Effect of a Modular Femoral Neck System on Femoral Anteversion and Range of Motion before Implant Impingement

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Abstract

We investigated the effect of a modular femoral neck system on 1) intraoperative femoral anteversion and on 2) range of motion (ROM) before prosthetic impingement in cementless total hip arthroplasty (THA) by using a 3-dimensional computer simulation. We measured intraoperative femoral anteversion and ROM (including internal rotation in 90° flexion, external rotation in 0° extension, flexion, and extension) by using computed tomography data of 53 patients who underwent cementless THA with a straight neck, 8° anteverted or retroverted neck, or 15° anteverted or retroverted neck. Then, we compared the actual values of version obtained with the 8° or 15° retroverted or anteverted necks from the straight neck. The actual value of femoral anteversion with the retroverted or anteverted necks was smaller (60–70%) than predicted value for those necks (e.g., when using an 8° anteverted neck, femoral anteversion increased by 5.7°). On the other hand, the change values of the above four ROMs with the modular necks were variable compared with the predicted values for those necks (e.g., when using an 8° anteverted neck, internal rotation increased by 11.9°, external rotation decreased by 14.6°, extension decreased by 6.8°, and flexion did not change). When selecting a modular neck, surgeons should be aware of this effect of retroverted or anteverted necks in terms of ROM, as well as the change value of femoral anteversion with one modular neck.

Keywords: Modular neck system; Total hip arthroplasty; Simulation of range of motion; Biomechanics

1. Introduction

In cementless total hip arthroplasty (THA), a modular neck system with femoral components can be useful to obtain ideal femoral anteversion and to adjust offset and leg length at the same time (Sariali et al., 2009; Sakai et al., 2010; Archibeck et al., 2011). Adjusting femoral anteversion is one
of the most important considerations in THA to reduce postoperative complications such as cup–neck impingement and hip dislocation (Sakai et al., 2000; Traina et al., 2009). In a modular neck system (interchangeable neck; Wright Medical Technology, Inc.), femoral anteversion is increased or decreased by 8° or 15° anterior or posterior leaning of the neck to the connecting plane between the femoral stem and neck (Sakai et al., 2000). In other words, the neck shifts the head anteriorly or posteriorly by 8° or 15° relative to the stem at the connecting plane (Figure 1).

![Fig. 1. Example Neck variation of the modular neck system in adjusting femoral anteversion](image)

(a) 15 degrees retroverted neck, (b) 8 degrees retroverted neck, (c) Straight neck, (d) 8 degrees anteverted neck, and (e) 15 degrees anteverted neck)

However, the effectiveness of a modular neck system in changing the original femoral anteversion has not been clarified on a coordinate system which is used to evaluate intraoperative femoral anteversion in THA. For example, when surgeons prefer a posterior approach, the coordinate system is acquired by flexing the knee and placing the tibia in a vertical position. Then, the intraoperative femoral anteversion is observed in relationship to the posterior axis of the thigh (Dorr et al., 2009). Actual values of version obtained with the 8° or 15° retroverted or anteverted necks from the straight neck are not same as those predicted values because the connecting plane and/or the longitudinal axis of the femoral bone is not parallel to the coordinate system. In addition, the influence of changed prosthetic anteversion on hip range of motion (ROM) before cup–neck impingement has not been clarified.

The purpose of this study was to investigate the effect of a modular femoral neck system with an anatomic stem (ANCA Fit; Wright Medical Technology, Inc.) and cementless cup (Lineage; Wright Medical Technology, Inc.) on intraoperative femoral anteversion and ROMs by using a 3-dimensional (3D) computer simulation.

## 2. Material and Methods

We retrospectively studied 53 patients who were scheduled for cementless THA and underwent preoperative computed tomography (CT) for 3D planning and simulation of ROMs. The population consisted of 8 men and 45 women with an average age of 63.8 years (range, 31–86 years) and a preoperative diagnosis of osteoarthritis (47 patients) or osteonecrosis of the femoral head (6 patients). We believed that a sample size of >50 hips was sufficient to address our research questions because previous studies (Bargar et al., 2010) using 3D models of total femurs had <50 cases.
To investigate the retroverting or anteverting effect of the modular neck, we compared the actual values of version obtained with the 8° or 15° retroverted or anteverted necks from the straight neck, with predicted values on the basis on an intraoperatively simulated coordinate system of Dorr et al (2009). We also compared the actual values of the following 4 ROMs (internal rotation in 90° flexion, external rotation in 0° extension, flexion, and extension) between the straight necks and each of the 4 modular necks with the predicted values of the modular necks. This study was approved by the Institutional Review Board.

We used preoperative CT (Aquillion One; Toshiba) data (1-mm slice thickness and increments) to create a 3D template of the anatomic stem on the femur in reconstructed multiplanar (coronal, sagittal, and axial) views by using preoperative planning software (Zed hip; LEXI Co., Ltd, Tokyo Japan)(Figure 2 and Table1).

Fig. 2. Multi-planar and three dimensional (3D) views of a 3D template of one anatomical stem.
Table 1  Femoral neck anteversion and range of motion before implant impingement with each modular short neck.

<table>
<thead>
<tr>
<th>Check Points</th>
<th>15 degrees (°) anteverted</th>
<th>8 ° anteverted</th>
<th>Straight</th>
<th>8 ° retroverted</th>
<th>15 ° retroverted</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Femoral neck anteversion</td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>(mean, (standard deviation, range))</td>
<td>38.6 (7.7, 24.2 to 62.9)</td>
<td>35.1 (7.7, 20.7 to 58.8)</td>
<td>29.5 (7.7, 15.1 to 53.7)</td>
<td>23.6 (7.7, 9.3 to 48.0)</td>
<td>20.1 (7.7, 5.7 to 44.3)</td>
</tr>
<tr>
<td>Change value from the value with straight neck</td>
<td>9.2 (0.6, 5.6 to 11.1)</td>
<td>5.7 (0.6, 2.1 to 7.7)</td>
<td>-</td>
<td>-5.8 (0.6, -9.3 to -3.8)</td>
<td>-9.4 (0.8, -13.0 to -5.7)</td>
</tr>
<tr>
<td>2. Range of motion before implant impingement</td>
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<tr>
<td>a) Internal rotation at 90° flexion (&lt;90°)</td>
<td>74.7 (10.7, 56 to 90)</td>
<td>66.3 (9.3, 49 to 90)</td>
<td>54.4 (8.6, 37 to 72)</td>
<td>37.7 (8.5, 23 to 57)</td>
<td>28.9 (8.3, 15 to 48)</td>
</tr>
<tr>
<td>Change value from the value with straight neck</td>
<td>20.3 (4.5, 17 to 44)</td>
<td>11.9 (1.4, 11 to 19)</td>
<td>-</td>
<td>-16.7 (1.3, -19 to -13)</td>
<td>-25.5 (1.4, -29 to -21)</td>
</tr>
<tr>
<td>a) External rotation at 0° extension (&lt;90°)</td>
<td>39.3 (8.6, 21 to 61)</td>
<td>49.1 (8.2, 31 to 64)</td>
<td>62.9 (8.1, 44 to 80)</td>
<td>75.9 (7.8, 56 to 90)</td>
<td>80.6 (7.2, 62 to 90)</td>
</tr>
<tr>
<td>Change value from the value with straight neck</td>
<td>-23.7 (2.2, -27 to -14)</td>
<td>-13.8 (1.3, -18 to -12)</td>
<td>-</td>
<td>12.9 (1.2, 10 to 15)</td>
<td>17.7 (2.1, 10 to 22)</td>
</tr>
<tr>
<td>c) Flexion (&lt;40°)</td>
<td>120 (0, all 120)</td>
<td>120 (0, all 120)</td>
<td>119.9 (0.3, 118 to 120)</td>
<td>117.7 (3.0, 110 to 120)</td>
<td>114.3 (5.2, 103 to 120)</td>
</tr>
<tr>
<td>Change value from the value with straight neck</td>
<td>no effect</td>
<td>no effect</td>
<td>-</td>
<td>no effect</td>
<td>-5.6 (5.1, -17 to 0)</td>
</tr>
<tr>
<td>d) Extension (&lt;40°)</td>
<td>26.2 (6.5, 14 to 38)</td>
<td>32.5 (6.0, 20 to 40)</td>
<td>39.3 (2.0, 30 to 40)</td>
<td>40 (0, all 40)</td>
<td>39.3 (2.0, 30 to 40)</td>
</tr>
<tr>
<td>Change value from the value with straight neck</td>
<td>-13.1 (5.8, -22 to -2)</td>
<td>-6.8 (5.2, -15 to 0)</td>
<td>-</td>
<td>no effect</td>
<td>no effect</td>
</tr>
</tbody>
</table>

*"no effect" means that mean change value is less than 5 °

Once the stem was templated to acquire the best “fit-and-fill” fixation, the software provided 3D surface-rendered models of the stem, prosthetic neck, prosthetic head, and developed femur from which the femoral head was resected above the cut line of the femoral neck. The center of the femoral head was set at the rotation center. Because we were able to rotate the 3D models in all directions, we established a coordinate system for evaluating intraoperative femoral anteversion with a posterior approach as follows: y-axis, line between the midpoint of both the posteromedial and posterolateral tips and the posterior tip of the greater trochanter; x-axis, line between the posteromedial and posterolateral condyle tips of the knee on a projected plane that was perpendicular to the y-axis; z-axis, line perpendicular to a plane with x- and y-axes and passing through the midpoint of both the posterior condyle tips (Kessler et al., 2008). The angle between
the x-axis and a line connecting the most proximal point of the stem shoulder and the center of the prosthetic femoral head was defined as intraoperative femoral anteversion (Dorr et al., 2009).

We measured the intraoperative femoral anteversion of the short straight necks. Neck length and diameter of the short straight necks were 28 and 10.6 mm, respectively. Then, we also measured the intraoperative femoral anteversion with the 8° or 15° retroverted or anteverted necks. Next, we also measured the intraoperative femoral anteversion of the long straight necks. Neck length and diameter of the long straight necks were 38.5 and 10.6 mm, respectively. Then, we also measured the intraoperative femoral anteversion with the 8° or 15° retroverted or anteverted necks.

We performed ROM simulation after virtual placement of the cup in the 3D preoperative planning software. This study was investigated to clarify the effect of the modular neck. Therefore, size of the cup, angle alignment of the cup and the size of the femoral head were fixed. A cup with a 52-mm diameter was used for all patients to avoid any effect of the cup diameter. Pelvic coordinate system was also fixed with the coordinate system of the femur. The cup was placed with an ideal orientation (40° inclination (Barrack 2003) and 20° anteversion (Widmer and Zurfluh 2004) based on the coordinate system of the femur. The diameter of the femoral head was fixed at 32 mm. Once the stem and cup were placed, ROM simulation could be performed with the rotation center. The coordinate system for measuring ROM was set as follows: y-axis, line between the rotation center (center of the prosthetic femoral head) and the midpoint of both the medial and lateral condyle tips of the distal femur (i.e., the mechanical axis of the femur); x-axis, a modified transepicondylar axis (clinical TEA (Berger et al., 2003)) determined by rotating the TEA around the above midpoint in the coronal plane through the y-axis and the TEA until it was perpendicular to the y-axis (Hananouchi et al 2008); z-axis, line perpendicular to a plane with x- and y-axes. The original point was the rotation center. The initial orientation of the femur was established as follows: the mechanical axis of the femur was parallel to the y-axis and the modified TEA was parallel to the coronal plane. The ROM simulation automatically detected whether prosthetic impingement between the cup and femoral neck occurred in any posture. Then, we measured the maximum angles of 4 ROMs with the short straight necks: internal rotation (upper limit, 90°) in 90° flexion, external rotation (upper limit, 90°) in 0° extension, pure flexion (upper limit, 120°), and pure extension (upper limit, 40°). We also measured the actual values of version obtained with the 8° or 15° retroverted or anteverted necks from the straight neck. If the mean change value in a category was less than 5°, the category was identified as “no effect.” We also investigated the above parameters with the long necks.

Regarding femoral anteversion and the ROMs before prosthetic impingement, we compared the actual values of version obtained with the 8° or 15° retroverted or anteverted necks from the straight neck. We conducted a paired t test using statistical software (StatView 5.0; SAS Institute Inc., Cary, NC).

3. Results

The actual values of femoral anteversion obtained with the retroverted or anteverted necks was lesser (60–70%) than the predicted values with these necks on the intraoperatively simulated coordinate system (Table 1).
On the other hand, the actual values of the four ROMs obtained with the 4 modular necks were variable compared with the predicted values for those necks (Table 1). For internal rotation in 90° flexion, the actual values obtained with the modular necks were greater than the default values for those necks. For example, mean internal rotation was 54.4° when using a short straight neck, whereas the angle was 37.7° with an 8° retroverted neck (−16.7°), 28.9° with a 15° retroverted neck (−25.5°), 66.3° with an 8° anteverted neck (+11.9°), and 74.7° with a 15° anteverted neck (+20.3°).

Results of external rotation in 0° extension were almost opposite of those of internal rotation in 90° flexion (Table 1). In simple flexion, the effects of the modular necks were not so significant. In simple extension, the effects with 8° and 15° retroverted necks were significant. While 8° and 15° anteverted necks decreased the femoral anteversion with those default values (Table 1). Results with the long necks were similar to those with the short necks (Table 2).

**Table 2** Femoral neck anteversion and range of motion before implant impingement with each modular long neck.

<table>
<thead>
<tr>
<th>Check Points</th>
<th>15 degrees (°) anteverted</th>
<th>8 ° anteverted</th>
<th>Straight</th>
<th>8° retroverted</th>
<th>15° retroverted</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Femoral neck anteversion</td>
<td>40.5 (7.8, 26.2 to 64.8)</td>
<td>36.1 (7.7, 21.7 to 60.3)</td>
<td>29.5 (7.7, 15.1 to 53.7)</td>
<td>22.7 (7.7, 8.3 to 47.0)</td>
<td>18.1 (7.8, 3.7 to 42.4)</td>
</tr>
<tr>
<td>Change value from the value with straight neck</td>
<td>11.1 (0.5, 8.6 to 12.0)</td>
<td>6.7 (0.2, 5.7 to 7.5)</td>
<td>-</td>
<td>-5.8 (0.6, -9.3 to -3.8)</td>
<td>-9.4 (0.8, -13.0 to -6.7)</td>
</tr>
</tbody>
</table>

2. Range of motion before implant impingement

| a) Internal rotation at 90° flexion (<90°) | 75.8 (11.0, 50 to 90) | 66.1 (9.3, 50 to 90) | 54.5 (8.6, 38 to 72) | 39.0 (8.4, 25 to 57) | 29.8 (8.7, 15 to 51) |
| Change value from the value with straight neck | 21.3 (3.4, 12 to 30) | 11.5 (1.5, 10 to 19) | - | -15.6 (1.0, -18 to -13) | -24.8 (1.7, -28 to -16) |

| b) External rotation at 0° extension (<90°) | 39.9 (8.3, 22 to 55) | 51.3 (8.2, 33 to 67) | 66.6 (8.1, 47 to 85) | 78.4 (7.8, 58 to 90) | 87.0 (4.1, 77 to 90) |
| Change value from the value with straight neck | -26.7 (2.5, -32 to -14) | -15.2 (1.2, -18 to -13) | - | 11.8 (2.6, 5 to 27) | 17.4 (3.3, 5 to 22) |

| c) Flexion (<40°) | 120 (0, all 120) | 120 (0, all 120) | 120 (0, all 120) | 118.4 (2.5, 111 to 120) | 114.7 (5.1, 104 to 120) |
| Change value from the value with straight neck | no effect | no effect | - | no effect | -5.3 (5.1, -16 to 0) |

| d) Extension (<40°) | 26.4 (6.5, 14 to 37) | 34.0 (5.6, 21 to 40) | 39.36 (1.4, 32 to 40) | 40 (0, all 40) | 40 (0, all 40) |
| Change value from the value with straight neck | -13.1 (6.0, -24 to -3) | -5.6 (5.2, -13 to 0) | - | no effect | no effect |

* "no effect" means that mean change value is less than 5°.
4. Discussion

We investigated the actual effects of modular necks and compared them with the predicted values when using those necks in terms of intraoperative femoral anteversion and ROMs before implant impingement.

One of our findings was that the effect of the modular neck was slightly lesser than its default value with regard to intraoperative femoral anteversion on our defined coordinate system. We attribute this finding to the difference between 2 coordinate systems: the connecting plane between the stem and the neck, and the aforementioned plane for evaluating intraoperative femoral anteversion. This result also might be due to femoral anterior or varus-valgus bowing. According to one previous report, femoral anterior bowing significantly influences femoral anteversion (Renkawitz et al., 2012). Further studies are required to investigate whether the initial value of femoral anteversion affects the actual values obtained with modular necks. On the basis of this result, some surgeons may prefer to use a larger value modular neck (15°) for adjusting clinically relevant femoral anteversion. However, we also think that surgeons have to pay attention to the following second result.

The second result was that the effect of the modular neck on ROMs was very different from that on adjusting femoral anteversion. In internal rotation at 90° flexion, the effects of the modular necks were greater (more 5° to 10°) than the default value of those necks. When using a 15° anteverted neck, approximately 20° were gained in internal rotation at 90° flexion, resulting in increased posterior stability. On the other hand, approximately 23.6° are lost in external rotation at 0° extension when using the same 15° anteverted neck. Therefore, extreme care is required when selecting a modular neck.

For selection of a modular neck, we believe that a computer simulation, such as that used in the present study, is very useful. Many surgeons may acknowledge that as femoral anteversion decreases, external rotation increases during 0° flexion, and that as anteversion increases, internal rotation increases during 90° flexion. However, these effects have not been clarified. One simulation study on ROM before impingement is similar to our study (Barsoum et al., 2012). In that study, the authors used commercially available CT data for only 1 male hip and investigated internal rotation at 90° flexion and external rotation at 0° extension while changing the alignment of the acetabular components (anteversion, 0°, 8°, 15°, 22°, or 30°; abduction, 25°, 35°, 45°, 55°, or 65°) and the femoral components with modular necks (–15°, –7°, 0°, 7°, or 15° from 20° anteversion). Internal rotation increased by a mean of –14.7°, –7.9°, 7.9°, and 16.9° with –15°, –7°, 7°, and 15° necks, respectively. External rotation increased by a mean of 16.9°, 8.5°, –10.5° and –23.1° with –15°, –7°, 7°, and 15° necks, respectively.

Some previous studies showed favorable mid- and long-term clinical results of cementless THA with this modular neck (Traina et al., 2009; Sakai et al., 2010; Traina et al., 2011). In particular, a recent comparative study (74 hips with this modular neck vs. 74 hips with a monoblock type) showed that this modular femoral neck system in cementless THA provided favorable long-term results without severe complications at a minimum of 13 years of follow-up (Sakai et al., 2010). There were significant differences in mean total Harris hip score (modular vs. nonmodular, 98.6 [range, 64 – 100] vs. 93.8 [range, 68 – 100]), incidence of osteolysis (27% vs. 79.7%), and incidence...
of equal leg lengths (≥6 mm, 92% vs. 61%)(Sakai et al., 2010). After following the criterion for the use of retroverted or anteverted necks (the authors aimed for between 15° and 30° of anteversion of the femoral neck), the rate of the use of retroverted (8 cases) or anteverted necks (one case) was only 12.2%. Because the rate was small and both groups had no dislocation, it is unclear whether the retroverted or anteverted necks contributed to the favorable clinical results. However, we believe that the use of a modular neck decreases the occurrence of neck–cup impingement, resulting in osteolysis. Another report on previous studies showed that the use of a retroverted neck in this modular neck system increased external rotation during extension (Traina et al., 2009). However, its expression was not clear, and the results were not quantitative.

We note several limitations of our study. First, we fixed a pelvic coordinate system, which was parallel to the femoral coordinate system. However, we indicated variations of the effect of the modular neck to some extent. Second, although the number of cases was small, we exceeded the minimum number of cases required for such 3D analysis (Widmer et al., 2004; 11. Kessler et al., 2008; Bargar et al., 2010; Patel et al., 2010). Third, we investigated only 1 stem. However, this stem has been very popular in term of the femoral modular neck in THA, and surgeons worldwide have published mid- or long-term results of THA with this stem (Traina et al., 2009; Sakai et al., 2010; Traina et al., 2011). Therefore, we believe that clarifying the effect of this modular neck is valuable.

5. Conclusion

To the best of our knowledge, the current study is the first to quantitatively indicate the effect of modular retroverted or anteverted necks in terms of both femoral anteversion and ROM before impingement. When selecting a modular neck, surgeons should be aware of the large effect of modular retroverted or anteverted necks in terms of ROM, as well as the actual value of femoral anteversion with one modular neck.

Acknowledgements

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References


