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Shortening Cemented Femoral Implants

An In Vitro Investigation to Quantify Exeter Femoral Implant Rotational Stability vs Simulated Implant Length

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Abstract: The Exeter stems vary in length from 90 to 150 mm. The shorter stems generally have lower offsets. The purpose of this study was to determine if length of stem, with fixed offset, affected rotational stability. Mechanical testing was carried out on 10 implant-cement constructs with 2 loading profiles, rising from chair and stair climbing, at different simulated implant lengths using purpose-built apparatus. This paper presents a mechanism for clinically observed rotational stability and explains the mechanical characteristics required for rotational stability in Exeter femoral stems. **Keywords:** femoral implant, rotational stability, preclinical testing, implant design.

The Exeter Universal stems (Stryker Orthopedics, Mahwah, NJ) have performed remarkably well since their introduction over 30 years ago [1]. Despite the long history and clinical evidence in the arthroplasty registries demonstrating that cemented femoral implants are performing excellently [2-4], it is still important to understand and quantify the mechanisms for their function to allow for future development. Recently, there has been a trend to shortening femoral implants for a variety of clinical indications [5-7]. In addition to the implant shortening, a growing need for shorter implants with large offsets has been identified in Eastern populations [8]. The changes to implant geometry have been made to address these clinical and anthromorphometry issues including primary bone stock removal, bowed femurs, and proximally trended isthmus [5,7,9,10]. Already, several Exeter stems on the market are 125 mm or shorter with the shortest being 90 mm in length, which address some of the clinical requirements. However, the design criteria for shorter femoral implants and the consequences of these changes have not been explored in the literature. This article explains the mechanical characteristics required for rotational stability in cemented implants at a number of lengths.

The Exeter stem is a design that implements the taper-slip engagement principle [11]. The implant migrates distally over the lifetime of the implant and continues to engage further within the cement mantle preventing aseptic loosening [1]. Subsidence of the stem within the mantle contributes to the rotational stability of the stem [12]. Rotational loads such as those encountered in stair climbing and rising from a chair are thought to be an important contributor to aseptic stem loosening [13]. Evidence of this failure mechanism was identified on nearly all implants inspected postrevision surgery for aseptic loosening [14].

Stem geometry has been shown to significantly affect rotational stability. In an radiostereometric analysis (RSA) study including a variety of cemented femoral implants, Glyn-Jones et al [9] demonstrated differences in rotational stability in implants with different proximal geometries. Difference in torsional resistance for uncemented implants has also been investigated, highlighting the role of proximal stem geometry on rotational stability [15].

The mechanism (loading regime) that results in rotational migration or instability or both is from torques and forces about the axis of the femur. In hip arthroplasty, the torques transmitted from daily activities are resisted by 2 components, frictional forces and surface normal forces [16]. In the case of polished tapered implants, the interaction between these 2 resistive forces is not clearly understood. In addition,

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there has yet to be a study that quantifies rotational resistance or rotational stiffness in cemented implants, which includes the combination of frictional forces and surface normal forces.

The purpose of this study is to quantify the resistance to rotational loads such as those seen in daily activities on an Exeter stem of varying length. To achieve this purpose, a single implant was progressively shortened by removing sections of the cement mantle from distal to proximal while maintaining anterior-posterior and mediolateral aspects. The model developed here defines the contributions to rotational stability of each section of a stem and presents a mechanism for rotational stability.

Materials and Methods

The method/process is divided into 3 sections, test equipment design, preparation of the test samples, and testing of these samples.

Test Equipment Design (Rationale)

A jig was designed and manufactured to test the effect of implant shortening on rotational stability of Exeter cemented femoral implants (Fig. 1). Its design was to serve 2 purposes, casting of the cement mantles and testing of the implant-cement interface. The apparatus consisted of a 2-part aluminum block with a cut out of the shape and volume for the implant and a greater than 2-mm-thick cement mantle. The aluminum block was attached to a biaxial material testing machine (Instron 8874; Norwood, Mass), which was used to apply forces and torques to the implant (Fig. 2).

The test apparatus was designed to isolate the cement-implant interface as far as practicable and to allow for reproducible simulation of implant shortening through shortening of the cement mantle. To ensure that the cement mantle was located in exactly the same position for each test, small, spherically shaped bulbs were included in the mold to resist movement in a manner similar to cement penetration into trabecular bone. Each bulb pair, located at the medial and lateral edges, was designed and tested to be capable of resisting the applied loads, in both compression and torsion.

Cement Mantle Preparation

Ten cement mantles were produced in the testing apparatus using Paladur dental acrylic (Heraeus-Kulzer GmbH, Wertheim, Germany) as per the manufacturer's instructions. The implanting process was carried out using an Instron 8874 biaxial materials testing machine and purpose-built mounting and alignment jigs. Cement preparation was carried out at 24°C to ensure consistent implant-cement interface characteristics. Implants, with poly methyl methacrylate (PMMA) distal centralizers, were inserted into the cement, using the Instron machine, 4 minutes after monomer was added to the polymer.

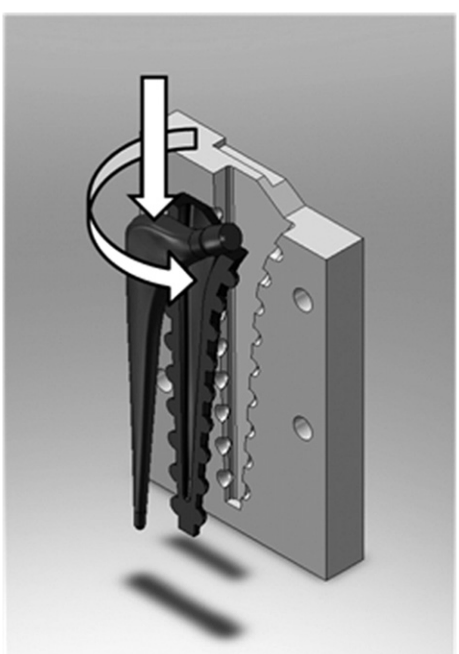

Fig. 1. Exploded section view of half of the experimental setup. The front object is an Exeter Universal stem with an offset of 44 mm and body size number 1. The middle object is the cement mantle. The back object is the mold. Compression and torsional loading directions are shown in white arrows.

Fig. 2. Experimental setup pictured. Mounted to the base of the Instron is mold, which supports the cement mantle construct during testing.