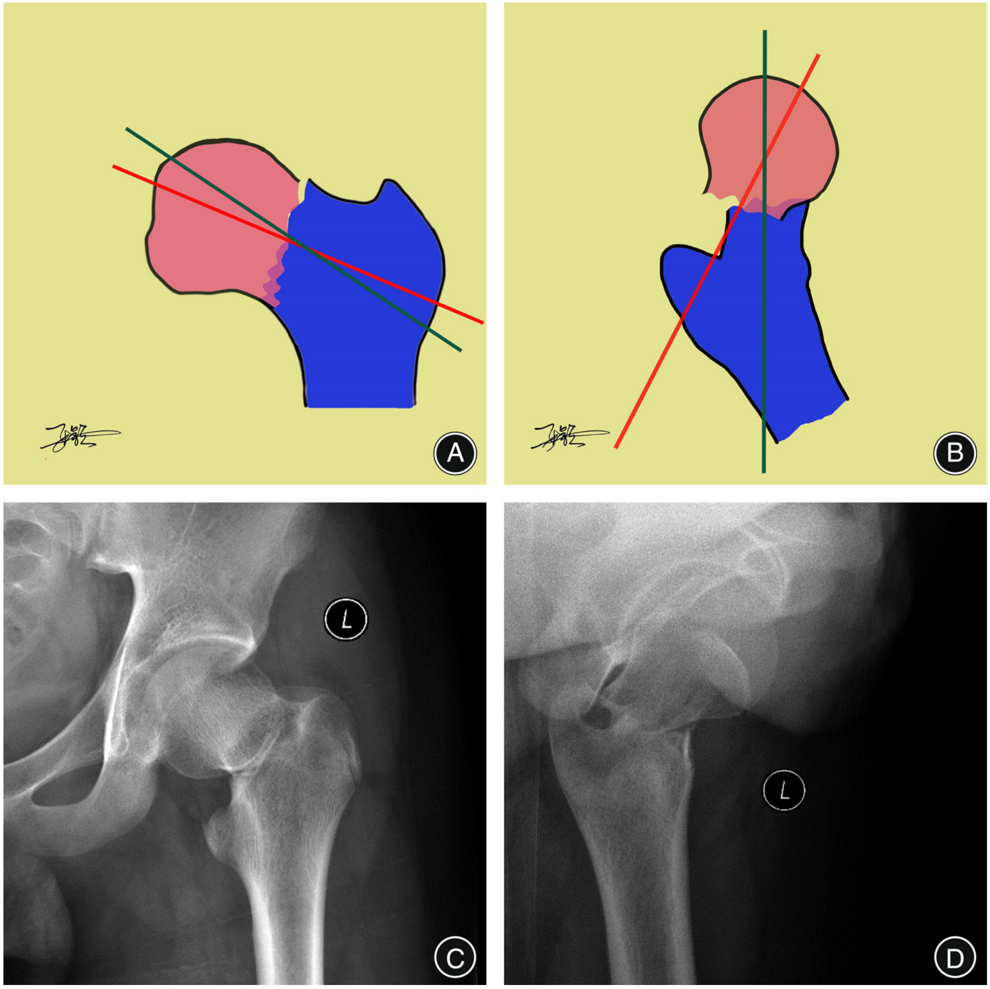

Fig. 4 A special type. SPT classification and DR diagrams. This type is extremely rare. From the analysis of the picture, the femoral head is flipped or rotated in this type. Since this type means rotational displacement of the femoral head, it may have an extremely high complication rate. SPT, special type.

we classified CDAC according to the key points of the PI, HDA, and CDA.

Combined Deflection Angle Classification

Some scholars have pointed out that the Garden classification has serious limitations in predicting the prognosis of FNF, which lacks a hierarchical correlation with the incidence of complications.[25–27] In our study, HDA was introduced into the typing system of CDAC, and the concept of CDA was defined, which was groundbreaking. Through the simple pelvis orthophoto and the affected side HIP axial photo, the spatial displacement of the femoral head after FNF can be clarified. A simple and effective 3D model was thus established. This has reduced the cost of 3D reconstruction in clinical settings. Furthermore, it has a higher accuracy and better promotion and application value. In clinical practice, there are many direct nonstandard radiographs, which we have deleted from this study. We suggest that, regardless of the type of classification used to determine the prognosis of FNF, it is necessary to standardize radiographs. Therefore, shaking during photography should be avoided.

In this study, we standardized the photographing method of image data. This can be potentially helpful in obtaining accurate measurement results. In pelvic orthophotos, the measurement of PI is based on the change in the femoral head angle. Since the femoral neck has been broken, the angle of the femoral head is not affected, even if there is a slight change in the lower limbs during removal. In the affected side hip axial photo, due to the use of potent analgesics before photography, the tips of the foot can be held perpendicular to the pelvic plane with the help of an assistant to avoid the angle change caused by the rotation of the lower limbs. If patients cannot do this after taking potent analgesics, hip computed tomography can be used as an auxiliary method. Through comparison, it has been found that the hip axial photo and hip computed tomography can obtain the same reliable measurement results.

Comparison between the Combined Deflection Angle Classification and the Garden Classification

Furthermore, the rank correlation between the actual incidence of complications and the increase in classification of

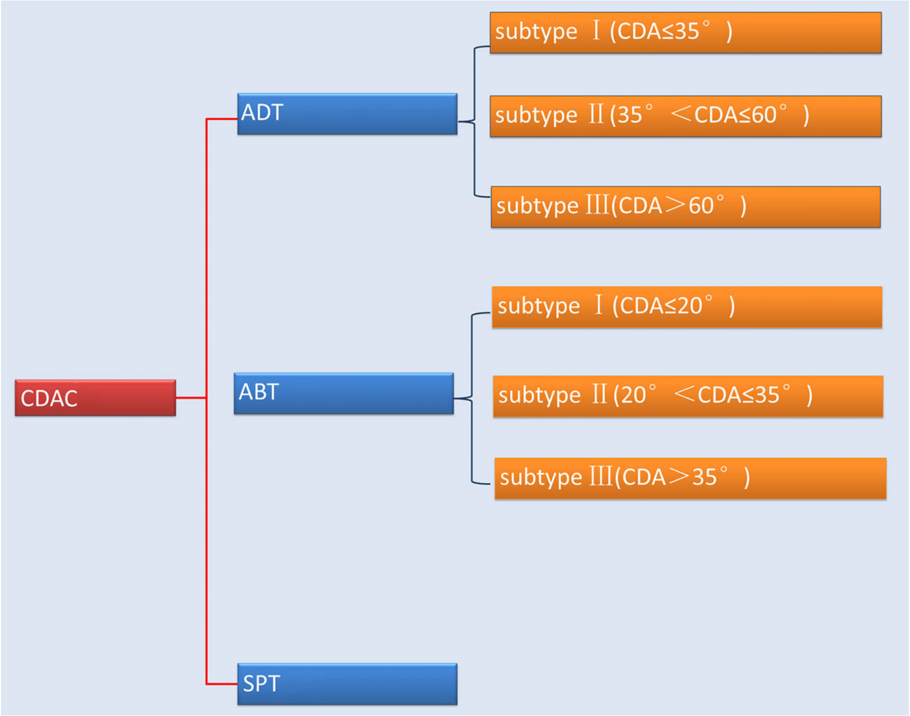

Fig. 5 CDAC sketch Map. CDAC is divided into three parts: ADT, ABT, and SPT. ADT is divided into three subtypes: subtype I (CDA ≤35°), subtype II (35° < CDA ≤60°), and subtype III (CDA > 60°). ABT is divided into three subtypes: subtype I (CDA ≤20°), subtype II (20° < CDA ≤35°), and subtype III (CDA > 35°). CDAC: combined deflection angle classification, ADT: angle adduction type, ABT: angle abduction type, SPT, special type.

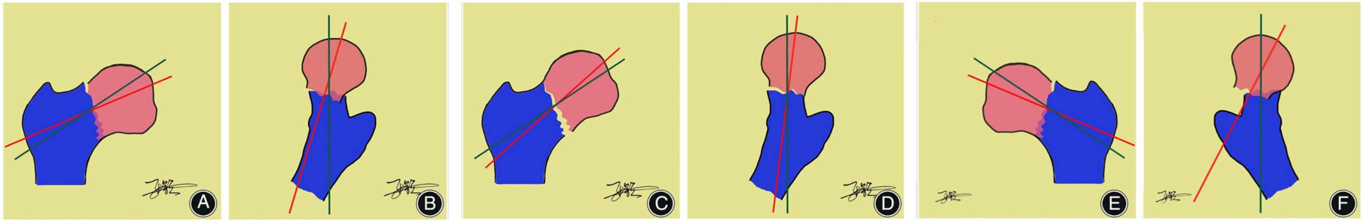

Fig. 6 The three main types in CDAC typing system. (A,B), classification diagram of the combined deflection angle adduction type (ADT); (C) and (D), classification diagram of the combined deflection angle abduction type (ABT); (E) and (F), classification diagram of combined deflection angle special type (SPT).

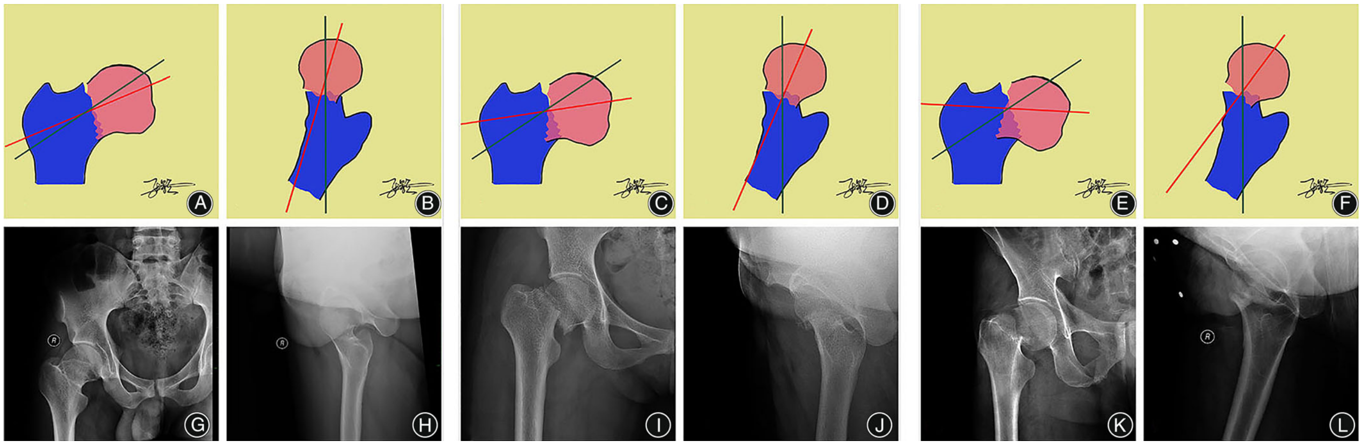

Fig. 7 ADT. ABGH: Subtype I classification diagram and DR diagram, CDIJ: subtype II classification diagram and DR diagram, EFKL: subtype III classification diagram and DR diagram. ADT, angle adduction type.

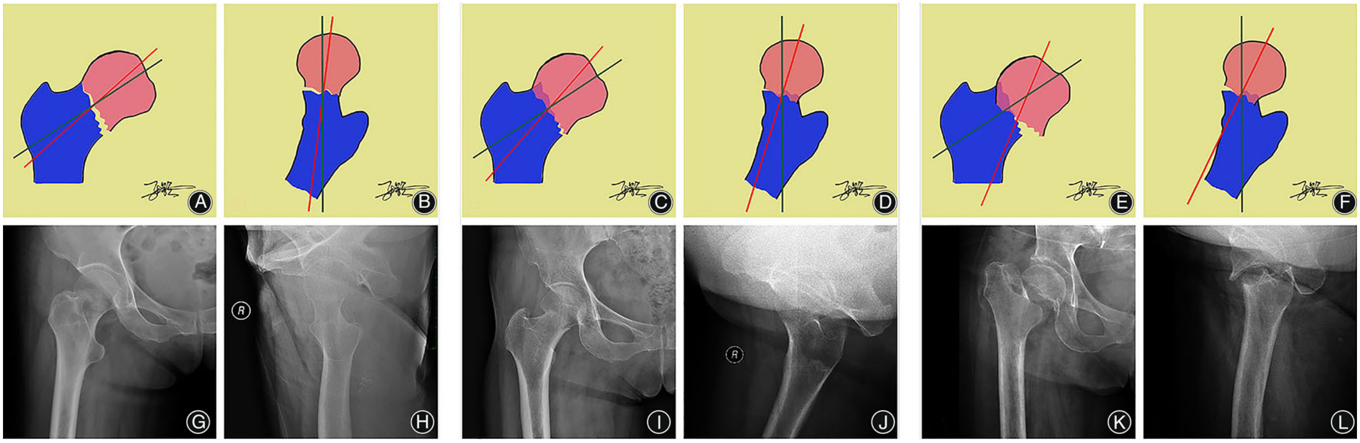

Fig. 8 ABT. ABGH: Subtype I classification diagram and DR diagram, CDIJ: subtype II classification diagram and DR diagram, EFKL: subtype III classification diagram and DR diagram. ABT, angle abduction type.

TABLE 6 Actual incidence of complications in CDAC

Types	Actual results Yes	Actual results No	Obs	Incidence of complications (%)	Std. Err.	Poisson exact 95% Conf. Interval lower limit	Poisson exact 95% Conf. Interval Upper limit	χ^2 value	*p* value
ADT								6.4816	0.039
Subtype I	1	8	9	0.11	0.1	0	0.48		
Subtype II	7	15	22	0.32	0.1	0.14	0.55		
Subtype III	15	12	27	0.56	0.1	0.35	0.75		
Total	25	33	58	0.43	0.07	0.3	0.57		
ABT								7.2423	0.027
Subtype I	0	5	5	0	0	0	0.52		
Subtype II	2	23	25	0.08	0.05	0.01	0.26		
Subtype III	7	12	19	0.37	0.11	0.16	0.62		
Total	9	40	49	0.18	0.06	0.09	0.32		
SPT	1	0	1	1	0	0.03	1		
Total(All)	35	73	108	32.41	0.05	0.24	0.42	9.5244	0.009

Notes: The results showed that in CDAC ADT *vs* ABT and SPT were statistically significant ($P = 0.009$), which indicated that: the incidence of complications, SPT (100%) > ADT (43%) > ABT (18%). There was statistical significance in ADT, $P = 0.039$, Subtype III (56%) > Subtype II (32%) > Subtype I (11%). There was statistical significance in ABT, $P = 0.027$, Subtype III (37%) > Subtype II (8%) > Subtype I (0%). The actual incidence of complications in CDAC were that: SPT (100%) > ADT Subtype III (56%) > ABT Subtype III (37%) > ADT Subtype II (32%) > ADT Subtype I (11%) > ABT Subtype II (8%) > ABT Subtype I (0%).; Abbreviations: ABT, combined deflection angle abduction type; ADT, combined deflection angle adduction type; CDAC, combined deflection angle classification; SPT, combined deflection angle special type.

TABLE 7 Actual incidence of complications in GC

Types		Actual results Yes	Actual results No	Obs	Incidence of complications (%)	Std. Err.	Poisson exact 95% Conf. interval lower limit	Poisson exact 95% Conf. interval Upper limit
GC	GC I	0	1	1	0	0	0	0.97
	GC II	7	18	25	0.28	0.09	0.12	0.49
	GC III	23	52	75	0.31	0.05	0.18	0.40
	GC IV	5	2	7	0.71	0.18	0.29	0.96
	Total(All)	35	73	108	32.41	0.05	0.24	0.42
	χ^2 value		5.6707					
	p value		0.129					

Note: although the actual incidence of complications GC IV (71%) > GC III (31%) > GC II (28%) > GCI (0%), but there was no statistical significance in GC, $P = 0.1$.; Abbreviation: GC, Garden classification.

CDAC and Garden classification was analyzed. The results showed that the incidence of complications increased gradually with the increase in the classification level in CDAC. However, there was no significant difference among each type of Garden classification. The accuracy of the prediction may be improved due to the increased accuracy in the classification. In CDAC, the actual incidence of complications was ranked as follows: SPT > ADT Subtype III > ABT Subtype III > ADT Subtype II > ADT Subtype I > ABT Subtype II > ABT Subtype I. Therefore, CDAC is more reliable in terms of predicting the post-operative complications of FNF.

Strengths and Limitations

This study proposed a novel clinical typing system based on the combination of deviation angles HDA and CDA, which was more accurate in predicting complications than the previous Garden classification. However, all results were obtained through retrospective analysis. This study has several limitations. First, patients with basic diseases (e.g., diabetes) were excluded. Patients with FNF who underwent internal fixation were relatively young, and older patients were more likely to receive joint replacement. Additionally, patients with diabetes are generally older than 45 years. The average age of the patients in the current study had an average age of 42.31 years. Therefore, whether there were differences in the incidence of diabetes among the patients was not analyzed in this study. Second, all the patients included in this study were operated on by our team and treated with three hollow screws arranged in an inverted triangle. Therefore, there were no differences in the arrangement, quantity, or quality of the cannulated screws. In addition, the preoperative waiting time and other related factors that might affect the prognosis of patients with FNF were not described in this study, which might confound the results. Third, this was a single-center study with a small sample size. Further investigations based on a larger sample size and multicenter study should be conducted.

Conclusion

In conclusion, CDAC is a new clinical typing system that can be used for the prognosis of complications and is convenient and easy to apply. However, the Garden classification cannot be completely ruled out as a classical FNF-typing system. Therefore, we suggest that CDAC and Garden classification should be combined for the diagnosis, treatment, and prognosis to obtain more accurate results. The limitation of this study is the relatively small sample size. Hence, a prospective multicenter randomized controlled trial in a follow-up study should be conducted.

Author Contributions

Conception and design of the research: Ying Zhang, Qiang Yuan, Wuyin Li; acquisition of data: Yiping Dong, Youwen Liu, Zhenhao Jing, Leilei Zhang; analysis and interpretation of data: Yiping Dong, Youwen Liu, Zhenhao Jing, Leilei Zhang; statistical analysis: Qiushi Wei, WH; obtaining funding: Ying Zhang, Wuyin Li; drafting the manuscript: Ying Zhang, Qiang Yuan; revision of manuscript for important intellectual content: HW, Wuyin Li. All authors read and approved the final manuscript.

Funding Information

This work was supported by National Science Foundation of China (grant number 81774348 and 81874477); and Science and Technology Project of Henan Province (grant number 212102310365).

Conflict of Interest

The authors declare that they have no conflicts of interest.

Ethics Statement

This study was approved by the ethics committee of the Luoyang Orthopedic-Traumatological Hospital (Orthopedics Hospital of Henan Province) (Approval No. 2014ZY02094). Informed consent was obtained from all the patients.

Data Availability Statement

The data supporting the findings of this study are available from the corresponding author upon request.

Supporting Information

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

Fig. S1. The axis on pelvis orthophoto and hip axial photo. The schematic diagram of FNF displacement. Pelvis orthophoto (A), Hip axial photo (B), varus offset of pelvis orthophoto (C), valgus offset of pelvis orthophoto (D) and FHPI offset of hip axial photo (E). FNF: Femoral neck fracture.

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