The Journal of Arthroplasty xxx (2016) 1–6

Contents lists available at ScienceDirect

The Journal of Arthroplasty

journal homepage: www.arthroplastyjournal.org

Original article

Comparative Fixation and Subsidence Profiles of Cementless Unicompartmental Knee Arthroplasty Implants

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ARTICLE INFO

Article history:
Received 4 December 2015
Received in revised form
15 January 2016
Accepted 12 February 2016
Available online XXX

Keywords:
UKA
cementless
fixation
micromotion
subsidence

ABSTRACT

Background: Aseptic loosening is the primary cause of failure for both cemented and cementless unicondylar knee replacements (UKRs). Micromotion and subsidence of tibial baseplate are two causes of failure, due to poor fixation and misalignment, respectively.

Methods: Stair ascent activity profiles from Bergmann et al and Li et al were used. Biphasic Sawbones models were prepared according to the surgical techniques of traditional and novel cementless UKRs. Implants were tested for 10,000 cycles representing post-operative bone interdigitation period, and micromotion was observed using speckle pattern measurements, which demonstrated sufficient resolution. Additionally, the test method proposed by Liddle et al was used to measure subsidence with pressure sensors under increasingly lateralized loading.

Results: Mean displacement due to micromotion for mediolateral and anteroposterior plane was consistently greater for traditional cementless UKR. Mean displacement for axial micromotion was significantly higher for traditional UKR at the anterior aspect of the implant; however, values were lower for the medial periphery of the implant. Subsidence was significantly lower for the novel design with increasingly lateralized loading, and indentation was not observed on the test substrate, when compared to the traditional design.

Conclusion: Our findings demonstrate that the novel cementless design is capable of fixation and elimination of subsidence in laboratory test settings. Both designs limit micromotion to below the established loosening micromotion value of 150 μm. The L-shaped keel design resists both micromotion and subsidence and may prevent failure modes that can lead to aseptic loosening for UKRs. These findings are highly relevant for clinical application.

Aseptic loosening is a primary failure mode of unicondylar knee arthroplasty (UKA) [1-4]. Most loosening cases involve the tibial component, which is prone to instability through two mechanisms [1,5]. First, micromotion under shear stress may prevent adequate fixation at the bone-implant interface [6]. Repeated micromotion stimulates ingrowth of fibrous tissue that may prevent subsequent osseointegration [2,6]. Second, component misalignment may result in eccentric loading of the tibial component by the femoral component [1]. The resulting abnormal force distribution may lead to tibial baseplate subsidence, insert dislocation, or polyethylene fracture [7-10].

Cementless UKA was introduced in the 1980s, in an effort to reduce the incidence of revision [2]. Three dimensional printed porous structures provide a surface which interdigitates with surrounding cancellous bone [11]. This technology permits secure implant fixation while avoiding potential pitfalls of cementation such as mantle failure, extrusion, loose bodies, and particle-induced osteolysis [1,2]. Studies have demonstrated equivalent outcomes between cementless and cemented UKA [3,12]. However, the former has the potential to remain susceptible to aseptic loosening and tibial baseplate subsidence. Optimizing biological fixation and maintaining a uniform load distribution therefore

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One or more of the authors of this paper have disclosed potential or pertinent conflicts of interest, which may include receipt of payment, either direct or indirect, institutional support, or association with an entity in the biomedical field which may be perceived to have potential conflict of interest with this work. For full disclosure statements refer to http://dx.doi.org/10.1016/j.arth.2016.02.034.

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http://dx.doi.org/10.1016/j.arth.2016.02.034
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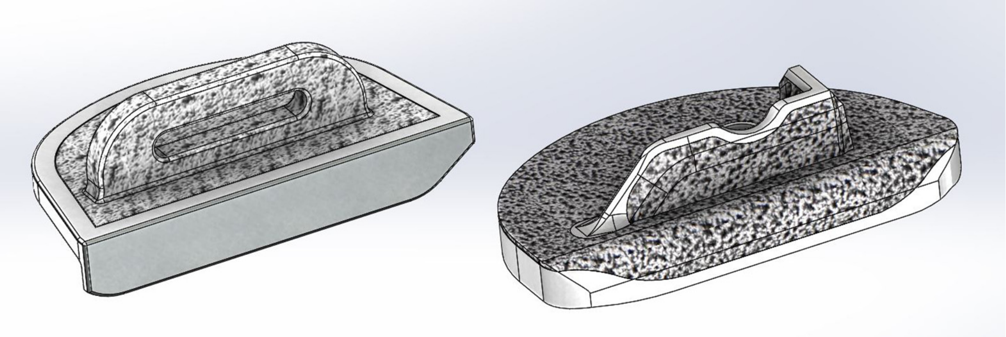

Fig. 1. Oxford Cementless (left) and Tritanium UKR (right) designs.

represent 2 key objectives toward the advancement of cementless UKA prostheses.

Recent advances in additive manufacturing have allowed the production of porous materials that accurately reproduce the structure of cancellous bone [13]. This may influence both the biological fixation and load-bearing properties of cementless implants. We hypothesized that a novel cementless UKA design implementing an additively manufactured porous titanium surface would exhibit equivalent or less micromotion and tibial component subsidence under physiologic loading conditions.

Materials and Methods

Implants

Two cementless UKA implants were directly compared in this study. The fixed bearing Stryker Tritanium UKR (Stryker Orthopaedics, Mahwah, NJ) incorporates a porous technology at the tibial baseplate (Fig. 1). The porous technology refers to a trabecular microstructure consisting of titanium alloy (Ti-6Al-4V), produced by an additive manufacturing process similar to processes outlined previously [11]. A right-angled tibial keel resists shear forces in both the coronal and sagittal planes (Fig. 1). The implant is inserted via a robotic arm–assisted technique according to the manufacturer's instructions similar to the process outlined previously in detail [14].

The mobile bearing Oxford Cementless (Zimmer Biomet, Warsaw, IN) is a modification of the cemented Oxford III. The tibial baseplate features a plasma-coated titanium and calcium hydroxyapatite coating [2,15]. This implant uses a straight keel with a longitudinal slot (Fig. 1) [2]. The Oxford Cementless is inserted with a manual technique, which has also been previously described [16].

Micromotion Testing

Biphasic bone models were constructed to measure implant micromotion under cyclical loading conditions. Each implant was tested 6 times with an individual specimen. Each specimen consisted of a new tibial construct, based on Sawbones (Pacific Research Laboratories Inc, Vashon Island, WA). Sawbones tibial block density was selected to replicate severely osteoporotic bone, featuring a 12.5 PCF polyurethane cancellous shell and 40 PCF cortical shell [17].

Tibial implants were inserted into the medial aspect of the Sawbones tibias using the manufacturer recommended surgical technique. Although the system is not cleared for use as bicompartmental UKR, implants were also inserted into the lateral aspect to balance the joint loads obtained from published total knee arthroplasty (TKA) data [18,19]. Manual placement of the Oxford Cementless implant required an implant-specific preparation consisting of burring an oval shape on the Sawbones surface ½ millimeter deep under the medial cut of the tibial baseplate due to a proud plasma coating region (Fig. 2). This was performed to ensure optimal implant seating and circumferential cortical contact. Tibial assemblies were spray painted with a black and white speckle pattern coating to track micromotion (Fig. 3A,B). Femoral constructs consisted of the femoral component cemented into an arbor positioned overhead (Fig. 3A).

Compressive load parameters were set to model stair ascent. Studies have demonstrated that this activity of daily living (ADL) generates among the highest forces on the knee (3.16-fold body weight) [20]. Implant micromotion is highly probable during stair climbing, secondary to high axial forces at the posterior tibial articulation [6,21]. The load was scaled to 60%, which represents the lower boundary of the standard deviation obtained from clinical data, to avoid damaging the tibial constructs [6,18].

Specimens were subjected to loading at 10,000 cycles using a 4-axis servohydraulic test machine (MTS Systems Corp, Eden Prairie, MN). Run-time corresponded to 13% of all ADL performed over an 8-week postoperative period [19]. Peak-Peak (P-P) micromotion between the baseplate and Sawbones in the coronal, sagittal, and axial axes was recorded at 3 locations (Fig. 4A-4C). Measurements were taken with the ARAMIS optical 3D deformation analysis system (GOM mbH, Braunschweig, DE) at time zero and after 10,000 cycles.

Lateral Subsidence Testing

Lateral subsidence under eccentric femoral loading was measured using the method outlined by Liddle et al [22]. Six specimens were prepared, each using a polyurethane Sawbones block to simulate the tibial plateau. A Tritanium UKR was inserted into the medial compartment of each specimen according to the manufacturer's instructions. The thickest available polyethylene insert (12 mm) was used to generate the largest moment under lateralized loading. Two thin-film pressure sensors (Tekscan Inc, Boston, MA) were inserted between the tibial baseplate and underlying Sawbones block, flanking the tibial keel in a parallel orientation to the anteroposterior (A/P) axis of the baseplate (Fig. 5) [22].

Tibial constructs were positioned in a vice under a servohydraulic test machine (MTS Systems Corp). A 32-mm spherical ball indenter of equivalent diameter to the femoral component was used as the end effector (Fig. 6). The indenter was aligned with the tibial sulcus, and an axial load of 2272 N was applied [18]. Corresponding to the peak force exerted on the knee at 90 degrees of flexion (3.16-fold body weight) during stair ascent, this load was used for dynamic calibration [1].

The loading process was repeated at the tibial sulcus, representing 0 degrees of flexion. Pressure values were retrieved from