
Masatoshi OBA, MD, Yutaka Inaba, MD, PhD, Naomi Kobayashi, MD, PhD, Hiroyuki Ike, MD, Yasuhide Hirata, MD, Masamitsu Tomioka, MD, Tomoyuki Saito, MD, PhD.
Yokohama City University, Yokohama, Kanagawa, Japan.

Disclosures:

Introduction: Excellent long-term results of total hip arthroplasties (THAs) using cementless tapered-wedge stems have been reported. Nevertheless, several authors have reported failure of osteointegration and early stem subsidence in a considerable number of patients receiving this type of implanted stem. The results of such case series suggest that the use of large-sized stems and steep proximal canal shapes of the femur lead to distal fixation of the tapered-wedge stem, preventing bone ingrowth into the proximal porous surface of the stem. These risk factors are derived from the findings of postoperative radiograph analyses, but the mechanism through which these risk factors affect the mode of stem fixation remains unclear. We conducted subject-specific finite element analyses (FEAs) and series of double-energy X-ray absorptiometry (DEXA) scans of the femurs after THAs to investigate the biomechanical behavior of cementless tapered-wedge stems implanted into femurs with various canal geometries.

Methods: We reviewed the standard anteroposterior radiographs of 72 consecutive patients who underwent THAs using Accolade® TMZF® stems (Stryker Orthopaedics, Mahwah, NJ, USA) at our institute. Among the hips, we identified eight femurs with a champagne flute-type canal (group A) and six with a stove pipe-type canal (group C). Eight femurs with a normal type canal (group B) were also included in this study. We constructed subject-specific three-dimensional finite element models based on postoperative CT data of the patients’ femurs using the software Mechanical Finder Ver. 6.2 (Research Center of Computational Mechanics, Shinagawa, Tokyo). Material properties of bone were calculated using the Hounsfield values in the CT data on the basis of Keyak’s rule (1) to determine the apparent density of each element. The stem was modeled with a Young’s modulus of 79.5 GPa and a Poisson’s ratio of 0.33. The bone-stem interface was considered to be fully bonded. A single-leg stance condition was used in the FEA; the models were clamped in the distal diaphyseal part of the femur. We applied joint reactive force (2400 N) exerted by the body weight on the prosthetic head and a force generated by the abductor muscles on the greater trochanter (1200 N). In each model, we calculated the mean equivalent stress on each part of the femoral bone, as defined by Gruen’s zone classification (2). FEAs of these 22 models were performed to study the distribution patterns of mechanical stress in postoperative femurs. To assess bone mineral density (BMD) change in the femurs, dual energy X-ray absorptiometry (DEXA) scans were performed at one week after surgery as a reference, followed by the scans performed at 3 months, 6 months, and 1 year after surgery. In each case, BMD was measured in each Gruen’s zone [1-7]. The BMD at each follow-up were converted to a mean ratio relative to the baseline reference. We compared the equivalent stress calculated by FEAs in each Gruen’s zone and the BMD change between 3 groups. The one-way analysis of variance test was used for statistical analysis. The level of statistical significant difference was set to 0.05.

Results: The mean age of the 22 included subjects was 61.4 (41-89) years. The average implanted stem size in group A, B, and C were 1.8, 2.9, and 4, respectively. The calculated equivalent stress distribution patterns of the models (Fig. 1) were different among the three groups. In group C models, the highest mean equivalent stress among three groups was seen in zone 4, whereas the lowest mean equivalent stress was seen in the metaphyseal-diaphyseal part of the femur (zones 2, 6). Although the femurs in group A had narrow canal shapes, in which distal fixation of the stem is likely to occur, the calculated mean equivalent stress in the proximal area (zone 1, 6.18 ± 3.4 MPa; zone 7, 7.5 ± 3.7 MPa) was higher than that in group C (zone 1, 3.8 ± 3.2 MPa; zone 7, 5.2 ± 4.9 MPa). The calculated stress contours on the middle cross-sections of the representative models for each group are shown in Fig. 2. The red area, which depicts relatively high equivalent stress distribution, is not seen in the contour figure for group C. The differences in mean BMD change after THAs were evident in medial-proximal area (zone 6 and 7) of the femur (Fig. 3). One year after surgery, significant BMD loss in zone 6 (p=0.001) and zone 7 (p=0.02) was seen in the femurs in group C compared to other 2 groups.

Discussion: The results of FEAs show that group C models had the strongest stress shielding among the three groups, and postoperative BMD loss at proximal area of the femurs seen in group C supported this finding. The major differences among the
three groups were their femoral canal shapes and implanted stem sizes. Both factors can affect postoperative stress distribution on the femur, but the FEA results of group A suggested that the tapered-wedge stem does not necessarily fix only its distal portion in a champagne-flute type canal. Furthermore, the mechanical stress distribution profile in the group C models implies that even in a broad femoral canal, large-size stems are fixed more distally than the proximal coated portion. For the Accolade® TMZF® stem, large-size stems are not designed geometrically similar to the small-size stems. Large-size stems have a flatter and broader tip compared to that of small-sized stems; this tip would be wedged into the femoral canal. The distal portion of this type of stem is not intended for bony fixation, so distal fixation of the stem may cause micromotion and failure of osteointegration at the proximal coated portion. White et al. (3) reported more than 1.5 mm of subsidence of Accolade® TMZF® stems in 36% of their cases over a 2-year period. They found that stem subsidence was related to the use of large-size (above number 4) stems. The FEA results obtained in the present study are consistent with their clinical observations.

**Significance:** In our subject-specific FEA results and the study in BMD change in the femurs, postoperative mechanical stress distributions in the femurs with large-size stems tend to shift distally. Distal engagement of the larger, tapered-wedge stem is thought to be related to early stem subsidence; the result of our study using FEAs and DEXA is consistent with the results of previous reports regarding this problem.

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Figure 3. The mean bone mineral density (BMD) change relative to baseline data which were obtained 1 week postoperatively (* p=0.02, ** p=0.001).

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