




## CLINICAL ARTICLE

# Comparison of Preoperative Computed Tomography and Intraoperative Estimation in Predicting the Version of a Single-Wedge Femoral Stem

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**Objective:** Early prediction of stem version aids in optimization of combined version during total hip arthroplasty (THA). This study aimed to analyze the discrepancy between stem version and native femoral version measured by different methods, and to explore which method can better predict the stem version.

**Methods:** We retrospectively reviewed 26 patients (39 hips) treated with robot-assisted THA in our hospital between September 2019 and December 2019. A straight, single-wedge, cementless stem (Accolade II) was used in all cases. Preoperative femoral version was measured at three levels on computerized tomography (CT) scan from the top to the middle level of femoral neck (Level 1 to Level 3). During THA, the version on cutting surface was measured prior to femoral broaching based on two reference lines: mid-cortical line and T line (trochanteric fossa to the middle of medial cortex). After femoral broaching, stem version was measured based on the femoral neck trial using Mako system (Stryker). In the statistical analysis, the difference and absolute discrepancy between stem version and femoral version measured with various methods were examined using paired t-test, and the relationship between stem version and various femoral versions were examined using correlation analysis.

**Results:** Mean femoral neck version (Level 1) was  $9.5^\circ \pm 2.6^\circ$  (range,  $-16.8^\circ$ - $42.5^\circ$ ), while mean stem version measured by Mako system was  $19.9^\circ \pm 2.0^\circ$  (range,  $-8.0^\circ$ - $49.0^\circ$ ). Femoral version measured with each method showed a moderate correlation with stem version ( $p < 0.05$ ). There was a significant difference between stem version and femoral version except at Level 3, with a mean difference of  $0.8^\circ \pm 13.6^\circ$  ( $p = 0.729$ ). With regard to the intraoperative estimation, stem version significantly increased compared to the value based on mid-cortical line, with a mean difference of  $8.4^\circ \pm 13.1^\circ$  ( $p < 0.001$ ). However, the mean value of stem version was a little smaller than that of femoral version measured by reference to T line, but without statistical significance ( $p = 0.156$ ). No postoperative dislocations occurred during the study period. No revision was required for any component.

**Conclusions:** The middle level of femoral neck on CT scan and T line on cutting surface are better references to measure femoral version for predicting postoperative stem version. However, the relationship between stem version and predictive value was flexible. Therefore, further three-dimensional studies of postoperative CT are needed to validate the press-fit fixation and rotational freedom of the single-wedge stem.

**Key words:** diagnostic imaging; femur neck; hip; arthroplasty; tomography

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Guoqiang Zhang will handle correspondence at all stages of refereeing and publication, also post-publication.

Received 26 August 2021; accepted 31 August 2022

## Introduction

Total hip arthroplasty (THA) is generally considered one of the most successful operations in relieving pain and restoring function. However, malpositioning of the components is associated with an increased risk of complications, such as impingement, dislocation, wear, and resultant early revision.<sup>1,2</sup>

In recent years, more attention has been paid to the positioning of femoral stem.<sup>3-5</sup> The stem position can be viewed in three different aspects, including stem version, varus/valgus alignment in the coronal plane, and tilt in the sagittal plane. Among them, stem version is particularly important, which forms part of the acknowledged combined version during THA.<sup>3</sup> When stem is placed in excessive version, adjustments will be required on acetabular side, leading to partial uncoverage of the cup.<sup>6</sup> On the contrary, adjustment of stem version creates concurrent changes in femoral offset, which potentially affects the function of abductor.<sup>7</sup> Thus early prediction of stem version aids in optimization of combined version and preparation of modular components.

Unlike cemented and conical femoral stem, a wedged cementless stem mainly follows the torsional direction of femoral canal and has little version adjustability. Effected by the natural torsion of proximal femur, different studies have reported wide variability of stem version ranging from 19° retroversion to 60° anteversion, deviating from the recommend value of 15°–20°.<sup>8,9</sup> Several methods have been developed to predict the postoperative stem version. Some special parameters were established based on plain radiograph to avoid unnecessary radiation exposure associated with CT. But they only worked indirectly to warn of excessive stem version with moderate correlation.<sup>10</sup> By contrast, measuring femoral version on two-dimensional CT slices remained the most commonly used, and the classical method benefitted from its convenience, accuracy, and repeatability.<sup>11</sup> However, controversial results were shown in different studies evaluating the discrepancy of native femoral version and postoperative stem version.<sup>12,13</sup> Apart from the variability of stem design, operative approach, and stem alignment in the coronal and sagittal plane, it can be also attributed to the inconsistency of reference level used for measurement.<sup>12,14,15</sup>

More researchers have found that the native version of femoral neck did not correlate well with stem version and should not be used as reference and target plan.<sup>16-18</sup> Moreover, from femoral neck to the distal isthmus, the version of the major axis on femoral canal slices tended to gradually increase.<sup>12,17</sup> Several studies have been performed to explore the optimal level on CT scan to predict the stem version. Although slight difference existed in the division of measurement levels, more evidence supported using the middle to inferior part of femoral neck for prediction.<sup>11,19,20</sup> Besides, intraoperative estimation of femoral version by manual goniometer or computer navigation was also useful to predict the stem version.<sup>3,21</sup> Several landmarks have been introduced, including the lesser trochanteric axis, the posterior lesser trochanter line, and reference axis on cutting surface.<sup>22-24</sup>

However, even though good correlation and small average difference have been reported with the use of CT scan or intraoperative measurement, the absolute discrepancy between predictive value and stem version was less concerning, which could mask the actual precision of each method. The purpose of the present study was: (i) to explore better preoperative radiographic method and intraoperative landmark to predict stem version; (ii) to determine the absolute discrepancy between stem version and femoral version measurements.

## Patients and Methods

### Inclusion and Exclusion Criteria

Inclusion criteria: (i) patients treated with robot-assisted THA; (ii) use of a uniform femoral stem; (iii) intraoperative use of a manual goniometer to measure the version on cutting surface; (iv) registration on femoral side to measure the version of stem trial by robot; (v) patients with preoperative CT scan from pelvis to knee. The exclusion criteria included: (i) patients with severe angulation deformity of the proximal femur or with Crowe type IV developmental dysplasia of the hip (DDH) or with active infection of the hip; (ii) patients with incomplete data or version record; (iii) patients with severe flexion contracture of the hips or knees.

### Patients

In this study, we retrospectively reviewed the patients treated with robot-assisted THA in our hospital between September 2019 and December 2019. Demographic and clinical data were collected retrospectively from electronic medical database. The version measured by using goniometer and robot was prospectively recorded. The study was approved by the Institutional Review Board of our hospital (S2017-099-01) and all patients were provided informed consent. Finally, 26 patients (39 hips) were enrolled in this study, including 13 unilateral cases and 13 bilateral cases. There were 14 men and 12 women, with a mean age of  $53 \pm 11$  years (range, 22–82 years) and mean body mass index of  $23.83 \pm 2.88$  kg/m<sup>2</sup> (range,  $17.93 \pm 34.25$  kg/m<sup>2</sup>). Within this cohort, five hips were primary osteoarthritis, nine hips were osteoarthritis secondary to DDH, 20 hips were osteonecrosis of femoral head, one hip was epiphyseal dysplasia of the hip, and four hips were ankylosing spondylitis. According to Crowe classification for DDH, five hips were type I, two hips were type II, and two hips were type III.

The Mako semi-active robotic system (Stryker, Mahwah, USA) was used to perform robot-assisted THA. A straight, single-wedge, cementless stem (Accolade II, Stryker, Mahwah, USA) was used in all cases.

### Surgical Procedure

#### Preoperative Preparation

Preoperative CT scans of the patients' pelvis, proximal femur, and knee were performed to obtain 3D bone models.

Special landmarks were then defined on the models for intraoperative registration.

### Surgical Details

In all cases, operation was performed with the patients in lateral decubitus position through the posterolateral approach. All surgeries were conducted by two senior arthroplasty surgeons who were well trained with the use of Mako system. Before preparing and draping the surgical field, an electrode was attached to the inferior pole of the patella for intraoperative assessment. During operation, the pelvic array was fixed by inserting three pins in the iliac crest. The femoral workflow was conducted with the “express” or “enhanced” technique.<sup>25</sup> During operation, surgeons tried to obtain adequate press-fit fixation, while aiming to obtain a combined version of 30°–50°, compatibly with optimal coverage of acetabular cup. The acetabular registration, acetabular reaming, and final implant placement were performed as per the standard technique.<sup>26</sup>

### Intraoperative Measurements of Femoral Version

Prior to femoral broaching, we measured the version on cutting surface with a manual goniometer. With the lower leg approximating posterior condylar line, we performed the measurement based on two reference lines. One was the long axis of cutting surface (mid-cortical line).<sup>27</sup> The other was the line connecting the trochanteric fossa and the middle of medial cortex on cutting surface (T line).<sup>28</sup>

### Measurement of Stem Version with MAKO

After femoral broaching, stem version was measured based on three checkpoints on the femoral neck trial (Figure 1).

### Postoperative Rehabilitation

After implantation of the prostheses, hip stability was tested through the full range of motion. On the first day after operation, patients were allowed to walk with crutches and partial weight-bearing. All patients received postoperative

intravenous antibiotic prophylaxis with third-generation cephalosporins. Low molecular weight heparin was also administered as antithrombotic prophylaxis.

### Radiographic Measurement

#### Preoperative Femoral Version Measurement with CT

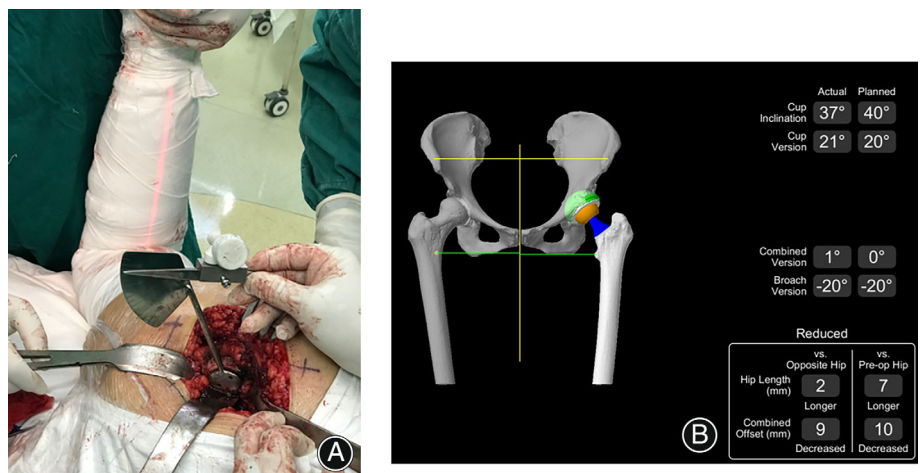
Preoperative images were performed using a 256-slice CT scanner (Brilliance iCT; Philips Healthcare, Cleveland, OH, USA) with patients' hip and knee fully extended and parallel to the examination table. The radiographic measurement was performed using an image processing and analysis system in our hospital. Preoperative femoral version was measured at three levels on scout film based on the study by Sugano *et al.*<sup>11,29</sup> Level 1 is the initial slice where the neck saddle merges with the great trochanter. Level 2 is the most proximal portion of the inferior neck that has no head portion. Level 3 is the middle level between Level 2 and a slice just above the lesser trochanter.

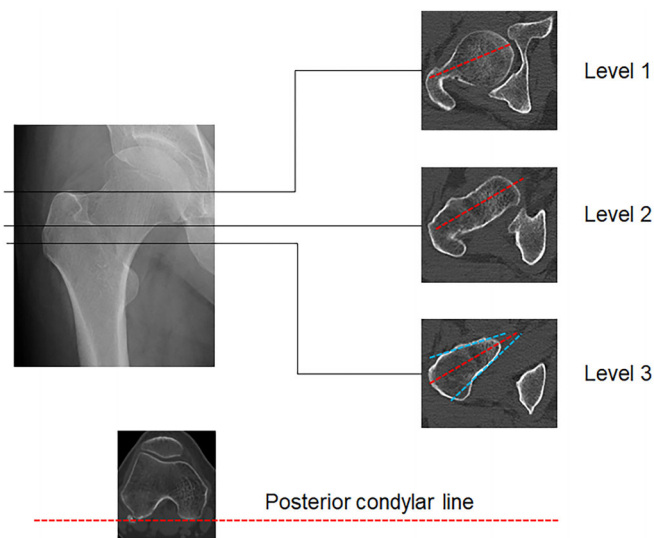
Version of Level 1 was defined as the angle between the line connecting the center of femoral head and the midpoint of the neck and the posterior condylar line. Version of Level 2 and Level 3 was defined as the angle between the line bisecting the anterior and posterior cortex of femoral neck and the posterior condylar line (Figure 2). For both the preoperative and intraoperative measurements, when the femoral or stem version indicated a superior position in reference to the posterior condylar line, it was defined as positive version.

#### Intra-Class Correlation Coefficients

All CT measurements were independently performed twice by two of the observers who had more than 5 years of experience in assessing CT scans. The interval between measurements was at least 1 month. They did not participate in the operations and were blinded to the clinical results at the time of assessment. The intra-observer reliabilities were evaluated using intra-class correlation coefficients (ICCs) and both

**Fig. 1** (A) Before femoral broaching, we measured the version by cutting surface with a manual goniometer. With the lower leg approximating posterior condylar line, we performed the measurement based on mid-cortical line and T line. (B) After femoral broaching, stem version was measured based on Mako robot system





**Fig. 2** Methods of preoperative femoral version measurement with CT. Level 1 is an initial slice where the neck saddle merges with the great trochanter. Level 2 is the most proximal portion of the inferior neck that has no head portion. Level 3 is the middle level between Level 2 and a slice just above the lesser trochanter. Version of Level 1 was defined as the angle between the line connecting the center of femoral head and the midpoint of the neck and the posterior condylar line. Version of Level 2 and Level 3 was defined as the angle between the line bisecting the anterior and posterior cortex of femoral neck and the posterior condylar line

were more than 0.9. The inter-observer variance also had an ICC more than 0.8. It indicated almost perfect agreement with all the CT measurements.

### Statistical Analysis

Descriptive data were presented using mean  $\pm$  standard deviation with ranges. Paired t-test was used to determine the difference and absolute discrepancy between stem version and femoral version measured with various methods. The relationship between stem version and various femoral versions were examined using correlation analysis. All statistical analyses were performed using SPSS version 26.0 (IBM Inc., Armonk, New York).  $p$  values  $<0.05$  were considered statistically significant.

## Results

### The Relationship between Preoperative CT Measurements and Stem Version

Mean femoral neck version (Level 1) was  $9.5^\circ \pm 2.6^\circ$  (range,  $-16.8$ – $42.5^\circ$ ), while mean stem version measured by Mako system was  $19.9^\circ \pm 2.0^\circ$  (range,  $-8.0$ – $49.0^\circ$ ) (Figure 3). Femoral version measured with CT showed a moderate correlation with stem version ( $p < 0.05$ ). From Level 1 to Level 3 of CT scans, the femoral version gradually increased,

indicating a tendency of anterior torsion of the proximal canal from superior to inferior portion. Besides, there was a significant difference between stem version and femoral version except at Level 3, with a mean difference of  $0.8^\circ \pm 13.6^\circ$  ( $t = 0.349$ ,  $p = 0.729$ ) (Table 1).

### Relationship between Intraoperative Measurement and Stem Version

With regard to the measurement by manual goniometer, femoral version also showed a moderate correlation with stem version ( $p < 0.05$ ). Stem version significantly increased compared to the value based on mid-cortical line, with a mean difference of  $8.4^\circ \pm 13.1^\circ$  ( $t = 3.986$ ,  $p < 0.001$ ). However, the mean value of stem version was a little smaller than that of femoral version measured by reference to T line, but without statistical significance ( $t = -1.447$ ,  $p = 0.156$ ) (Table 1).

### Absolute Discrepancy between Stem Version and Femoral Version Measurements

The absolute value and distribution of discrepancy between stem version and femoral version measured with different methods was shown in Table 2. There was no significant difference of absolute discrepancy among them.

### Distribution of Stem Version Relative to Femoral Version Measurements

At both Level 1 and Level 2 of CT scan, stem version increased in 25 hips (64.1%) by  $5^\circ$  or more. But at Level 3, no similar trend was observed. And the percentage of increased and decreased stem version was the same.

Considering the reference line on cutting surface, stem version increased in 23 hips (59.0%) by  $5^\circ$  or more compared to the value based on mid-cortical line and decreased in 20 hips (51.3%) by  $5^\circ$  or more compared to the value based on T line (Table 2).

### Complications

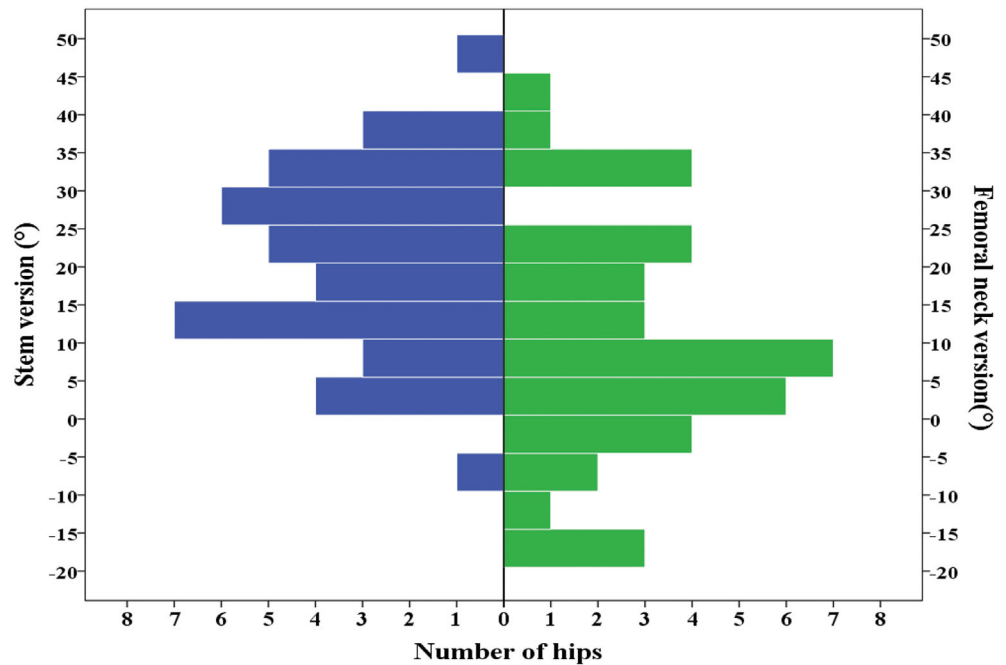
Patients were followed for a minimum of 1 year. No postoperative dislocations and other complications occurred during the study period. No revision was required for any component.

### Discussion

Based on our results, we found there were no significant differences between stem version and femoral version at the middle level of femoral neck on CT scan or T line on cutting surface. So, they are potentially better references to measure femoral version for predicting postoperative stem version.

### The Importance of Predicting Stem Version

Appropriate implant positioning in cementless THA is important in obtaining stable and long-term clinical results. Conversely, implant malpositioning can cause postoperative prosthetic impingement or dislocation, decreased range of



**Fig. 3** Distribution of femoral neck version (Level 1) and stem version in this cohort

**TABLE 1** Femoral version measured by each method and correlations with stem version

		Femoral version (mean $\pm$ SD, ranges)	Stem version (mean $\pm$ SD, ranges)	Difference (stem version minus femoral version) (mean $\pm$ SD, ranges)	r (p value)
CT scan-based measurement	Level 1	9.5° $\pm$ 2.6° (-16.8°-42.5°)	19.9° $\pm$ 2.0° (-8.0-49.0°)	10.4° $\pm$ 12.9° (-18.4°-35.8°) <sup>a</sup>	0.601 (<0.001)
	Level 2	10.3° $\pm$ 2.7° (-19.7°-45.3°)		9.6° $\pm$ 14.3° (-22.3°-36.5°) <sup>a</sup>	0.547 (<0.001)
	Level 3	19.1° $\pm$ 2.5° (-4.8°-53.5°)		0.8° $\pm$ 13.6° (-32.8°-25.8°)	0.547 (<0.001)
Manual goniometer- based measurement	Mid- cortical line	11.5° $\pm$ 2.0° (-9.0°-40.0°)		8.4° $\pm$ 13.1° (-21.0°-34.0°) <sup>a</sup>	0.437 (0.005)
	T line	23.1° $\pm$ 2.2° (-6.0°-55.0°)		-3.2° $\pm$ 13.9° (-27.0°-26.0°)	0.424 (0.007)

Abbreviations: CT, computed tomography; r, correlation coefficient; SD, standard deviation.; <sup>a</sup> Difference between stem version and femoral version was statistically significant ( $p < 0.05$ ).

motion, accelerated wear, and even implant failure.<sup>1,2</sup> In contrast to the orientation of acetabular cup, postoperative stem version showed high variability in the literature, and was not always equivalent to femoral neck version.<sup>17,18</sup> Therefore, we examined the discrepancy between stem version and native femoral version measured by different methods, and explored the level or reference line where the native femoral version most closely fit the stem version.

#### ***Femoral Neck Version Should Not Be Used as an Index for Stem Version***

Traditionally the recommendation for femoral stem positioning is to restore native offset and version. However, it can

result in great variability of final stem version due to the wide range in natural version of femoral neck, especially among patients with severe hip deformity. In this study, although moderate correlation was found between femoral neck version (Level 1) and stem version, there was a significant difference of 10.4°  $\pm$  12.9°. Early studies have been conducted on differences between the femoral neck and stem version. Hirata *et al.*<sup>17</sup> reported a difference of 9.8°  $\pm$  8.8° with a final stem version ranging from 14° to 63.2°, and Emerson *et al.*<sup>18</sup> found a similar difference of 8.1°  $\pm$  7.4° with a final stem version ranging from -11° to 22°. In recent years, more studies have suggested that femoral neck version should not be used as an index when inserting the femoral

**TABLE 2 Absolute value and distribution of discrepancy between stem version and femoral version measured with different methods**

Method	Absolute discrepancy (mean $\pm$ SD, range)	Stem version minus femoral version <sup>a</sup>		
		<−5°	≥−5° and <5°	>5°
Level 1	13.2° $\pm$ 9.9° (1.0°–35.8°)	5 (12.8)	9 (23.1)	25 (64.1)
Level 2	13.8° $\pm$ 10.2° (0.11°–36.47°)	6 (15.4)	8 (20.5)	25 (64.1)
Level 3	11.2° $\pm$ 7.5° (0.22°–32.8°)	14 (35.9)	11 (28.2)	14 (35.9)
Mid-cortical line	12.3° $\pm$ 9.3° (0°–34.0°)	6 (15.4)	10 (25.6)	23 (59.0)
T line	12.3° $\pm$ 7.5° (1.0°–27.0°)	20 (51.3)	8 (20.5)	11 (28.2)

<sup>a</sup>Data were given as the number of hips with the percentage in parentheses. SD, standard deviation.

stem.<sup>16</sup> Because the “best-fit” position of femoral stem is only partially dictated by the native version of femoral neck, which is also a compromise of fitting the stem with the torsion, twist, and isthmus of femoral canal. Besides, previous studies showed that the femoral version increases as the measurement site moves from proximal metaphyseal level towards the distal isthmus.<sup>12,17</sup> The same tendency was also observed in our results.

#### **Explorations for Better Preoperative Radiographic Method to Predict Stem Version**

Many studies have been conducted to explore the optimal level which can predict the postoperative stem version. Park *et al.*<sup>11</sup> reported that femoral version measured *via* the middle level of the femoral neck (Level 3) could better predict postoperative stem version with a mean difference of 2.3°  $\pm$  5.9°. Similar to the result of Park *et al.*,<sup>11</sup> our data also supported the predictive value of Level 3. Hirata *et al.*<sup>17</sup> and Taniguchi *et al.*<sup>12</sup> performed studies to determine the level at which femoral version most closely approximated stem version, with the same division of measurement sites. In the study by Hirata *et al.*,<sup>17</sup> the discrepancy of version between native femur and a metaphyseal fit stem was found minimum (−0.1°  $\pm$  8.4°) at the level of center of lesser trochanter (CLT). In the study by Taniguchi *et al.*,<sup>12</sup> two designs of femoral component were used, including the metaphyseal fit and single-wedge stem. Interestingly, only in the single-wedge stem groups and at the level of CLT, the discrepancy was found not statistically different (mean difference of −1.6°). Both of their results indicated that CLT was the optimal level of predicting the postoperative stem version. Moreover, Huang *et al.* found that the version of calcar femorale or canal version at the inferior femoral neck, and canal version at CLT level all exhibited a strong positive correlation with stem version in patients with DDH.<sup>30</sup> However, CLT is a bony structure deviating from the main femoral canal, which cannot reflect the true axis of femoral canal. Besides, Tetsunaga *et al.* demonstrated that the morphology of calcar femorale differed according to the severity of hip deformity, which made it less reliable to predict the stem version. And sometimes clearing the calcar femorale would be necessary to adjust the version of a non-modular stem.<sup>31</sup>

Recently, Yu *et al.* also found femoral version at the middle level of the femoral neck (10 mm above the lesser trochanter base) showed no significant difference with stem version both for single-wedge and metaphyseal fit stem.<sup>19</sup> And their results discouraged the use of CLT as a reference for inserting femoral stem (mean difference  $\geq$  35°). Based on the principle of 3-point fixation, Yu *et al.*<sup>19</sup> first assessed the relationship between stem version and the various combinations of average value between anterior and posterior cortex at different levels. They found that the version of anterior cortex at the lesser trochanter and that of posterior cortex at the femoral neck may help predict postoperative stem version.

#### **Explorations for Better Intraoperative Landmark to Predict Stem Version**

Apart from measurement on preoperative CT scan, we also explored the predictive value of two different reference lines on cutting surface. Both mid-cortical line and T line were the anatomical reference guides for stem version during THA, proposed by Suh *et al.*<sup>27</sup> and Tsukeoka *et al.*,<sup>28</sup> respectively. However, originally, the mid-cortical was used for targeting the femoral neck version on the contralateral side, and T line for the native femoral neck version. In this study, we found femoral version measured based on T line was closer to stem version. The distribution of discrepancy in Table 2 showed that the stem version of quite a large proportion of hips was probably greater than the value based on mid-cortical line, and smaller than that based on T line. Furthermore, we thought the reference line on cutting surface could guide the version of stem insertion more directly compared with preoperative measurement on CT scans. It is worth noting that we are not bound to place the stem parallel to the reference line, but we can adjust stem version according to the reference line to obtain a more physiological position. Some study supported using CLT as an anatomical reference guide for stem anteversion.<sup>22</sup> However, during operation, CLT is tridimensional, not an apparent point to recognize, leading to more measurement bias compared with the mid-cortical line and T line.

### **Absolute Discrepancy between Stem Version and Femoral Version Measurements**

What cannot be ignored was that less attention was paid to the absolute value of discrepancy between predictive value and stem version.<sup>9,21</sup> Although there was no difference between the mean value of stem version and femoral version measured at Level 3 or based on T line in this study, they also showed a mean absolute discrepancy of  $11.2^\circ \pm 7.5^\circ$  and  $12.3^\circ \pm 7.5^\circ$ , respectively. And there was no significant difference of absolute discrepancy among the five methods.

### **Other Influencing Factors of Stem Version**

Besides, a greater standard deviation of difference between femoral version and stem version could be observed both in this study and previous studies, which implied that stem version could be influenced by multiple factors.<sup>11,12,17,19,32</sup> Many factors have been demonstrated to influence postoperative stem version, including stem design, operative approach, osteotomy height, and stem alignment in the coronal and sagittal plane. Actually, the spatial position of femoral stem is the combined effect of stem shape, femoral canal anatomy, and surgical maneuvers, which partially explains the variability of stem version.<sup>3,12,14,33</sup>

### **Limitations and Strengths**

This study had several limitations. First, only one design of femoral stem was analyzed in this study. Although single-wedge stem is similar to other designs currently available, our findings may not be applied to other stem designs. Second, restricted by sample size, no subgroup analysis was made to different diagnoses. Third, we used the stem trial version of the final broach as the stem version, which may create systemic error. However, a high correlation ( $r = 0.89$ ) was found between the version of the final broach and the definitive stem version, with mean difference of  $1.9^\circ \pm 3.5^\circ$ .<sup>16</sup> Fourth, some well-known factors including stem alignment and osteotomy height were not taken into account in this study.

Despite these limitations, in this study we first compared the method of preoperative radiographic measurement and intraoperative goniometer in predicting femoral stem version. Besides, we paid attention to the absolute

discrepancy between predictive value and stem version, not the widely used average discrepancy which is possibly offset by positive and negative values.

### **Conclusion**

In conclusion, single-wedge stem has a wide variation of postoperative version. The middle level of femoral neck on CT scan and T line on cutting surface are better references to measure femoral version for predicting postoperative stem version. However, the relationship between stem version and predictive value was flexible according to the absolute value of their discrepancy. Therefore, further three-dimensional studies of postoperative CT are needed to validate the press-fit fixation and rotational freedom of the single-wedge stem.

### **Disclosure**

None of the authors associated with this paper has disclosed any potential or pertinent conflicts which may be perceived to have impending conflict with this work.

### **Acknowledgements**

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

### **Author Contribution**

JYS: collected and analyzed data and co-wrote the paper. JYCZ: analyzed data with JMS and co-wrote the paper. JMS and QYZ: assessed the radiographs and collected data. TJL and BHZ: measured the radiographs and collected data. TJL: supervised the radiographic assessment and analyzed the data. YGZ: designed the study, performed the surgery, and revised the paper. GQZ: designed the overall study and revised the paper. All the authors have approved the final version of manuscript.

### **Authorship Declaration**

All authors listed meet the authorship criteria according to the latest guidelines of the International Committee of Medical Journal Editors and all authors are in agreement with the manuscript.

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