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Design changes improve contact patterns and articular surface damage in total knee arthroplasty

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ABSTRACT

Background: The Optetrak® PS (Exactech, Inc., Gainesville, FL) has been a well-functioning posterior stabilized knee replacement since its introduction in 1995. In 2009, the Optetrak Logic® incorporated modifications to the anterior face of the tibial post and the corresponding anterior articulating surface of the femoral component to reduce edge loading on the polyethylene post. In this study, we provide the rationale for the design change and compare the damage on retrieved tibial components of both designs to demonstrate the effectiveness of the design modifications in decreasing post damage.

Methods: We integrated retrieval findings of tibial post damage with finite element analysis to redesign the anterior tibial post-femoral box articulation. We then used subsequent retrieval analysis on a 3:1 matched sample of 60 PS and 20 Logic® inserts to examine the impact of the design change on polyethylene damage.

Results: Polyethylene stresses were markedly reduced when rounded contact geometries were incorporated. The comparison of the new and old designs using retrieval analysis demonstrated that the redesign led to reduction in surface damage and deformation on the tibial post.

Conclusions: This study shows the use of a design cycle by which a problem is identified through retrieval analysis, analytical tools are used to suggest design solutions, and then retrieval analysis is applied again on the new design to confirm improved performance.

Clinical relevance: Anterior post damage has been markedly reduced through the introduction of design changes to the post-box geometry.

1. Introduction

The Optetrak® PS (Exactech, Inc., Gainesville, FL) was designed in 1995 as an evolution of the Insall-Burstein® Posterior-Stabilized knee system (Zimmer, Warsaw, IN). The conformity between the tibial and femoral components was modified to reduce polyethylene contact stresses [1], and the trochlea of the femoral component was deepened and lengthened to improve patellar tracking and reduce patellar clunk. The survivorship rate of this knee implant has been excellent, ranging from 94 to 98% at 10 years [2,3].

In 2009, the Optetrak Logic® was introduced, incorporating further modifications to the Optetrak® PS. The articular conformity and patellar tracking remained unchanged; however, the intercondylar box geometry on the femoral component was modified to be more bone preserving by changing the angle of the box cut and rounding off its corners [4]. Maximum flexion was also increased from 120° to 145°.

In addition, the articulation between the anterior face of the tibial post and the corresponding articular surface of the femoral component was redesigned to reduce polyethylene post contact stresses and edge loading when the knee was in full extension. The anterior face of the tibial post was changed from a flat surface to a saddle shape. A matched saddle shape articulation was incorporated into the anterior cam of the femoral component.

Tibial post damage has been found in most PS implant designs examined with retrieval analysis [5–7]. For example, we previously examined PS posts of retrieved components from three knee designs: NexGen® (Zimmer, Inc., Warsaw IN), Optetrak®, and Genesis® II (Smith and Nephew, Inc. Memphis, TN) [6]. Post damage varied among the designs with the Optetrak® inserts showing the most damage on the anterior surface of the post, producing a "bowtie" damage sign (Fig. 1), while Genesis® II inserts had the most damage on the posterior surface. Damage to the posterior surface of the post is expected since repeated articulation with the femoral cam during flexion provides the mechanical constraint to femoral anterior translation that is the prime basis of PS designs [8]. Anterior post impingement is an

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Fig. 1. Representative photo of an Optetrak® PS tibial post with "bowtie" damage.

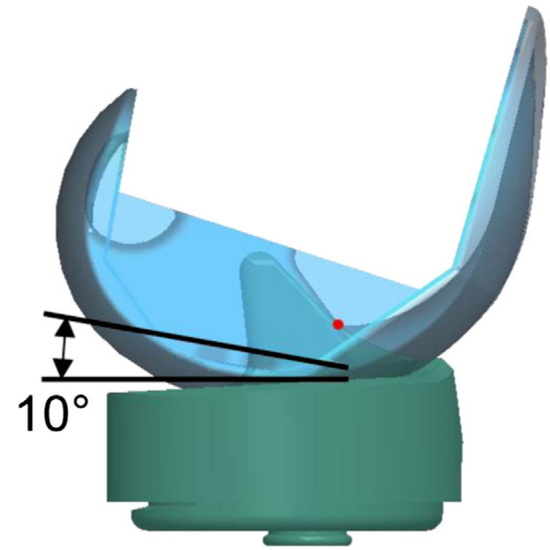

Fig. 2. The computer-generated solid model of the Optetrak® PS total knee prosthesis demonstrating the 10° of hyperextension used to model unintended contact.

unintended articulation occurring in hyperextension and at low flexion angles [6,9,10]. In extreme cases, this damage led to fracture of the post and the need for revision surgery [11].

The damage observed in the retrieval analysis of the Optetrak® PS formed the basis for the design modifications that were introduced in the Optetrak Logic® design. Here we describe the analytical basis for the design changes made to the tibial post and femoral anterior cam from the Optetrak® PS to the Optetrak Logic® designs. We then present the results of a subsequent retrieval analysis comparing the location and severity of damage on the articulating surface and tibial post between these two designs. We aimed to establish the effectiveness of the design modification in successfully decreasing the surface damage on the tibial posts of the Optetrak Logic®, while not adversely affecting damage to the tibiofemoral articulating surfaces.

2. Materials and methods

2.1. Design analysis

Computer models of the Optetrak® PS total knee prosthesis were modified to facilitate finite element (FE) meshing of the tibial post and the femoral anterior cam (Figs. 2 and 3). To model the unintended contact between the post and the cam, the components were positioned simulating 10° of hyperextension. The metallic cam was modeled as a rigid indenter. The post was modeled as ultrahigh molecular weight polyethylene using a true stress-strain relationship [1]. The constitutive model was based upon a von Mises yield surface with isotropic hardening. FE meshes were created using Patran (MSC Software, Santa Ana, CA), which was also used for post-processing.

The tibial post FE mesh was constructed using 8-noded hexagonal brick elements; the anterior cam surface was modeled with 4-noded rectangular shell elements. Because the post-cam mechanism is symmetric about the sagittal plane, a symmetric boundary condition was used, so only half the mechanism was modeled. The distal face of the post was fixed in all directions, and the cam was allowed to translate only in the direction of contact (i.e. perpendicular to the post at the contact point) simulating contact that would constrain movement of this surface.

The applied load of 445 N was based on a 2D free body diagram of loads derived from gait data at maximum hyperextension. This load was applied to the reference node of the cam indenter, and its direction was perpendicular to the post at the point of contact. Frictional contact between the post and cam was defined with a friction coefficient of 0.15. Analyses were performed using Abaqus (Abaqus Inc, Waltham, MA). Analyses were conducted using three sizes of the Optetrak® PS components and one modified design that was comparable in size to the Size 3 Optetrak®. The goal was to reduce the stress in the post to below the ultimate strength of the material. The new design incorporated changes to the curvature of the post and cam surfaces with the goal of reducing contact stress and edge loading; this design was then incorporated into the commercial Optetrak Logic® design.

2.2. Retrieval analysis

Twenty retrieved Optetrak Logic® polyethylene inserts were match paired on a 1 to 3 basis with 60 Optetrak® PS inserts. This matching was chosen based on the high number of retrieved Optetrak® PS inserts in our retrieval system in order to provide as much data as possible. The matching variables were age, BMI, length of implantation (LOI), radiographic AP and flexion–extension alignment of the femoral and tibial components, and indication for revision (Table 1). The inserts were obtained from our ongoing Institutional Review Board-approved implant retrieval system. The Optetrak Logic® retrievals consisted of all the components of this design removed at revision surgeries performed at our institution up to August 2011. The matching Optetrak® PS inserts were selected from all of the inserts that were retrieved at our institution since 1995 when the implant was first commercially introduced. All of the polyethylene tibial inserts were compression molded and had been sterilized by gamma-irradiation in an inert environment prior to implantation.

No significant differences existed between the two groups with respect to the matched variables (Table 1). The average patient age at the time of revision surgery was 65 $\pm$ 9.3 yrs in the Optetrak Logic® group, and 64.9 $\pm$ 9.8 yrs in the Optetrak® PS group ($p = 0.985$). Average BMI of the Logic group was 30.1 $\pm$ 5.9, while that of the PS group was 31.4 $\pm$ 6.1 ($p = 0.412$). Because the Optetrak Logic® was only made available commercially in 2009, the average LOI was short at 0.83 $\pm$ 0.64 yrs; the LOI for the matched PS group was 0.87 $\pm$ 0.65 years ($p = 0.993$). The most common reason for revision in the Logic group was infection (10 of the 20 knees), followed by stiffness