



The Relationship between Femoral Stem Tilt and Stem Length in Total Hip Arthroplasty: A Retrospective Case-Control Study

Jae Youn Yoon, MD, Won Young Seo, MD*, Hee Joong Kim, MD*, Jeong Joon Yoo, MD*

Department of Orthopedics, Dongguk University Ilsan Hospital, Goyang,

*Department of Orthopedic Surgery, Seoul National University College of Medicine, Seoul, Korea

Background: The current trend of using short femoral stems in total hip arthroplasty (THA) is associated with angular deviation of the femoral stem towards the native femoral axis. The purpose of this study was to compare the difference in stem tilt angle between two different stems with a similar design except for the stem length.

Methods: This is a retrospective review of 66 patients who underwent primary THA between April 2012 and May 2016, using a trans-gluteal direct lateral approach by a single surgeon. We evaluated the femoral stem tilt angle in both the coronal and sagittal planes and performed multivariate logistic regression analysis to evaluate possible risk factors. We also simulated the range of motion (ROM) of the hip joint using three-dimensional computer-aided design software (SolidWorks, 2016) to examine the clinical significance of femoral stem tilt.

Results: The mean coronal tilt angle was $1.8^\circ \pm 1.0^\circ$ in the conventional stem group and $1.6^\circ \pm 1.1^\circ$ in the short stem group, showing no statistically significant difference between the groups ($p = 0.570$). However, the mean sagittal tilt angle was $4.0^\circ \pm 2.0^\circ$ in the conventional stem group and $7.8^\circ \pm 2.0^\circ$ in the short stem group ($p < 0.001$). The stem type and stem length had a linear correlation with the sagittal tilt angle ($p < 0.001$) in multivariate regression analysis. A simulated hip ROM demonstrated a 3.8° decrease in extension in proportion to a 3.8° increase in the mean sagittal stem tilt angle of the short femoral stem.

Conclusions: Anterior femoral stem tilting in the sagittal plane was prominent when the shorter stem was used, and anterior tilting was responsible for decreased ROM in hip extension.

Keywords: Hip joint, Total hip arthroplasty, Prosthesis design, Sagittal stem alignment, Combined anteversion

Total hip arthroplasty (THA) is commonly performed worldwide because of its excellent mid- to long-term outcome, and cementless design of the femoral stem has become a fixation of choice.¹⁾ A contemporary short-stem design for the femoral component has been introduced to preserve proximal bone stock, reduce the incidence of

thigh pain, decrease stress shield, and allow more physiologic proximal bone loading.²⁻⁶⁾ Insertion of a shorter stem also enables the operator to preserve more bone and soft tissue, facilitating lesser surgical trauma and theoretically producing a more favourable environment for future revision.⁷⁾

However, malposition of the implant can cause impingement, more frequent dislocation, excessive wear, and aseptic loosening.⁸⁻¹⁰⁾ Several studies have been conducted on the clinical outcomes of stem malalignment in the coronal plane (varus/valgus).^{11,12)} Stem tilting, however, can occur in the sagittal plane (anterior/posterior), but related data are lacking.¹³⁾

This study aimed to (1) compare the difference in

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Correspondence to: Jeong Joon Yoo, MD

Department of Orthopedic Surgery, Seoul National University College of Medicine, 101 Daehak-ro, Jongno-Gu, Seoul 03080, Korea

Tel: +82-2-2072-1994, Fax: +82-2-764-2718

E-mail: jjyos@snu.ac.kr

coronal and sagittal femoral stem tilt between two groups who underwent THA using different types of femoral stems, which have similar geographic features, except for the stem length, (2) analyse the association between the stem length and the stem tilt angle, and (3) investigate the effect of the femoral stem tilt on the range of motion (ROM) of a simulated hip joint.

METHODS

Study Population and Methods

The study was approved by the Institutional Review Board of Seoul National University Hospital (IRB No. H-1702-108-833), and all patients provided informed consent. Between April 2012 and May 2016, cementless THA was performed using a stem with a conventional length (Bencox ID stem; Corentec, Seoul, Korea) in 176 patients (199 hips) and using a different stem with a shorter length (Bencox M stem; Corentec) in 238 patients (275 hips). The inclusion criteria for the study were osteoarthritis, osteonecrosis of the femoral head, rheumatoid arthritis, posttraumatic osteoarthritis, and infectious sequelae of the hip joint. Patients who underwent bilateral THA or were treated for other medical causes, such as a pathologic fracture or rare genetic disease, and patients from whom we were unable to achieve true anteroposterior (AP) and lateral views from plain radiography were excluded from the study. Based on the inclusion criteria, 133 patients (152

hips) and 182 patients (214 hips) in both groups were initially selected from the cohort, then 19 patients (38 hips) and 22 patients (44 hips) who had undergone bilateral THA were excluded from the study. Among the selected 114 patients (114 hips) in the conventional stem group, 33 hips (33 patients) in which true radiographic projections for a stem were identified anteroposteriorly and laterally were selected. For the shorter stem group, 33 patients who were able to obtain true AP and lateral views were selected sequentially for direct comparison between the two groups. Retrospective clinical and radiological evaluation of the patients in both groups was then initiated; a case control study was conducted thereafter. Patients' basic demographic factors are presented in Table 1 and both groups showed no statistically significant differences, except for the follow-up period.

The conventional and short length stems are single-wedged prostheses with a double-tapered-press fit and classified as type 1 femoral stems.¹⁴⁾ The stems are made of titanium alloy and have titanium plasma-sprayed porous coating with a pore diameter of 50–200 μm at the proximal half of the implants. The AP diameter of the stem is narrower than the mediolateral diameter and has a flat body in the sagittal plane, which provides rotational stability at the metaphysis of the proximal femur.¹⁴⁾ Both stems have a same centrum-collum-diaphyseal angle of 132° and show similar geographical features except for the length. The M (shorter) stems are 2.2–4.0 cm shorter than the ID

Table 1. Demographic Details of the Two Groups

Demographic variable	Conventional (ID) stem (n = 33)	Short (M) stem (n = 33)	p-value
Age (yr)	51.2 \pm 16.7 (25–80)	55.7 \pm 11.8 (30–79)	0.208
Sex (male : female)	15 : 18	10 : 23	0.205
Height (m)	1.64 \pm 0.11 (1.42–1.85)	1.60 \pm 0.09 (1.42–1.80)	0.071
Weight (kg)	51.2 \pm 2.7 (43–81)	55.7 \pm 11.8 (40–98)	0.682
Body mass index (kg/m ²)	22.9 \pm 2.9 (16.4–30.9)	23.9 \pm 4.8 (15.6–39.3)	0.672
Diagnosis			0.395
ONFH	20 (60.61)	21 (63.64)	
Femoral neck fracture	5 (15.15)	2 (6.06)	
Degenerative arthritis	4 (12.12)	8 (24.24)	
Others (RA, septic sequelae, SSFx)	4 (12.12)	2 (6.06)	
Follow-up (mo)	27.5 \pm 8.9 (11–42)	12.4 \pm 5.9 (6–24)	0.208

Values are presented as mean \pm standard deviation (range) or number (%).

ONFH: osteonecrosis of femoral head, RA: rheumatoid arthritis, SSFx: subchondral stress fracture.

(conventional length) stems (Fig. 1).

All operations were performed by a single surgeon (JJY) at one institution using a transgluteal direct lateral approach. Extreme caution was taken to minimize the alignment discrepancy between the axis of the femoral shaft and the implant while cutting and breaking the femoral neck. Both the acetabular and femoral components were inserted in a press-fit manner. The stability of the hip was assessed by checking its passive ROM with the reduction of trial implants. Adequate size and alignment of the implants and leg length were also checked using intraoperative radiographic images. All patients received perioperative intravenous antibiotics and routine postoperative thromboembolic prophylaxis, including an intermittent sequential compression device. Patients were allowed to walk with partial weight-bearing using 2 crutches until 6 weeks postoperatively and were gradually guided to walk with full weight-bearing afterward. All patients were followed up in the clinic at regular intervals (6 weeks, 3

months, 6 months, and 12 months after surgery, and subsequently annually). Patients were assessed for thigh pain and hip pain, limping gait, and ROM, and radiographic inspection was performed to detect possible abnormalities.

Methods of Assessment

Radiographic assessment was performed using a standard radiographic protocol to obtain the true projection of the stem. The AP view of the hip joint was taken in the standing position with both lower extremities rotated 15° internally to compensate for the normal anteversion of the proximal femur. The distance between the tube and film was approximately 120 cm. In the translateral view, the patient was placed on the table in the supine position with the contralateral leg lifted and hip and knee joints flexed above 80°. Simultaneously, the ipsilateral limb was internally rotated by 15°. The beam was oriented at 45° angle to the affected limb.¹⁵⁾ Radiographic images, which were taken from the true projection of the stem, were evaluated to determine the coronal and sagittal stem tilt angles. Radiographic analysis was conducted by two experienced radiographical experts (JJY and JYY).

The femoral stem tilt angle refers to the angle formed by the intersecting lines between the femoral stem axis and the femoral anatomical axis in the coronal and sagittal planes (Fig. 2).¹¹⁾ A three-dimensional (3D) computer-aided design (CAD) software (SolidWorks; Dassault Systèmes Solid Works Corp., Waltham, MA, USA) was used to set up a reference value for implant position to create a virtual 3D hip model. The neutral position of the acetabular cup was set at 45° inclination and 15° anteversion, with an outer diameter of 56 mm. The femoral stem was set at 6° adduction and 10° antetorsion. The size of the reference head used in the simulation was 36 mm. Finally, we simulated the hip ROM by substituting the stem tilt

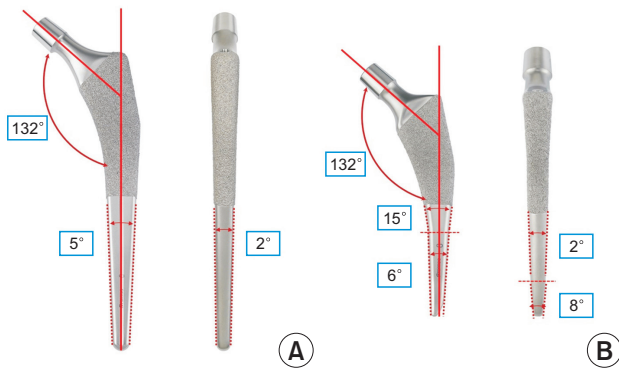


Fig. 1. Photographic images of a conventional stem and a short stem. Bencox ID stem (A) and Bencox M stem (B) show similar geographical features except for the length.

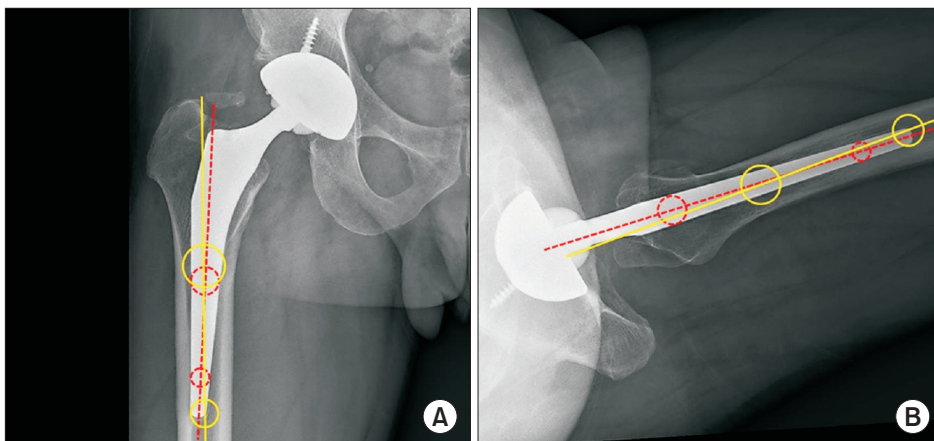


Fig. 2. Coronal and sagittal stem tilt angle in true anteroposterior (AP) and translateral radiographs. (A) Coronal stem tilt: angle between the femoral anatomical axis (FAA; yellow straight line) and the femoral stem axis (FSA; red dotted line) in the AP view. (B) Sagittal stem tilt: angle between FAA and FSA in the translateral view.

angle into the software.

Statistical Analysis

Baseline characteristics and radiological results were compared between the two groups using statistical analysis. Student *t*-test or the Wilcoxon rank-sum test was used for numerical data, and the chi-square test or Fisher's exact test for categorical data. Multiple regression analysis with a stepwise selection method was performed to control for multiple collinearities between independent variables, and all variables were considered for multivariate models. The entry condition was set at $p < 0.05$, and the removal condition was set at $p > 0.10$. All statistical analyses were performed using SAS ver. 9.3 (SAS Institute, Cary, NC, USA), and a probability level of 0.05 was used for all tests.

RESULTS

Radiographically, the coronal stem tilt angle was not significantly different between the two groups, but the sagittal tilt angle showed statistically significant difference ($p < 0.001$), with a mean angular difference of 3.8° (Table 2). The short stem tip was directed more posteriorly than that of the conventional stem on the postoperative lateral X-ray view (Fig. 3).

In univariate analysis, the stem type and the stem length (in absolute value) showed statistically significant correlation with the sagittal tilt angle (Table 3). In multivariate analysis, only the stem type and patient's age at the time of operation were identified as factors affecting the sagittal stem tilt (Table 4). When the age was revised, the M stem group had a 3.8° increment in the sagittal femoral stem tilt angle compared to the ID stem group ($p < 0.001$).

Subsequently, we substituted the value acquired from the multivariate regression analysis to simulate the change in ROM of the implanted hip joint using 3D CAD software. When the femoral sagittal tilt angle was increased by approximately 3.8° in the M stem group, the simulated hip joint revealed a 3.8° increase in hip flexion and a 3.8° decrease in hip extension (Fig. 4).

Table 2. Radiographically Assessed Coronal and Sagittal Stem Tilt Angles

Stem type	Conventional (ID) stem	Short (M) stem	<i>p</i> -value
Coronal tilt angle ($^\circ$)	1.8 ± 0.9 (0.1–3.6)	1.6 ± 1.1 (0.1–3.8)	0.570
Sagittal tilt angle ($^\circ$)	4.0 ± 2.0 (0.7–7.5)	7.8 ± 2.0 (2.9–11.0)	< 0.001

Values are presented as mean \pm standard deviation (range).

No hip pain or limping was reported during follow-up. One patient in each group complained of mild thigh pain but did not require medication or surgical correction. Radiographically, there were no complications, such as reactive radiographic lines and femoral and acetabular osteolysis. Eventually, there were no cases of revision in either group.

DISCUSSION

The current study showed that shorter femoral stems tilted more anteriorly in the sagittal plane compared to conventional stems. Several factors are known to affect the femoral stem tilt in the sagittal plane. Hayashi et al.⁴ reported that the accuracy of the anterior stem tilt was affected by the high body mass index (BMI) of patients in both the conventional stem group ($p = 0.033$) and the short-tapered stem group ($p = 0.047$). However, there was no significant difference in BMI between the two groups ($p = 0.672$) and no statistically significant relationship between BMI and sagittal stem tilt ($p = 0.731$) in our study.

Meanwhile, Vaughan et al.¹⁶ reported differences in femoral stem position depending on the surgical approach. In their study, the stem tip was directed more backward in the anterolateral approach than in the posterior approach ($p = 0.01$). The authors emphasized that the morphological characteristics of the proximal femur and the levering effect of the posteriorly located gluteal muscles may induce

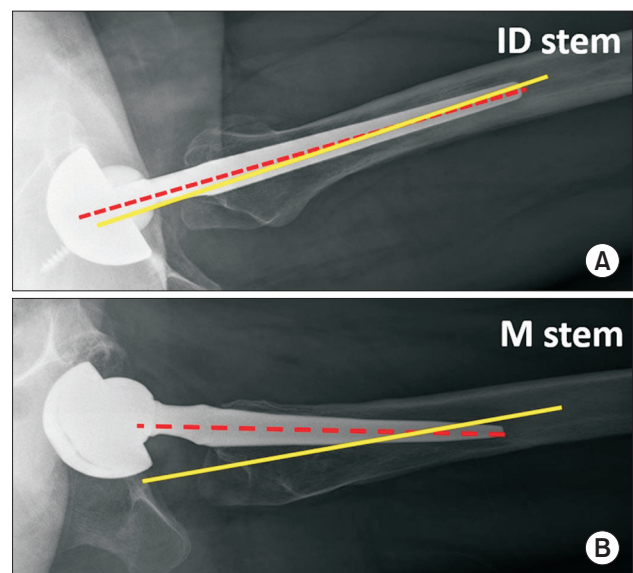


Fig. 3. Translatlateral radiographs of both stems. (A) Bencox ID stem. (B) Bencox M stem. Yellow straight lines refer to the femoral anatomical axis and red dotted lines refer to the femoral stem axis.

Table 3. Univariate Regression Analysis between Sagittal Stem Tilt and Other Variables

Variable	Parameter estimate	Standard error	p-value
Stem type			< 0.001
Conventional (ID) stem (reference)	-	-	
Short (M) stem	3.585	0.491	
Age (yr)	-0.020	0.023	0.381
Sex			0.734
Male (reference)	-	-	
Female	-0.234	0.685	
Height (m)	-0.517	3.338	0.877
Weight (kg)	0.004	0.029	0.899
Body mass index (kg/m ²)	0.029	0.085	0.731
Diagnosis (model)			0.246
ONFH (reference)			
Femoral neck Fracture	-1.807	1.085	0.101
Degenerative arthritis	-0.241	0.871	0.783
Others (RA, septic sequelae, SSFx)	-1.641	1.160	0.162
Stem length	-0.116	0.019	< 0.001

ONFH: osteonecrosis of femoral head, RA: rheumatoid arthritis, SSFx: subchondral stress fracture.

Table 4. Multivariate Regression Analysis with Stepwise Selection

Variable	Parameter estimate	Standard error	p-value
Stem type			< 0.001
Conventional (ID) stem (reference)			
Short (M) stem	3.769	0.479	
Age (yr)	-0.041	0.017	0.017

an anteriorly located entry point of the femoral stem and eventually cause anterior sagittal tilting of the stem in the anterolateral approach. In our study, however, both groups underwent surgery using the same surgical approach of the same surgeon. Therefore, sagittal stem tilt would be affected mainly by stem type or length.

Despite the small effect size, the patient's age was also found to be a co-factor related to anterior sagittal stem tilt in the multivariate analysis (Table 4). Thus, the result may be a combined effect of other clinical factors, not statistically accessed. First, the individual degree of femoral

bowing, especially the proximal femur, would also affect the outcome. As the patient ages, the femur bone tends to bend more anteriorly, and the proximal femur geometry changes. Since the anterior convexity of the femoral shaft changes to posterior near the lesser trochanter and since the femoral neck axis lies anterior to the femoral shaft due to its natural anteversion and anterior bowing, the insertion site of the femoral stem may be located more anteriorly. Besides the morphologic characteristics, concern for iatrogenic fracture is another issue. Many surgeons do not prefer giving excessive force to the posterolateral direction of the femur to insert the stem in a neutral position, especially in elderly patients with poor bone quality. Therefore, there is a possibility that the stem might be tilted anteriorly in sagittal plane.

The difference in 3D simulated ROM between the two groups in our study is attributable to the effect of functional anteversion. Muller et al.¹³⁾ have identified that femoral anteversion and sagittal stem tilt work interdependently under the concept of combined anteversion. When anterior sagittal stem tilts occur, as in our cases, the femoral head center moves forward and changes the positional relationship between the proximal femur and the stem,

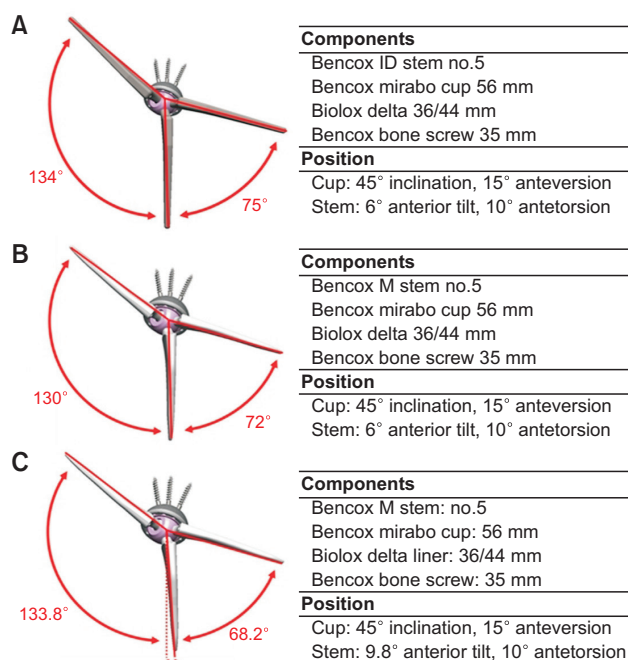


Fig. 4. Simulated range of motion (ROM) using three-dimensional software. (A) Simulated maximum flexion and extension range of ID stem. (B) Simulated maximum flexion and extension range of M stem. (C) Change in ROM of M stem following 3.8° increment in anterior sagittal stem tilt.

which leads to a functional increase in femoral anteversion.¹³⁾ Increased anteversion can increase the risk of early impingement between instruments and bones and limit maximum joint ROM.^{17,18)}

Interestingly, our simulated ROM changes have only appeared in hip flexion and extension and mainly were consistent with other studies.^{13,17,19)} However, our simulation is based on the fixed stem position (10° anteversion, 3.8° anterior sagittal tilt), and depending on alignment parameter settings, maximal impingement-free flexion/extension and even internal/external rotation capacity can differ in a wide range.

Our study has several limitations. First, the small sample size limits the detection of other clinical factors related to stem tilt. All 199 patients who underwent THA using the ID stem were initially examined to obtain true AP

and translateral radiographic images. Eventually, 33 patients were eligible for inclusion. The patients who underwent THA using the M stem were then similarly examined and measured until 33 patients were chosen. Therefore, results are affected by the patient recruitment method and number. However, statistically significant data regarding the sagittal femoral tilt angle were obtained, and by evaluating only the patients who underwent surgery performed by a single surgeon, confounding factors between the two groups were minimized. Other limitations were related to the inclusion criteria. We only evaluated patients from whom we could obtain true AP and lateral radiographic views of the hip. The real angular difference between the two groups may differ depending on the criteria or radiologic interpretation. Two radiographic experts, who were unaware of the patient's medical information, conducted the radiological assessment to overcome this limitation and interobserver discrepancies were resolved through discussion. Finally, radiologic evaluation using computed tomography may have been more accurate in assessing the true femoral stem tilt angle. However, we consider that additional radiologic hazards to patients and low cost-effectiveness would lessen efficacy.

In conclusion, our study showed that the use of a shorter femoral stem in THA was associated with an increase in anterior femoral tilt in the sagittal plane. In the recent trend of using shorter femoral stems in THA, our results call attention of hip surgeons since anterior stem tilt reduces hip extension, increasing the risk of posterior impingement and the chance of anterior dislocation.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

ORCID

Jae Youn Yoon <https://orcid.org/0000-0003-4449-7314>
 Won Young Seo <https://orcid.org/0000-0003-0266-5076>
 Hee Joong Kim <https://orcid.org/0000-0002-3994-5672>
 Jeong Joon Yoo <https://orcid.org/0000-0002-6304-0101>

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