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Basic Science

Tapered vs Cylindrical Stem Fixation in a Model of Femoral Bone Deficiency in Revision Total Hip Arthroplasty

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ABSTRACT

Background: Distal fixation achieved with a tapered stem design has demonstrated favorable clinical results in revision total hip arthroplasty in the setting of severe bone defects. However, stem subsidence is common with this stem design.
Purpose: The purpose of this study is to compare the initial fixation stability of a tapered stem design to a fully porous-coated cylindrical stem design in a model of severe femoral bone deficiency.
Methods: Tapered and cylindrical stems (n = 8) were implanted into a model femur with progressively shorter segments for fixation (9, 6, or 3 cm). The stems were axially loaded, and the force to produce subsidence was recorded.
Results: Average loads to produce 150 μm of displacement with a 3-cm segment were higher for the tapered stem (393 N vs 221 N, $P < .01$). No difference was observed in the 6- or 9-cm models. Average loads to produce failure (>4-mm subsidence) were also higher for tapered stems with a 3-cm segment (1574 N vs 500 N, $P < .0001$). A regression analysis determined the minimum segment length of 1.5-2.5 cm to obtain stable fixation with a tapered stem design ($R^2 = 0.78$, $P < .001$).
Conclusions: Tapered stems required higher loads to produce subsidence than cylindrical stems in a revision THA model. Revision tapered stems require a minimum intact segment of 1.5-2.5 cm to obtain adequate initial fixation stability. Revision tapered stems have superior initial fixation stability to cylindrical stems in the setting of severe bone loss.

Total hip arthroplasty (THA) is an extremely successful surgical procedure to relieve pain and to restore function in patients with end-stage hip pathology. However, complications including prosthesis loosening, infection, and fractures may necessitate revision surgery. When performing revision THA, preoperative planning and appropriate implant selection are paramount to achieving a successful and durable outcome for the patient. Implant selection for the femoral reconstruction is dictated by the structural integrity of the femur at the time of revision surgery. Krishnamurthy et al [1] described a widely used classification system of femoral bone defects based on the success rate of fully porous-coated cylindrical stems (Table 1).

The medium- to long-term success rate of fully porous-coated cylindrical stems has been excellent in revision surgery. However, a high failure rate of these stems has been reported in a subset of patients with type III and type IV femoral deficiencies [2]. Multiple authors have reported good clinical results at midterm follow-up by achieving distal fixation with tapered stems in type III and type IV defects [3-5]. However, stem subsidence has been reported to occur in up to 35% of patients [4,6,7]. To date, there are little data reported on the minimum amount of intact femoral diaphysis to obtain stable fixation using distal tapered stem geometry.

The purpose of this study is to compare the initial fixation stability of the tapered stem to the fully porous-coated cylindrical stem in a model of severe femoral bone deficiency simulating revision THA. Moreover, we sought to determine the minimum amount of intact femur needed to obtain stable initial fixation using a tapered stem design.

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Table 1
Paprosky Classification of Femoral Bone Defects.

Paprosky Femoral Bone Defect	Extent of Femoral Bone Defect
Type I	Intact metaphysis and diaphysis
Type II	Significant metaphyseal damage
Type IIIA	Diaphyseal damage with >4 cm of intact bone near isthmus
Type IIIB	Diaphyseal damage with <4 cm of intact bone near isthmus
Type IV	Loss of structural integrity, widened canal with thin cortices

Methods

Two cementless revision femoral stems designs were included: (1) a distal tapered geometry (Wagner SL Revision; Zimmer, Warsaw, IN) and (2) a distal cylindrical geometry (VerSys Porous FullCoat; Zimmer). The tapered stem was a titanium shaft with a circular cross section and a 2° taper. The tapered stem has flutes for rotational stability and a grit blasted surface texture for bone ongrowth. The cylindrical stem has a cobalt–chrome shaft with a circular cross section and has a beaded porous coating to allow for bone ingrowth (Fig. 1). Both stems were 18 mm in diameter. The tapered stem was 265 mm in length, and the cylindrical stem was 255 mm in length. Each stem was implanted into a rigid polyurethane foam block designed for orthopaedic biomechanical testing (Pacific Research Laboratories, Sawbones, Vashon Island, WA). Bone quality in revision femoral reconstructive situations is frequently diminished; therefore, a medium-density (0.48 g/cm^3) polyurethane was selected to simulate the femur [8,9]. The blocks were prepared using the appropriate instrumentation for each stem design as provided by the manufacturer.

A revision THA model with a progressively shorter segment of intact bone was created by machining the blocks to have lengths of 9, 6, or 3 cm, respectively. This corresponds to the amount of intact bone presented in type II, type IIIA, and type IIIB defects, respectively. A power analysis was performed and determined that for an alpha value of 0.05 and a power level of 0.8; a minimum 6 specimens in each group were necessary. A total of 48 specimens (n = 8 for each group) were prepared for testing.

Fig. 1. (A) Zimmer Wagner SL Revision stem with 2° taper distal geometry and (B) Zimmer VerSys FullCoat Revision stem with cylindrical distal geometry.

The stems were axially loaded using a servoelectric material testing system (BOSE 3330AT; Eden Prairie, MN). A 1500-N axial load was used to implant each specimen at a rate of 100 N/s. Testing was then performed under load control with a cyclic waveform that applied a baseline axial load of 50 N and an initial cycle peak to 100 N and a return to the baseline for a dwell of 10 seconds. The dwell time was to allow for creep in the specimens between load applications. Each subsequent cycle peak was increased 50 N progressively with a target maximum axial load of 2600 N. Testing was stopped if the maximum load was reached or if the measured axial displacement was >4 mm (Fig. 2).

Two outcomes were recorded: (1) the amount of force required to produce 150 μm of axial displacement and (2) the load to failure, which was defined as 4-mm axial displacement. The number of stems in each group that were able to withstand the 2600-N load was also recorded. Statistical analysis was performed using analysis of variance followed by Tukey multiple comparison test to compare the means between groups (GraphPad Prism, version 6; GraphPad Software, La Jolla, CA). Fisher exact test was used to test the

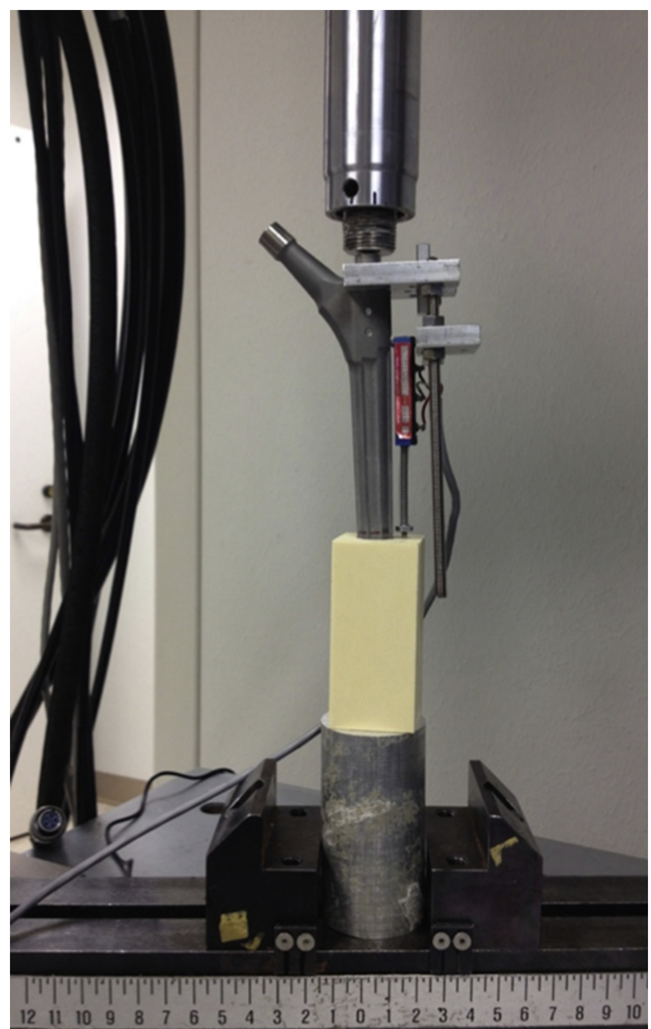

Fig. 2. Each model femur had a stem implanted, and the stems were axially loaded using a servoelectric material testing system (BOSE 3330AT; Eden Prairie, MN) until the stem failed.