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Basic Science

Biomechanical Comparison of 2 Different Femoral Stems in the Shortening Osteotomy of the High-Riding Hip

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ABSTRACT

Background: We hypothesized that a rectangular cross-sectional femoral stem may produce more initial stability of the transverse subtrochanteric femoral shortening osteotomy rather than a circular cross-sectional stem.
Methods: Twenty, fourth-generation, synthetic femur models were inserted with either circular or rectangular cross-sectional femoral stems after 3 cm of transverse subtrochanteric shortening. Half of the models were tested with axial bending and the other half with torsional loads. After the femora underwent cyclic loading, they were loaded until failure. Outcome parameters were stiffness values before and after cyclical loading, failure loads/torques, and displacements at the osteotomy sites.
Results: In axial bending tests, the results were not significantly different between the groups. Under rotational forces, the mean stiffness value before cyclical loading and failure torque of the cylindrical stems was significantly higher than that of rectangular cross-sectional stems (11.8 ± 1.2 vs 7.1 ± 2.8 Nm/degree; $P = .009$ and 136.9 ± 60.2 vs 27.1 ± 17.5 Nm; $P = .027$ Nm, respectively). The mean amounts of displacements at the osteotomy sites were not significantly different between the groups in any direction in both axial and rotational tests.
Conclusions: According to the results of the study, using straight, cylindrical femoral stems can increase rotational stability of the transverse osteotomy more than the rectangular cross-sectional stems although the latter one has the advantages of rectangular geometrical design.

Total hip arthroplasty (THA) with femoral shortening is an effective and successful treatment method in patients with high hip dislocation secondary to developmental dysplasia of the hip [1,2]. The reconstruction of the hip in these patients may be accomplished with the use of shortening femoral osteotomy to allow placement of the acetabular component into the anatomic acetabulum. Reconstruction of the rotational center of the hip in its anatomic level is strongly recommended to decrease the rate of aseptic loosening [3-7]. However, distraction of the reconstructed femur over 3-4 cm during reduction of the hip may increase the risk for the neurovascular structures such as sciatic or femoral nerve palsy [8-11]. Femoral shortening with the osteotomies is expected to minimize this risk. Although most osteotomies are performed on the subtrochanteric region, they may also be performed in the metaphysis [8,12] or diaphysis [13]. Subtrochanteric osteotomies may be transverse [14,15], oblique [2,16], step cut [1,17], or V shaped [18]. Currently, the choice is generally made on the pathoanatomic characteristics of the femur, and the preference and the experience of the surgeon.

The literature reports use of both cylindrical cross-sectional, metaphyseal and diaphyseal press-fit femoral components [19,20] and rectangular cross-sectional, tapered, metaphyseal press-fit femoral stems [15,21,22] after the osteotomies. Although the type of femoral component may impact the clinical outcome, no difference in the outcome of THA has been reported when different types of stems were used in patients who required femoral shortening

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osteotomy. In addition, proper intraoperative assessment for torsional and axial stability of different stem types is poor because surgeons can only test stability by hand.

This study was conceived and executed to compare the stability of 2 different types of femoral component on the axial and rotational stabilities of the transverse subtrochanteric shortening osteotomies. The hypothesis of the present study was that rectangular cross-sectional femoral stem may result in increased rotational stability of the osteotomy than cylindrical femoral stems because of their cross-sectional design.

Materials and Methods

This biomechanical study was performed by using a servohydraulic test device (MTS 858 Mini Bionix II, Eden Prairie, MN) for axial and torsional loading. Twenty, synthetic, polyurethane, identical, fourth-generation, left, medium-size femur models (Sawbones 3403; Malmö, Sweden) were divided into 2 groups each consisting of 10 specimens. In group I, metaphyseal and diaphyseal press-fit, cylindrical cross-sectional, straight stems (Primary Echelon, no: 17; Smith & Nephew, Memphis, TN) were used, and in group II, metaphyseal press-fit, rectangular cross-sectional, tapered femoral stems (SL-Plus, no: 16; Smith & Nephew) were used (Fig. 1A,B). In the piloting phase of the experiment, femoral medullae were reamed and broached with the largest broach possible to determine appropriate sizes of the femoral stems for the press-fit placement.

All implantations were performed by one experienced orthopedic surgeon. To have a standard head resection and a shortening osteotomy, osteotomy lines were measured and drawn on the models, and cuts were made using a low-profile electric saw. The neck osteotomy was performed 1.5 cm proximal to the trochanter minor and with an angle of 45° relative to the shaft. After reaming and broaching, 3 cm of subtrochanteric resection was applied, using the transverse osteotomy. The first transverse cut was performed perpendicular to the anatomic axis of the femur and 20 mm distal to the level of the lesser trochanter, and the second cut was parallel and 30 mm distal to the first one. No rotational adjustment to the greater trochanter was necessary, as the synthetic specimen has normal anatomy. After inserting one of the 2 types of the femoral stems in the medulla of the shortened models, resected synthetic bone segments were divided into 2 parts and fixed to the medial and lateral sides of the osteotomy using a steel cable to simulate original surgical techniques.

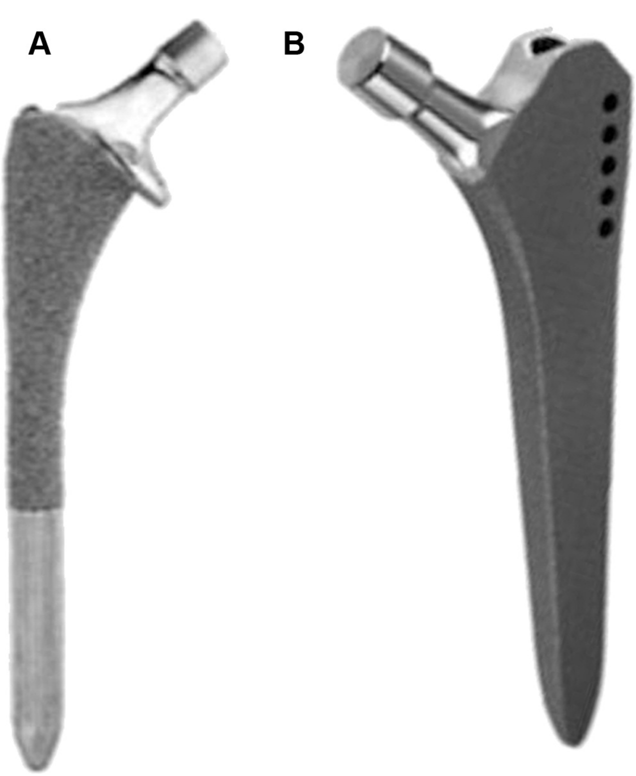

Fig. 1. (A) Cylindrical cross-sectional, metaphyseal and diaphyseal press-fit femoral stem. (B) Rectangular cross-sectional, metaphyseal press-fit, tapered femoral stem.

Two cross Kirschner wires with the diameter of 2 mm were inserted to the femoral condyles, and the distal ends of the femur specimens were embedded in polyester putty. Polyvinyl chloride (PVC) pipes 110 mm in diameter and 60 mm in height were used as a scaffold for this procedure. A custom-made centralizer was used during this procedure so that the femoral stem of the construct could be placed perpendicular to base of the PVC pipe and its long axis would pass through the center of the PVC pipe.

Test Protocol

Of the 10 models in each group, 5 were tested under axial forces and the remaining 5 under rotational forces. Any displacement at the osteotomy site was detected using a 3-dimensional digital imaging correlation system (Vic-3D, Correlated Solutions Inc) operating simultaneously with the MTS device [23]. This system was capable to measure displacements as small as 1 μm in mediolateral (x), vertical (y), and anteroposterior (z) directions [24,25]. For this reason, motions of the random assay patterns, which were stuck to the proximal and distal parts of the osteotomy, were recorded by 2 digital cameras before the initial loading, after the initial loading, and after each 1000 cyclical loading, and displacements of the osteotomy in 3-dimensions were calculated digitally using the captured images.

Axial Load Tests

The force was transmitted to the femoral stem, which was kept at 16° valgus to simulate the single-leg stance phase of the gait, through a +0 head (Smith & Nephew, USA) and a cup similar to the acetabular liner (Fig. 2A) [23]. After application of the preload (3 Hz, from 100 N to 1000 N, 10 cycles) for the stability of the constructions, the system was released and loaded again (initial loading) up to 1000 N with a velocity of 50 N/s to measure the baseline stiffness values. The specimens that have not failed during initial loading tests were loaded with 1000 N at 3 Hz for 10,000 cycles to simulate walking with partial weight bearing after hip arthroplasty with femoral shortening [23]. After each 1000 cycles, stiffness of the models and displacements at the osteotomy site were recorded. Finally, the models were loaded to failure axially using displacement control mode at a speed of 15 mm/min, and the maximum force that caused failure in the specimens was recorded.

Rotational Load Tests

The femoral stems were rotated around their longitudinal axis through an apparatus fixed to the stems to minimize bending moments in the specimens during rotation of the stems (Fig. 2B). After preloading (3 Hz, from 0.5 to 10 Nm, 10 cycles), the system was released and the models were torsioned (initial torque) with a velocity of 0.2 Nm/s and 10 Nm of torque to measure the initial stiffness values [23]. Then, 10,000 cycles of torsion (0.5-10 Nm) was applied at 3 Hz under torsional control [23]. After each 1000 cycles, stiffness values of the models and displacements at the osteotomy