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Intraoperative Periprosthetic Femur Fracture: A Biomechanical Analysis of Cerclage Fixation

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ABSTRACT

Intraoperative periprosthetic femur fracture is a known complication of total hip arthroplasty (THA) and a variety of cerclage systems are available to manage these fractures. The purpose of this study was to examine the in situ biomechanical response of cerclage systems for fixation of periprosthetic femur fractures that occur during cementless THA. We compared cobalt chrome (CoCr) cables, synthetic cables, monofilament wires and hose clamps under axial compressive and torsional loading. Metallic constructs with a positive locking system performed the best, supporting the highest loads with minimal implant subsidence (both axial and angular) after loading. Overall, the CoCr cable and hose clamp had the highest construct stiffness and least reduction in stiffness with increased loading. They were not demonstrably different from each other.

Intraoperative periprosthetic femur fracture is a known complication of total hip arthroplasty (THA). The incidence of intraoperative periprosthetic femur fracture has been reported to be between 0.1–1% for cemented [1,2] and 5.4% for uncemented primary THA [2], compared to 3.6–12.5% in cemented [2,3] and 8.8–45.9% in uncemented revision THA [1,2,4–7]. Risk factors for intraoperative periprosthetic femur fracture include the use of minimally invasive techniques [8], the use of press-fit cementless stems [1,2,4–6,8,9], revision operations [1,2,4–6,8,9], gender [8,9], bone loss or disease [3,5–8], and technical challenges at the time of the operation [8–15].

Treatment options for periprosthetic femur fractures in uncemented THA depend on the site of the fracture and the stability of the implant as well as surgeon preference and comfort [16]. A number of options have been proposed ranging from combinations of long stem femoral components, extramedullary fixation with cerclage cables, plates, and strut grafts [6–8,15,17]. Several studies have previously demonstrated differences in fixation technique and biomechanical advantages of various cerclage constructs in fixation of periprosthetic femur fractures [8,16–31]. Although metallic cerclage cables have been previously shown to provide more strength than twisted monofilament wire, cable use is associated with other complications and limitations in minimally invasive applications [18–22,32]. As a result, there has been a renewed interest in wire cerclage systems and newer materials such as synthetic cables have emerged as potential alternatives to traditional metallic cables [23–25,33–35].

The purpose of this study was to examine the in situ biomechanical response of cerclage systems for fixation of periprosthetic femur fractures that occur during cementless THA. We compared metallic cables, synthetic cables, monofilament wires and hose clamps under axial compressive and torsional rotational loading.

Methods

Femoral Preparation

Twenty-four large 4th generation composite femurs (model 3404, SawBones, Pacific Research Laboratories, Inc., Vashon, Washington) were used in this study. The femurs were prepared according to the manufacturer technique guide for an uncemented, tapered femoral stem (Zimmer M/L Taper, Warsaw, Indiana). A standard femoral neck osteotomy was performed with an oscillating saw at a height of 10 mm proximal to the lesser trochanter. A box punch and canal finder were inserted into the femur, followed by a lateralizing reamer. The femur was then broached sequentially to size 12.5. A periprosthetic fracture was created with a thin kerf blade (0.022 inch) band saw by placing the femur in a standardized jig and creating a longitudinal fracture extending 127 mm distally from the osteotomy plane. Using a band

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saw allowed for creation of a uniform and repeatable fracture pattern [32,36,37]. When considering intraoperative periprosthetic fractures, it has been suggested that the most common fracture pattern occurs from the level of the femoral neck down to the lesser trochanter, in the proximal 1/3 of the femur and as such our fracture modeled these previously reported patterns [1,6,14,15,28,29,38]. The femur was placed in a jig designed to standardize distal femur resection and the femoral condyles were resected 7 cm proximal to the distal end of the femur. The femur was then potted in custom made axial compression or torsional test fixtures using a two part epoxy filler and allowed to cure (Figs. 1 and 2).

Construct Preparation

The periprosthetic fracture was reduced using two cerclage constructs, one proximally at the level of the lesser trochanter and the other located 51 mm distal to the proximal position. This configuration was based on previously published reports and senior surgeon experience [24,29,37,39]. Tensioning of each construct was performed using the manufacturers' specification. Cobalt–chrome (CoCr) (1.6 mm Dall-Miles cables, Stryker) and synthetic cables (SuperCables, Kinamed, Camarillo, CA) were tensioned with the manufacturer tensioners. Hose clamp tensioning is engaged by a worm-screw so a torque limiting screw driver was used (25 in/lb). Monofilament wires (16 gauge stainless steel) were tensioned using an aeronautic safety wire twister (Milbar model 25W, Stride Tool, Glenwillow, OH). A total of six femurs were prepared for each of the four constructs: 1) CoCr cable, 2) hose clamp, 3) monofilament wire, and 4) synthetic cable (Fig. 1). After placement of the cerclage construct to reduce and fix the standardized fracture pattern, a size 12.5 femoral component (Zimmer M/L Taper, Warsaw, Indiana) with standard neck was impacted into the proximal femur and a 32 mm + 0 CoCr femoral head was impacted onto the trunnion. All constructs were prepared by the senior surgeon.

Axial Load Testing

Three femurs per construct type were selected for axial load testing. The potted distal end was clamped into the servohydraulic test frame (Model 8501M, Instron, Norwood, MA) and angulated at 25° of adduction and 0° of anteversion to approximate single-leg stance. At the proximal end, the femoral head of the implant interfaced with a hemicircular loading plate attached to the actuator applying the load. The axial tests were started by applying a 50 N preload followed by a loading rate of 0.8 mm/min. Axial load testing was terminated after a displacement of 20 mm.

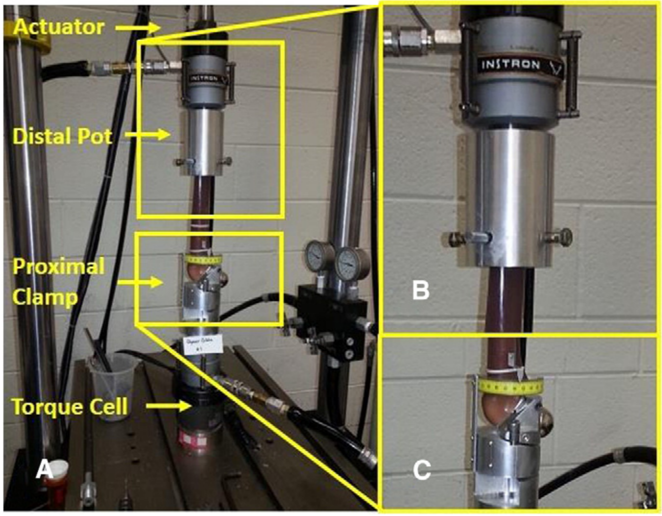

Fig. 2. Torsional test setup of femoral constructs. Note, the proximal femur is at the bottom of the figure and the distal femur is at the top. (A) Entire femoral construct installation in the Instron. (B) Detail of distal femur potting and interface to the Instron actuator. (C) Detail of proximal clamping and interface to the Instron torque cell.

The mechanical parameters that were measured during axial load testing included: subsidence onset and failure force, subsidence onset and failure displacement, stiffness, and total implant subsidence within the femur. The load–displacement histories are subdivided into two regions delineating the start of implant subsidence and characterized by two stiffnesses. Stiffness is defined as the slope of the linear part of the curve in these two regions. Subsidence onset force and displacement are defined as the intersection of the lines defining these two stiffnesses. Failure force and displacement were defined as the force maximum preceding a rapid force drop, indicative of hardware or femur failure. Total implant subsidence within the femur is defined as the difference between the failure displacement and the subsidence onset displacement. High definition video recorded during each trial was correlated with the biomechanical results on the force–displacement plots.

Comparisons of these parameters were then conducted between construct groups by one-way ANOVA and post-hoc Tukey–Kramer comparison except for the subsidence values, which were log transformed prior to statistical analysis due to failed normality tests. Regression analysis was used to determine the relationship between the total implant subsidence and the other mechanical parameters studied. The regression analysis is important because it indicates a relationship between

CoCr Cable Hose Clamp Monofilament Wire Synthetic Cable

Fig. 1. Cerclage constructs.