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Fixation of Non-Cemented Total Hip Arthroplasty Femoral Components in a Simulated Proximal Bone Defect Model

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ABSTRACT

An accelerated sequential proximal femoral bone loss model was used to measure the initial stability of three noncemented femoral stem designs: fully porous-coated, proximally porous-coated, and dual-tapered, diaphyseal press-fit (N = 18). Only dual-tapered, diaphyseal press-fit stems remained stable with as much as 105 mm of bone loss, with average cyclic micromotion remaining below 25 μm in ML and below 10 μm in AP planes. In contrast, with proximally coated and fully coated stem designs with circular or oval cross-sections, 60 mm of bone loss, resulting in lower than 10 cm of diaphyseal bone contact length, led to gross instability, increasing average cyclic micromotions to greater than 100 μm prior to failure. Therefore, the results provide support for using a dual-tapered stem in revision cases with proximal bone loss.

Today, the vast majority of total hip arthroplasties in the US and many other countries incorporate non-cemented femoral components. One of the attractions of non-cemented femoral stems is the simplicity of achieving adequate initial fixation. Over the years, several different types of non-cemented femoral stem designs have emerged with unique methods of fixation, including long, fully coated porous ingrowth stems and shorter, press-fit designs.

Over the years, several design approaches to fixation of non-cemented femoral components have been successfully established. Prior to the advent of porous ingrowth surfaces, non-cemented implants relied solely on press-fit and wedge designs for initial stability. Today, press-fit designs without porous ingrowth surfaces are still in widespread use [1–14]. However, most contemporary designs of non-cemented femoral stems incorporate porous ingrowth surfaces, and are designed for either proximal ingrowth fixation or proximal and distal ingrowth fixation. Numerous studies have reported excellent long term clinical results for a variety of porous ingrowth femoral components [10,15–24].

Unlike primary hip arthroplasties, revision total hip arthroplasties often involve a substantial amount of proximal femoral bone loss [25–40]. Lack of adequate proximal fixation is known to lead to failure, as initial stability is required to achieve adequate bone ingrowth for long term fixation of non-cemented implants [41,42]. Specifically, it is commonly accepted that interface motions above 150 μm can hinder bone ingrowth [41,43], while some studies have even suggested that as little as 20 to 30 μm is necessary to enable stable ingrowth [43,44]. Therefore, in revision cases with substantial proximal bone loss, an implant must perhaps, rely more heavily on achieving initial stability by either meta-diaphyseal or distal diaphyseal fixation.

The purpose of this study was to measure the initial stability of three types of non-cemented femoral stems, selected to cover the spectrum of commonly used non-cemented fixation approaches for primary arthroplasty, under simulated progressive bone loss or bone defect conditions. Each femoral stem design was intended to achieve stability in one of three ways (1) meta-diaphyseal fixation, (2) proximal fixation, or (3) proximal and distal fixation (a.k.a. "fully coated"). Stability was measured at the bone-stem interface under physiological loading, using composite biomechanical testing femurs. Implants were tested either (1) during simulated progressive bone loss consisting of increasing levels of resected bone, or (2) after simulated removal of a dynamic hip screw (DHS), intended to represent a typical clinical bone defect scenario. The study was designed to determine if any of the non-cemented designs typically used in primary arthroplasty cases would be viable candidates in the presence of severe proximal bone loss.

The Conflict of Interest statement associated with this article can be found at http://dx.doi.org/10.1016/j.arth.2013.01.017.

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Materials and Methods

Materials

Three femoral stem designs, each designed to achieve fixation within the femoral canal in a different way, were tested: (1) the Versys Fiber Metal Taper hip prosthesis (Zimmer, Inc., Warsaw, IN) with a proximal porous fiber metal ingrowth surface and a polished cylindrical distal tip, (2) the Versys Beaded Full Coat Plus hip prosthesis (Zimmer, Inc., Warsaw, IN) with extensive porous coating for proximal and distal ingrowth, and (3) the dual-tapered Alloclassic hip prosthesis (Zimmer, Inc., Warsaw, IN) with a rectangular cross-section (Fig. 1).

Fourth generation composite anatomic femurs were used to eliminate the variability in shape and quality among cadaveric femurs (Sawbones, Pacific Research Laboratories, Vashon Island, WA). These models have been thoroughly tested and are well established in biomechanical micromotion testing [45–52]. The simulated cortical bone, made of short fiber filled epoxy (density of 1.64 g/cc), has a tensile strength of 106 MPa, compressive strength of 157 MPa, and a modulus of elasticity of 16 GPa. The simulated cancellous bone, made of rigid polyurethane foam (density of 0.27 g/cc), has a compressive strength of 6.0 MPa and a modulus of elasticity of 155 MPa. Each of the three stem designs was tested in six composite femurs of the same size, for a total of 18. A progressive bone loss scenario was simulated by testing three specimens per stem design as follows: (1) intact, after initial implantation and (2) with increasing levels of bone resection (Fig. 2). The remaining nine specimens, again three specimens per stem design, were tested after bone loss created by a simulated removal of a dynamic hip screw (DHS), representing one of the most common clinically relevant bone loss scenarios (Fig. 3). These specimens were also tested (1) intact, with DHS bone loss simulation and after initial implantation and (2) with one level of bone ressection.

Surgical Methods

All stems were implanted by the same surgeon using the instrumentation and protocol specified by the manufacturer for clinical application. Specifically, using the rasps provided by the manufacturer for each of the stem designs, the fully coated and dual-tapered stems were inserted using a line to line fit, while the rasps corresponding to the proximally coated stem were sized to achieve a proximal press-fit of 1 mm in both the anteroposterior and medio-lateral directions. Implant size was determined by the geometry of the composite femur (fully coated: 12, proximally coated: 12, dual-tapered: 5). Anteroposterior and mediolateral radiographs were taken before testing to verify proper component alignment, as well as after testing was completed to view stem migration.

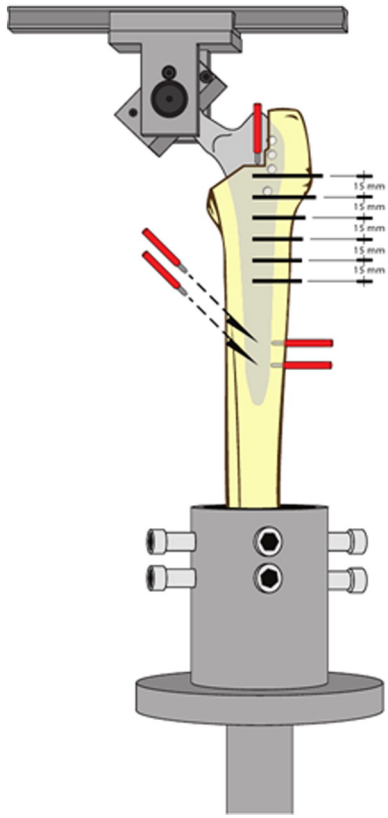

Fig. 2. Anteroposterior view of the testing set-up configuration with marks for the sequential transverse cuts and the location of the 5 DVRTs (in red).

Progressive Bone Loss Simulation

Specimens were first tested intact, after implantation of the stem, simulating a healthy amount of bone. After loading and measurement of initial stability, a transverse cut was made, 30 mm distal to the proximal shoulder, simulating the first bone loss condition (Cut 1).

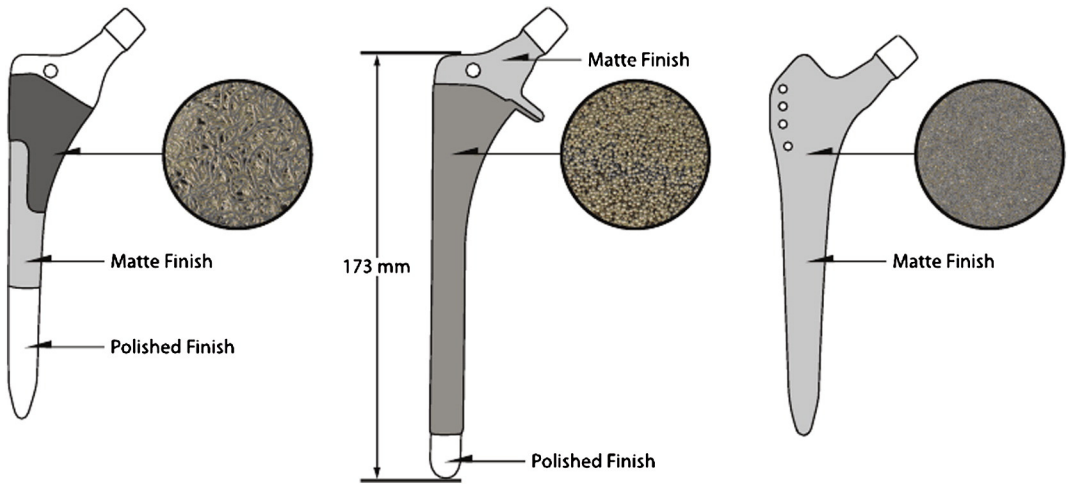

Fig. 1. Detailed drawings of the femoral stems used. From left to right: the Versys Fiber Metal Taper hip prosthesis (Zimmer, Inc., Warsaw, IN) with a proximal porous fiber metal ingrowth surface and a polished cylindrical distal tip; the Versys Beaded Full Coat Plus hip prosthesis (Zimmer, Inc., Warsaw, IN) with extensive porous coating for proximal and distal ingrowth; and, the dual-tapered Alloclassic hip prosthesis (Zimmer, Inc., Warsaw, IN) with a rectangular cross-section.