


## CLINICAL ARTICLE

# Optimal Level of Femoral Neck for Predicting Postoperative Stem Anteversion in Total Hip Arthroplasty for Crowe Type I Dysplastic Hip

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**Objective:** To investigate the optimal level of femoral neck for measuring femoral anteversion to predict postoperative stem anteversion in Crowe type I developmental dysplasia of the hip.

**Methods:** This retrospective study analyzed 108 Crowe type I hips that underwent THA between January 2016 and December 2017, including 70 women and 19 men with a mean age of  $63.08 \pm 9.13$  (range, 41–83) years. The single-wedge stem was used in 37 hips, the double-wedge stem was used in 71 hips. Computed tomography scans were performed pre- and post-operation. Femoral anteversion at six levels of the proximal femur were measured via preoperative two-dimensional computed tomography. Femoral anteversion at the level of the femoral neck osteotomy plane and postoperative stem anteversion were measured via three-dimensional reconstructed models.

**Results:** The mean follow-up period was 18.5 months (range, 12–27 months). The mean preoperative Harris Hip Score was  $51.5 \pm 8.7$  and improved to  $90.4 \pm 7.8$  ( $P < 0.001$ ) by the last follow-up. There were no intraoperative fractures, and no infections occurred during the follow-up period. Two patients developed deep venous thrombosis. There was no sign of prosthetic loosening in all hips. No significant correlations were found between the height of the femoral neck osteotomy plane and postoperative stem anteversion ( $r = -0.119$ ,  $P = 0.220$ ). Femoral anteversion decreased gradually from  $64.00^\circ \pm 10.51^\circ$  at the center of lesser trochanter to  $15.21^\circ \pm 13.31^\circ$  at the head–neck junction, which was changed from more to less than stem anteversion ( $24.37^\circ \pm 13.86^\circ$ ). The femoral anteversion at femoral head–neck junction ( $15.21^\circ \pm 13.31^\circ$ ) was significantly less than postoperative stem anteversion ( $P = 0.000$ ), with a difference of  $-9.16^\circ \pm 9.27^\circ$ . The femoral anteversion at the level of the osteotomy plane ( $28.48^\circ \pm 15.34^\circ$ ) was significantly more than the postoperative stem anteversion ( $P = 0.000$ ), with a difference of  $4.11^\circ \pm 9.56^\circ$ . Among all six levels and the level of osteotomy, femoral anteversion at the 10-mm level above the proximal base of lesser trochanter ( $22.65 \pm 12.92$ ) displayed the smallest difference ( $-1.72^\circ \pm 8.90^\circ$ ) and a good correlation ( $r = 0.764$ ) with postoperative stem anteversion for all 108 hips, with a moderate correlation of 0.465 for single-wedge stem hips and an excellent correlation of 0.821 for double-wedge stem hips.

**Conclusion:** For Crowe type I hips, femoral anteversion would be different if it was measured via different levels of the femoral neck. The 10-mm level above the proximal base of the lesser trochanter could be an optimum choice for measuring femoral anteversion to predict postoperative stem anteversion.

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## Introduction

Total hip arthroplasty (THA) has been an effective method to relieve pain and improve function for adult patients with developmental dysplasia of the hip (DDH)<sup>1</sup>. Compared with ordinary hip osteoarthritis patients, DDH patients have abnormal anatomies, which increases the difficulty of THA operation and the occurrence of postoperative complications<sup>2</sup>. The most notable of these morphological variants is the increased likelihood to have excessive native femoral anteversion<sup>2</sup>. Previously, we have showed that native femoral anteversion in DDH patients is significantly greater than that in normal patients<sup>3</sup>. The study by Sugano *et al.*<sup>4</sup> found that patients with DDH had an average increase of 10°–14° of anteversion of the native femoral neck and the incidence of anteversion greater than 40° was 23%. Similarly, the study by Noble *et al.*<sup>5</sup> found femoral anteversion was increased in patients with DDH on average by 5° to 16°. The anteversion increased with increased subluxation of the hip. However, even in mild DDH cases (Crowe I), there was a significant increase in anteversion. Hence, abnormal femoral anteversion should be considered in THA for DDH patients, even for the mild Crowe type I hips<sup>2,6</sup>. Combined anteversion means the sum of the cup and stem anteversion in THA. The combined anteversion theory has become a popular way to avoid impingement and dislocation, and maximize hip range of motion<sup>7</sup>. Previously, we have shown that the concept of combined anteversion contributes to joint stability after THA for DDH patients<sup>8,9</sup>. Cementless, straight, tapered femoral stems are commonly used, which depends mainly on the anatomy of the proximal femur, and in whom adjusting the anteversion of the femoral stem is difficult<sup>10</sup>. If the preoperative femoral anteversion angle is eccentric, a monoblock or modular stem with adjustable anteversion is preferable to correct excessive anteversion<sup>2,11</sup>. Therefore, prediction of the postoperative anteversion of the femoral stem helps choose an appropriate femoral prosthesis and optimize the combined anteversion<sup>2</sup>.

Preoperative computed tomography (CT) can help assess femoral anteversion, which is thought to be the most accurate imaging method currently available<sup>12</sup>. Although several methods have been developed to predict postoperative stem anteversion, no standard predictive method has been established. Three-dimensional CT technique can measure the native femoral anteversion more accurately than two-dimensional CT, but it does not show an advantage in predicting the postoperative stem anteversion, and this technique is time-consuming making it inaccessible for surgeons<sup>13</sup>. The classical method of Sugano, of measuring femoral anteversion based on two-dimensional CT image, remains the most commonly used method because of its convenience, accuracy, and repeatability<sup>14,15</sup>. However, whether

measuring femoral anteversion via two-dimensional CT can predict postoperative stem anteversion remains controversial. Some studies reported that postoperative stem anteversion was predictable, but the results varied widely<sup>13,16–18</sup>, with the reported difference between preoperative femoral anteversion and postoperative stem anteversion varying from  $2.3^\circ \pm 5.9^\circ$  to  $22.7^\circ \pm 11.6^\circ$ , and the correlation coefficient varying from 0.46 to 0.93. Furthermore, some studies found that it was difficult to predict postoperative stem anteversion, especially for the single-wedge stems<sup>16,19</sup>. We speculated that one main reason for the controversy may lie in the inconsistency of the methods used to measure femoral anteversion for stem anteversion prediction. Because of the torsion in the proximal femur<sup>16,17</sup>, the anteversion angle measured at different levels of the femoral neck could be different. However, at present, the optimal level of the femoral neck for measuring femoral anteversion to predict postoperative stem anteversion is not yet established.

The “acetabular first” technique remains the most commonly used in THA. Intraoperatively estimating the femoral anteversion at the level of the femoral neck osteotomy plane to predict the postoperative stem anteversion and then adjusting the cup anteversion accordingly is one method often used in the “acetabular first” technique to target combined anteversion within the safe zone. Previously, we reported the effectiveness of this method for DDH patients who underwent THA, which reduced dislocation risk and achieved better impingement-free range of motion<sup>8,9</sup>. However, the difference of the femoral anteversion at the level of the osteotomy plane with the postoperative stem anteversion remains to be elucidated.

To our best knowledge, there were few reports on the prediction of postoperative stem anteversion in DDH patients<sup>16</sup>. Crowe type I hips are the most common candidates for THA in the four Crowe types. Therefore, this study aimed: (i) to retrospectively analyze the characteristics of femoral anteversion in Crowe type I hips; (ii) to explore the optimal level of the femoral neck for measuring femoral anteversion to predict postoperative stem anteversion.

## Materials and Methods

### Inclusion and Exclusion Criteria

This was a single center retrospective study, approved by the local institutional review board. The inclusion criteria followed the P (participant), I (intervention), C (comparison), O (outcome), S (study design) principle: (i) Participant: adult Crowe type I hips according to Crowe classification<sup>20</sup>, having extreme impairment of daily activity; (ii) Intervention: underwent THA between January 2016 and December 2017; (iii) Comparison: the differences of femoral anteversion at

different levels with the postoperative stem anteversion; (iv) Outcome: the optimal level of femoral neck for predicting postoperative stem anteversion; and (v) Study design: a retrospective study. The exclusion criteria were: (i) previous hip surgery; (ii) lack of integral imaging data; (iii) obvious flexion contracture of the hip; and (iv) more than 3° malalignment of the stem in the coronal and/or sagittal plane<sup>18</sup>.

### Patient Data

A total of 147 consecutive THAs were performed for Crowe type I DDH patients between January 2016 and December 2017. In total, 39 hips were excluded from this study because of insufficient preoperative or postoperative CT data (27 hips), obvious flexion contracture of the hip (three hips), and more than 3° malalignment of the stem in the coronal and/or sagittal plane (nine hips). The remaining 108 hips (89 patients) were included in the study, including 70 women and 19 men with a mean age of  $63.08 \pm 9.13$  (range, 41–83) years. The single-wedge stem was used in 37 hips (Accolade, Stryker, Howmedica, Mahwah, NJ, USA); the double-wedge stem was used in 71 hips (Secur-fit, Stryker, Howmedica, Mahwah, NJ, USA).

### CT Scanning

CT evaluation was performed as we previously reported<sup>21</sup> by using the Hitachi Radix Turbo (Tokyo, Japan) (120 kVp, 200 mA, 5-mm collimation, 5 mm/s table speed, and 5-mm resolution index) device. By using axial sections passing from the anterior superior iliac spine to the tibial tubercle, patients underwent 1-mm interval CT in the supine position with the hips and knees fully extended and the lower limbs as horizontal and parallel as possible. Pre- and postoperative CT data were stored in Digital Imaging and Communication in Medicine (DICOM) format. Femoral measurement was performed using the Radiant DICOM Viewer (version 4.6.9, 64-bit, Medixant Company, Poland).

### Surgical Procedure

All operations were performed by the same group of surgeons, with the posterolateral approach and “acetabular first” technique with the concept of combined anteversion. The procedure has been described in detail previously<sup>8,9</sup>. Briefly, after dislocating the femoral head posteriorly, the femoral neck osteotomy was conducted (45° from the femoral anatomical axis). The assistant positioned the knee joint at a 90° angle in the flexion position with the foot arch upward, perpendicular to the horizontal plane. The femoral anteversion was evaluated by examining the axis of the femoral neck osteotomy plane and horizontal plane. Then, the acetabular cup was implanted targeting the combined anteversion of  $40^\circ \pm 15^\circ$ . Routine intraoperative fluoroscopy was used to verify the size and position of the final femoral broach to achieve “best-fit”. Finally, the stem was press-fitted according to the geometry of the native proximal femur

### Follow-up and Assessment

Outpatient follow-ups were performed 1, 3, 6, and 12 months after surgery. Subsequently, yearly follow-ups were performed. Clinical and imageological assessments were performed.

### Harris Hip Score

The Harris hip score (HHS) was used to assess the hip joint function of each patient prior to surgery and at each follow-up examination after surgery<sup>22</sup>. The HHS score system mainly includes the four aspects of pain, function, absence of deformity, and range of motion. The score standard had a maximum of 100 points (best possible outcome). A total score < 70 is considered a poor score, 70–80 fair, 80–90 good, and 90–100 excellent.

### Radiographic Assessment

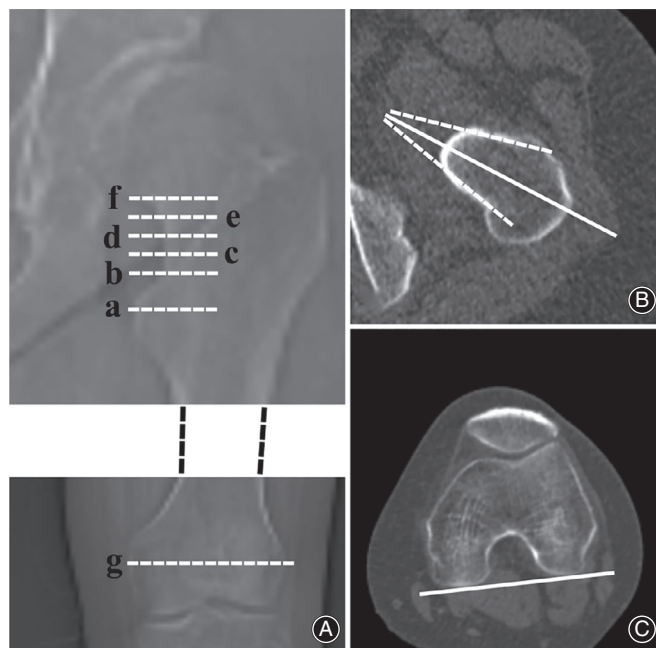
A series of radiographs of the pelvis were obtained at each follow-up visit and were carefully assessed for loosening of the prosthesis. The stability of the acetabular components was assessed radiographically using the method of DeLee and Charnley<sup>23</sup> and that of the femoral components using the method of Gruen *et al.*<sup>24</sup>. Specifically, the criteria are as follows: (i) Stable fixation, no prosthesis displacement, no radiolucency or sclerotic band around the prosthesis; (ii) Fibrous stability, no prosthesis displacement, radiolucency <1mm around the prosthesis; (iii) Probable loosening, no prosthesis displacement, a discontinuous radiolucency >2 mm around the prosthesis; and (iv) Definite loosening, prosthesis displacement or breakage, screw breakage or sclerotic band around the screw, continuous radiolucency >2 mm around the prosthesis.

### CT Assessment

To facilitate preoperative measurement, femoral anteversion was measured at six levels (level a–f) of the proximal femur via preoperative two-dimensional CT (Fig. 1A). The six levels were as follows: level a, center of the lesser trochanter; level b, proximal base of the lesser trochanter; level c, 5 mm above level b; level d, 10 mm above level b; level e, 15mm above level b; level f, femoral head–neck junction (just below the head). The anteversions of the anterior cortex and posterior cortex at six levels were measured respectively as the angles formed by the cortical lines and the posterior aspect of the femoral condylar line (Fig. 1B and C). The femoral anteversion at each level was calculated using the classical method as the average of the anterior cortex anteversion and posterior cortex anteversion<sup>16</sup>.

The height of the femoral head–neck junction was measured as the vertical distance between the proximal base of the lesser trochanter and the medial edge of the femoral head–neck junction (just below the head). The height of the femoral neck osteotomy plane was measured as the vertical distance between the proximal base of the lesser trochanter and the medial edge of the osteotomy plane.

Femoral anteversion at the level of the femoral neck osteotomy plane and postoperative stem anteversion were



**Fig. 1** Measurement of femoral anteversion via two-dimensional computed tomography. (A) Six measurement levels of femoral anteversion: level a, centre of the lesser trochanter; level b, proximal base of the lesser trochanter; level c, 5 mm above level b; level d, 10 mm above level b; level e, 15 mm above level b; level f, femoral head-neck junction; g, the level showed the most posterior points of the femoral condyles. (B) Anteverisions of the anterior cortex and posterior cortex were measured respectively as the angles formed by the cortical lines (white dashed lines) and the posterior aspect of the femoral condylar line. Femoral anteversion was calculated as the average of the anterior cortex anteversion and posterior cortex anteversion (white solid line). (C) Posterior aspect of the femoral condylar line at level g.

measured on three-dimensional models, which were reconstructed with Mimics software (version 15.0; Materialize, Leuven, Belgium) (Fig. 2). The femoral neck osteotomy plane for each three-dimensional model was simulated at the height measured on postoperative two-dimensional CT and at 45° angle from the femoral anatomical axis (the same as the with surgical operation). The femoral anteversion of each model was measured as the average of the anterior cortex anteversion and the posterior cortex anteversion (Fig. 2A). The postoperative stem anteversion of each model was measured as the angle formed by the stem neck major axis and the posterior aspect of the femoral condylar line<sup>25</sup> (Fig. 2B). All CT measurements were performed twice over an interval of more than 2 weeks by two orthopaedic surgeons.

### Statistical Analysis

Data were expressed as the mean  $\pm$  standard deviation. All statistical analyses were performed using SPSS software for Windows (version 18.0; SPSS, Chicago, IL, USA). The

intraclass correlation coefficients of interobserver and intraobserver reliabilities were calculated. The Shapiro–Wilk test for normal distribution was used before any statistical analysis was performed. The Wilcoxon signed rank test was used to assess the difference between preoperative femoral anteversion and postoperative stem anteversion. Spearman’s correlation analysis was done to evaluate the association between each preoperative anteversion and postoperative stem anteversion. A  $P$  value  $<0.05$  was considered to represent a significant difference. Correlation ( $r$ ) was characterized as poor (0.00 to 0.20), fair (0.21 to 0.40), moderate (0.41 to 0.60), good (0.61 to 0.80), or excellent (0.81 to 1.00).

## Results

### Harris Hip Score

The mean follow-up period was 18.5 months (range, 12–27 months). The mean preoperative Harris hip score was  $51.5 \pm 8.7$  and improved to  $90.4 \pm 7.8$  ( $P < 0.001$ ) by the last follow-up.

### Radiographic Results

The radiological stability of the acetabular and femoral components were assessed and there was no definite sign of prosthetic loosening in all hips.

### Intraobserver and Interobserver Reliabilities

The intraclass correlation coefficients for intraobserver and interobserver reliabilities were excellent (0.888–0.967 and 0.844–0.958, respectively).

### Height of the Head-Neck Junction

Generally, for all 108 hips, the mean preoperative height of the head-neck junction was  $17.70 \pm 2.66$  mm, including five hips with head-neck junction height  $< 15$  mm (11.00–14.50 mm) and 103 hips with  $\geq 15$  mm (15.00–25.00 mm).

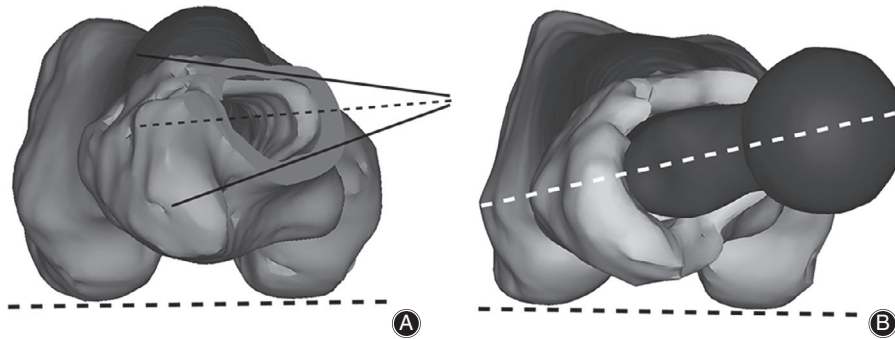
### Height of the Femoral Neck Osteotomy Plane

The mean height of the femoral neck osteotomy plane was  $5.11 \pm 2.98$  mm. The mean postoperative stem anteversion was  $24.37^\circ \pm 13.86^\circ$ . No significant correlations were found between the height of the femoral neck osteotomy plane and postoperative stem anteversion ( $r = -0.119$ ,  $P = 0.220$ ).

### Characteristics of Femoral Anteversion

Generally, from the center of the lesser trochanter (level a) to the head-neck junction (level f), the anterior cortex anteversion changed slightly (between  $14.54^\circ \pm 13.68^\circ$  and  $9.08^\circ \pm 14.98^\circ$ ), while the posterior cortex anteversion markedly changed with a gradual decrease (from  $113.46^\circ \pm 12.11^\circ$  to  $18.77^\circ \pm 13.66^\circ$ ). Accordingly, the femoral anteversion was reduced gradually from  $64.00^\circ \pm 10.51^\circ$  at level a to  $15.21^\circ \pm 13.31^\circ$  at level f, which was from more than stem anteversion to less than stem anteversion (Table 1). Hence, these results verified that femoral anteversion would be different if it is measured via different levels of the femoral neck (Fig. 3).





**Fig. 2** Measurement of femoral anteversion and stem anteversion via three-dimensional reconstructed computed tomography. (A) The femoral anteversion at the level of the osteotomy plane was measured as the average (thin black dashed line) of the anterior cortex anteversion and posterior cortex anteversion (black solid lines) relative to the posterior aspect of the femoral condylar line (thick black dashed line). (B) The stem anteversion was measured as the angle formed by the stem neck major axis (white dashed line) and the posterior aspect of the femoral condylar line (black dashed line).

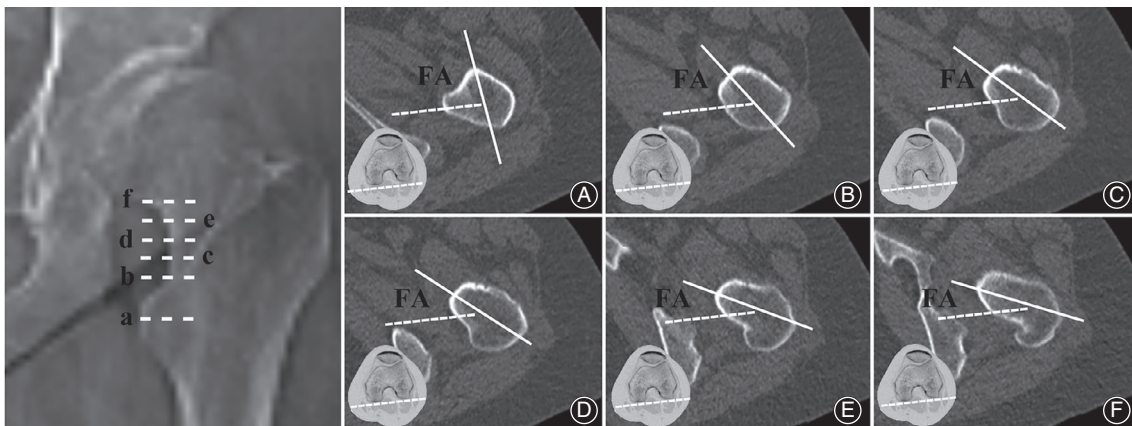
**Difference Between Femoral Anteversion and Postoperative Stem Anteversion**

For all 108 hips (Table 1), good correlations were shown between femoral anteversion at all measurement levels and postoperative

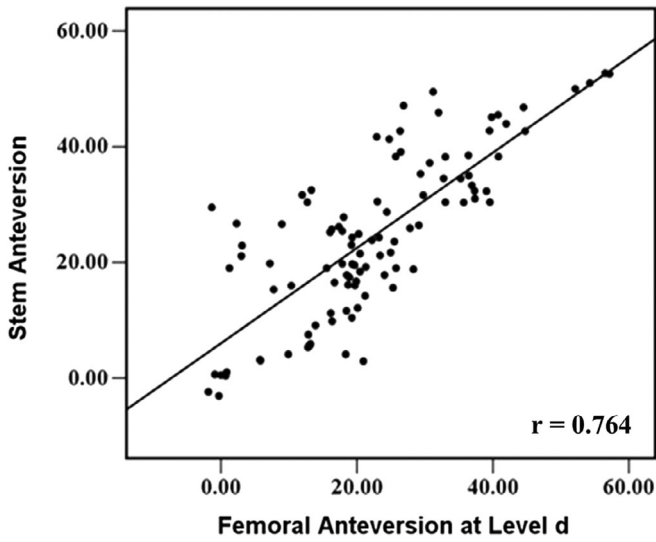
stem anteversion ( $r = 0.602-0.793$ ); however, only the femoral anteversion at level d ( $22.65^\circ \pm 12.92^\circ$ ) showed no statistical difference with postoperative stem anteversion ( $P = 0.402$ ), with a difference of  $-1.72^\circ \pm 8.90^\circ$  and a correlation of 0.764 (Fig. 4).

TABLE 1. Femoral anteversion measured at different levels								
Level	No.	Anterior cortex anteversion (°)	Posterior cortex anteversion (°)	Femoral anteversion (°)	Stem anteversion (°)	Difference (°)	P	r (P)
a	108	14.54 ± 13.68	113.46 ± 12.11	64.00 ± 10.51	24.37 ± 13.86	39.63 ± 10.89	0.000	0.602 (0.000)
b	108	13.60 ± 13.56	52.61 ± 19.06	33.10 ± 15.33	24.37 ± 13.86	8.73 ± 9.16	0.000	0.793 (0.000)
c	108	12.07 ± 14.00	45.49 ± 16.80	28.78 ± 14.52	24.37 ± 13.86	4.41 ± 9.70	0.000	0.751 (0.000)
d	108	9.08 ± 14.98	36.22 ± 12.46	22.65 ± 12.92	24.37 ± 13.86	-1.72 ± 8.90	0.402	0.764 (0.000)
e	103	9.43 ± 15.27	25.64 ± 12.85	17.53 ± 12.76	24.40 ± 14.00	-6.87 ± 8.73	0.000	0.787 (0.000)
f	108	11.64 ± 14.15	18.77 ± 13.66	15.21 ± 13.31	24.37 ± 13.86	-9.16 ± 9.27	0.000	0.764 (0.000)
Osteotomy plane	108	11.48 ± 14.01	45.47 ± 18.74	28.48 ± 15.34	24.37 ± 13.86	4.11 ± 9.56	0.000	0.767 (0.000)

Level, refer to Fig. 1; Difference = femoral anteversion – stem anteversion



**Fig. 3** Change in femoral anteversion measured at different levels. From level a to f, the femoral anteversion (FA) was reduced gradually. Level a-f, refer to Fig. 1. White dashed line: the posterior aspect of the femoral condylar line; white solid line: the middle line of the anterior cortex and posterior cortex.



**Fig. 4** Correlation of femoral anteversion measured at level d with stem anteversion for all 108 hips.

Level f (head–neck junction) was often used for measuring femoral anteversion in previous studies<sup>15,16</sup>. Our results showed that the femoral anteversion at level f ( $15.21^\circ \pm 13.31^\circ$ ) was significantly less than postoperative stem anteversion ( $P = 0.000$ ), with a difference of  $-9.16^\circ \pm 9.27^\circ$ . In addition, as an intraoperative reference 8, the femoral anteversion at the level of the osteotomy plane ( $28.48^\circ \pm 15.34^\circ$ ) was significantly more than the postoperative stem anteversion ( $P = 0.000$ ), with a difference of  $4.11^\circ \pm 9.56^\circ$ . Hence, our results showed that femoral anteversion at level d (10-mm level above the proximal base of the lesser trochanter) displayed minimum difference with postoperative stem anteversion, with a good correlation.

**Anteversion Prediction for Single-Wedge and Double-Wedge Stems**

We further analyzed whether femoral anteversion measured at level d could be used as a predictor for postoperative stem anteversion for both single-wedge and double-wedge stems (Table 2). For single-wedge stems, moderate correlations were shown between femoral anteversion at all measurement levels and stem anteversion ( $r = 0.417$ – $0.578$ ). The femoral anteversion at level c, level d, and osteotomy plane showed no statistical difference with postoperative stem anteversion ( $P = 0.081$ ,  $0.597$ , and  $0.131$ , respectively), while the femoral anteversion at level d showed the smallest difference of  $-0.23^\circ \pm 9.54^\circ$  in the stem anteversion, with a correlation of  $0.465$  (Fig. 5A). For double-wedge stems, good to excellent correlations were found between femoral anteversion at all measurement levels and stem anteversion ( $r = 0.637$ – $0.874$ ), while only the femoral anteversion at level d showed no statistical difference in stem anteversion ( $P = 0.123$ ), with a difference of  $-2.50^\circ \pm 8.52^\circ$  and an excellent correlation of  $0.821$  (Fig. 5B).

**TABLE 2 Comparison between the femoral anteversion (°) at each level and the anteversion (°) of single-wedge and double-wedge stems**

Level	Single wedge stems				Double wedge stems							
	No.	Femoral anteversion	Stem anteversion	Difference (°)	P	r (P)	No.	Femoral anteversion	Stem anteversion	Difference (°)	P	r (P)
a	37	62.46 ± 7.75	20.64 ± 11.17	41.82 ± 10.22	0.000	0.417 (0.01)	71	64.80 ± 11.66	26.32 ± 14.78	38.48 ± 11.13	0.000	0.637 (0.000)
b	37	28.26 ± 12.92	20.64 ± 11.17	7.61 ± 12.01	0.000	0.541 (0.001)	71	35.63 ± 15.96	26.32 ± 14.78	9.31 ± 7.28	0.000	0.874 (0.000)
c	37	23.90 ± 12.68	20.64 ± 11.17	3.26 ± 11.79	0.081	0.460 (0.004)	71	31.33 ± 14.84	26.32 ± 14.78	5.01 ± 8.44	0.000	0.822 (0.000)
d	37	20.41 ± 8.60	20.64 ± 11.17	-0.23 ± 9.54	0.597	0.465 (0.004)	71	23.82 ± 14.60	26.32 ± 14.78	-2.50 ± 8.52	0.123	0.821 (0.000)
e	36	14.73 ± 8.93	20.98 ± 11.14	-6.25 ± 9.69	0.001	0.578 (0.000)	67	19.04 ± 14.24	26.24 ± 15.08	-7.20 ± 8.22	0.000	0.832 (0.000)
f	37	12.58 ± 10.95	20.64 ± 11.17	-8.06 ± 10.81	0.000	0.536 (0.001)	71	16.59 ± 14.27	26.32 ± 14.78	-9.72 ± 8.38	0.000	0.820 (0.000)
Osteotomy plane	37	23.03 ± 12.85	20.64 ± 11.17	2.39 ± 11.13	0.131	0.557 (0.000)	71	31.32 ± 15.83	26.32 ± 14.78	5.00 ± 8.58	0.000	0.820 (0.000)

Level, refer to Fig. 1; Difference = femoral anteversion – stem anteversion

Hence, the 10-mm level above the proximal base of the lesser trochanter could be chosen as the optimal level for measuring femoral anteversion to predict postoperative stem anteversion in Crowe type I DDH hips, which is applicable for both single-wedge and double-wedge stems.

### Complications

There were no intraoperative fractures, and no infections occurred during the follow-up period. Two patients developed deep venous thrombosis; this condition resolved after anticoagulation treatment with low molecular-weight heparin. No patients required revision during the follow-up period.

### Discussion

#### Prediction of Stem Anteversion for DDH

As for the prediction of postoperative stem anteversion via preoperative two-dimensional CT, few studies were conducted for DDH patients. The study by Taniguchi *et al.*<sup>16</sup> showed that for the double-wedge stem, the difference between femoral anteversion and stem anteversion was  $17.2^\circ \pm 8.3^\circ$ , the correlation coefficient was 0.78; for the single-wedge stem, the difference was  $22.7^\circ \pm 11.6^\circ$ , the correlation coefficient was 0.46. Compared with their findings, the current study showed similar correlations, but smaller differences. In their study, patients with Crowe types were not listed, which demonstrates different femoral anteversion<sup>26</sup>, and larger differences than that of other previous studies were shown<sup>16</sup>.

#### Optimal Femoral Neck Level for the Prediction of Stem Anteversion

This study demonstrated that the femoral anteversion value may be different if it is measured at different levels of the femoral neck for Crowe type I DDH hips. From the center of lesser trochanter to head-neck junction, femoral anteversion reduced gradually from more to less than postoperative stem

anteversion. Although several methods of measuring the femoral anteversion via two-dimensional CT have been reported<sup>16,18,19,27,28</sup>, there is no report on the optimal level of the femoral neck recommended to measure preoperative femoral anteversion for the prediction of postoperative stem anteversion. The study by Kwan *et al.*<sup>13</sup> reported that femoral anteversion measured via the middle level of the femoral neck could predict postoperative stem anteversion better than that measured at the head-neck junction level. The current study clearly showed that, for Crowe type I DDH hips, femoral anteversion at the 10-mm level above the proximal base of the lesser trochanter showed the smallest difference with the stem anteversion among different levels of femoral neck, including the level of the head-neck junction and the level of the osteotomy plane, which were often used for the prediction of postoperative stem anteversion in clinical practice<sup>8,9,16</sup>.

#### Prediction of Stem Anteversion for Hips with Different Femoral Stems

Similar to the study by Taniguchi *et al.*<sup>16</sup>, the double-wedge stem showed a better correlation with femoral anteversion than the single-wedge stem in the current study. It has been believed that the difference is related to the stem design. Compared with the double-wedge stem, the single-wedge stem is relatively thin<sup>29</sup>, has more freedom in the horizontal plane<sup>7</sup>, and is prone to tilting<sup>17</sup>, which could change the stem anteversion. However, only one measurement method was used in the current study and the study by Taniguchi *et al.*<sup>16</sup>. The femoral anteversion value measured by different methods is different even for the same patient<sup>13,15</sup>. There may be one measurement method that could be more suitable for predicting the anteversion of a specific stem than other methods. Hence, further studies are needed to compare the difference between the femoral neck and stem anteversion in a single-wedge stem compared to a double-wedge stem.

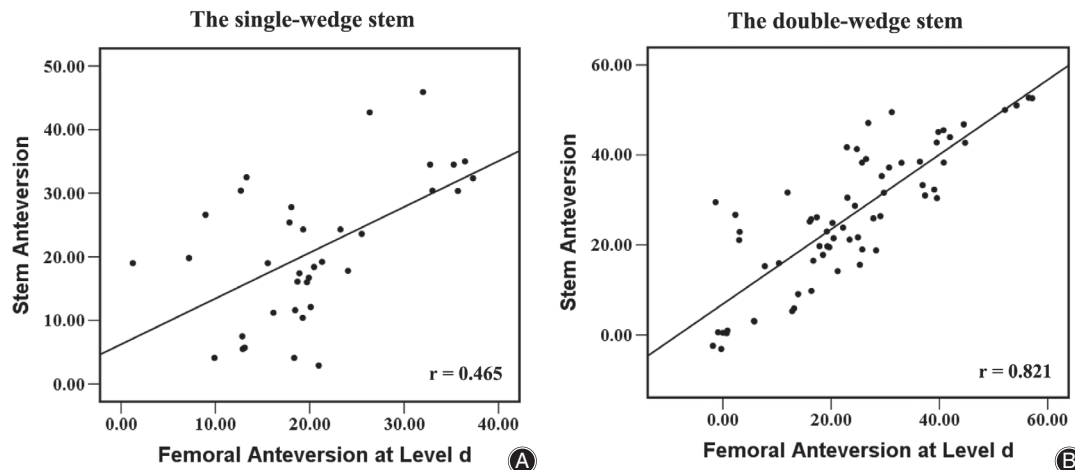


Fig. 5 Correlations of femoral anteversion measured at level d with stem anteversion for single-wedge stems (A) and double-wedge stems (B).

### Limitations of the Study

One limitation to this study is that the femoral neck osteotomy plane for each three-dimensional model was simulated at the level measured via postoperative two-dimensional CT and at 45° angle from the femoral anatomical axis used intraoperatively. There may be some difference in the actual situation. The point-to-point match technique of preoperative and postoperative models<sup>30</sup> may provide more accuracy, but it is more complicated. However, to our knowledge, this is the first study on the prediction of postoperative stem anteversion in Crowe type I DDH patients.

### Conclusion

This study demonstrated that femoral anteversion is different if it is measured via different levels of the femoral neck in Crowe type I DDH patients. The 10-mm level above the proximal base of the lesser trochanter displayed the smallest difference with postoperative stem anteversion, with

moderate correlations with single-wedge stems, and excellent correlations with double-wedge stems, which would be an optimum choice for measuring femoral anteversion to predict postoperative stem anteversion in Crowe type I hips.

### Authorship declaration

Zhenan Zhu, Mengning Yan, and Yuanqing Mao contributed to the study design; Degang Yu and Zanjing Zhai performed the data collection and drafted the manuscript, Jingwei Zhang and Huiwu Li contributed to the statistical data analyses. All authors contributed to interpretation of results, and critical revisions of the manuscript; and they all agreed on its final appearance.

### Conflict of interest

There are no conflicts of interest to declare.

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