Backside Wear in Modern Total Knee Designs

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Abstract Although modularity affords various options to the orthopedic surgeon, these benefits come at a price. The unintended bearing surface between the back surface of the tibial insert and the metallic tray results in micromotion leading to polyethylene wear debris. The objective of this study was to examine the backside wear of tibial inserts from three modern total knee designs with very different locking mechanisms: Insall-Burstein II® (IB II®), Optetrak®, and Advance®. A random sample of 71 inserts were obtained from our institution's retrieval collection and examined to assess the extent of wear, depth of wear, and wear damage modes. Patient records were also obtained to determine patient age, body mass index, length of implantation, and reason for revision. Modes of wear damage (abrasion, burnishing, scratching, delamination, third body debris, surface deformation, and pitting) were then scored in each zone from 0 to 3 (0=0%, 1=0–10%, 2=10–50%, and 3=>50%). The depth of wear was subjectively identified as removal of manufacturing identification markings stamped onto the inferior surface of the polyethylene. Both Advance® and IB II® polyethylene inserts showed significantly higher scores for backside wear than the Optetrak® inserts. All IB II® and Advance® implants showed evidence of backside wear, whereas 17% (5 out of 30) of the retrieved Optetrak® implants had no observable wear. There were no significant differences when comparing the depth of wear score between designs. The locking mechanism greatly affects the propensity for wear and should be considered when choosing a knee implant system.

Key words polyethylene · wear · knee · backside · back surface · locking mechanism

Introduction

Since 1977, Hospital for Special Surgery was collecting total joint replacements removed at revision surgery. Today, over 17,000 implants reside in the retrieval system. Examination of retrieved implants is one of the few ways to assess in vivo performance of these orthopedic devices and has often led to early warnings of unanticipated problems. Examples include identification of casting defects in cobalt alloy stems [1], premature wear-related failures of carbon-fiber-reinforced and heat-pressed polyethylenes [2–5], and the deleterious effects of oxidative degradation on polyethylene wear resistance [6–9]. Studying retrieved implants is also an opportunity to complete the design loop. Designing new implants often relies on finite element analysis and preclinical laboratory testing to support the introduction of the design into clinical use. The analysis of implants retrieved at revision surgery provides valuable information about clinical performance that can be used to justify design changes and to modify designs whose performance proves inadequate. An example was the ongoing assessment of wear in total condylar knee designs, leading to improvements from the IB I® to the IB II® to the Optetrak® and Advance® designs [10–12].

In the current study, access to large numbers of implants of related designs was used to evaluate implant wear in modular total knee replacements. Modularity is a common design feature of nearly all commercially available total knee replacements. Modularity is advantageous to the surgeon by allowing intraoperative choice with regard to the component thickness and implant constraint [13, 14]. At revision, modularity allows exchange of worn polyethylene inserts without disturbing the bony fixation of the metallic tray [13, 15, 16]. Modularity also provides the surgeon with access to fixation surface so that adjuvant screw fixation can be used before inserting the polyethylene.

These benefits, however, come with a price. For example, the additional interface between a tibial polyethylene insert and the underlying superior surface of the metallic tray creates an unintentional bearing surface. Micromotion is inevitable at this interface, therefore creating a source of polyethylene wear debris [17–20].

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Clinical reports have correlated instances of implant failure caused by osteolysis with tibial inserts found to be worn and loosely fitting within their metallic trays [21–24]. This backside wear on the nonarticulating surface is thought to be of greater significance than that on the articular surface because of the larger degree of contact between the polyethylene and metal baseplate [25].

In certain modular implants, holes intended for adjunct screw or cement fixation allow egress of debris directly to the fixation interfaces [18, 25]. Protrusions of polyethylene were also noted to occur from the undersurface of the insert into these screw holes [26, 27], most likely caused by creep of the polyethylene secondary to the large compressive forces applied to the articular surface upon weight bearing [25–27].

A number of factors affect the propensity for backside wear. These include the design of the articular surfaces, which affects the stress distribution through the insert [28], the surface finish of the metallic tray in contact with the insert, which affects abrasive and adhesive polyethylene wear [29], and the implantation time of the insert [20, 30]. The mechanism used to lock the insert in the tray was also shown to affect the propensity for wear. Because wear requires micromotion, the locking mechanism may be the most important factor [31].

To explore the influence of locking mechanisms, we examined retrieved inserts and trays from three metal-backed total knee replacement designs for evidence of backside wear. The three designs have very different locking mechanisms; however, all three have similar articular surface geometries on both the femoral and tibial components, incorporating condylar, toroidal shapes. Thus, the contact stresses and load distribution are similar, minimizing them as a confounding factor influencing difference in backside wear between the designs. One of the designs, the Insall Burstein® II (IB II®, Zimmer, Warsaw, IN, USA), has had successful long-term follow-up [32, 33], allowing the opportunity to explore the relationship between backside wear and clinical performance among these designs.

Materials and methods

A random sample of 30 IB II® (Zimmer) and 30 Optetrak® (Exactech, Gainesville, FL, USA) (from a sample population of 154 and 109, respectively) were obtained from the Hospital for Special Surgery retrieval system. Only 11 Advance® (Wright Medical Technologies, Arlington, TN,

Table 2 The number of patients that were revised for each of the listed reasons

	Infection	Aseptic Loosening	Mechanical Failure/Pain	Fracture/Dislocation
IB II®	7	9	13	1
Optetrak®	12	2	14	2
Advance®	4	–	6	–

Unavailable for one patient in Advance group.

USA) implants were available; given the small sample size, all were included in the study. Patient records were available for all IB II® and Optetrak® implants and 10 of 11 of the Advance®. Under a protocol approved by the Institutional Review Board, records were used to determine patient age, body mass index (BMI), the length of time the components had been implanted, and reason for removal/revision (Tables 1 and 2).

Different mechanisms are employed in these three designs for capturing the polyethylene insert in the metal tray (Fig. 1). The IB II® captures the polyethylene with interconnecting dovetails on the insert and on the anterior and posterior walls of the metallic tray. An anterior locking pin is used to prevent medialateral movement between the insert and tray. Conversely, the Optetrak design has a partial peripheral capture, whereas the Advance implant has rails that extend around the posterior half of the tray with two central anterior metallic locking posts. The backsides of all of the polyethylene inserts were machined. The superior surface of all of the tibial trays of all designs had a matte finish.

All inserts were assessed for extent of wear, depth of wear, and wear damage modes. The back surfaces of the implants were examined with a light stereomicroscope at a $\times 10$ magnification. To assess the location of wear on the tibial inserts, we defined four zones: anterolateral, posterolateral, anteromedial, and posteromedial (Fig. 2). Modes of wear damage, including abrasion, burnishing, scratching, delamination, third body debris, surface deformation, and pitting, were each assigned a score from 0 to 3 for each of the four zones. If a damage mode was absent from a zone, a grade of 0 was assigned, grade 1 if the wear mode occurred in less than 10% of the quadrant, grade 2 if in 10 to 50%, and grade 3 was assigned if more than 50% of the surface of that section was affected [34]. Wear scores in all quadrants were summed to determine a total damage score for each individual insert.

The depth of wear was subjectively identified as removal of material using a technique unique to backside wear. For inserts from two of the three designs (IB II® and Advance®), the manufacturer had stamped identification numbers onto the inferior polyethylene surface. The depths of these stamped markings were measured with a coordinate measuring machine to be at least 0.03 mm [18]. The absence of these stampings in retrievals indicated a loss of polyethylene to at least the depth of the stamping. The wear was scored subjectively using a 0 to 2 grading system to indicate no, partial, or complete removal of markings. The

Table 1 Patient demographics for retrieved implants of the three designs

	BMI	Age (Years)	Length of Implantation (Years)
IB II®	32 ± 17	63 ± 36	3.6 ± 6.4
Optetrak®	29 ± 12	66 ± 31	2.6 ± 2.9
Advance®	27 ± 6	69 ± 11	2.4 ± 2.8

Fig. 1. Images of tibial insert and tray for each of the three evaluated designs: (A) IB II®, (B) Optetrak®, and (C) Advance®

manufacturer of the Optetrak® design does not stamp the back of the polyethylene inserts with markings; therefore, this analysis could not be performed on these implants.

A one-way analysis of variance was used to compare total wear scores among designs, and Spearman's correlation was used to compare patient demographics with the implant wear grades. The type I error rate, alpha, was set at 0.05.

Results

Both IB II® and Advance® polyethylene inserts showed significantly ($p < 0.05$) higher scores for backside wear (Fig. 3) than the Optetrak® inserts, although backside wear

scores were not significantly different between the IB II® and Advance® inserts. All IB II® and Advance® implants showed evidence of wear, whereas 17% (5 out of 30) of the retrieved Optetrak® implants had no backside wear that could be identified at $\times 10$ magnification.

Burnishing and pitting were the dominant wear damage modes and were observed on the backsides of inserts from all three designs. All IB II® and Advance® inserts showed evidence of burnishing compared to 80% (6 out of 30) of the Optetrak® implants. Pitting was also least common in the retrieved Optetrak® implants (30% or 10 out of 30). Surface deformation and scratching was also noted but were a rare finding with less than 5% of retrieved inserts having evidence of these wear modes. No other damage modes were found in any of the designs.

No significant differences existed among the patients who had received the three designs when comparing the weights, heights, or ages. However, a significant positive correlation was found between length of implantation and the cumulative wear score for the IB II® implants ($r = 0.69$,

Fig. 2. Backside surface of an IB II® polyethylene insert retrieved after 6 months of implantation. Each surface was divided into four quadrants: AL = anterolateral, PL = posterolateral, AM = anteromedial, PM = posteromedial. Despite the short implantation time and the lack of removal of the markings, the surface shows mild burnishing and extrusion of polyethylene consistent with grade 2 creep

Fig. 3. Total backside wear score comparison for the three designs. Both the IB II® and Advance® inserts had significantly higher wear grades than the Optetrak® inserts (*significant difference, $p < 0.05$)

Fig. 4. Backside of an Advance® tibial insert with complete removal of the manufacturer's markings on the left side, consistent with a grade 2, and a partial removal of the markings on right side, consistent with a grade 1

$p=0.01$). The IB II® implants had been in use for a longer time than the other two designs (Table 1).

No correlation was found among the location on the backside (anteromedial, anterolateral, posteromedial, and posterolateral) and the wear scores for any of the three implant designs. Similarly, no significant differences were found in depth score (the removal of the stamped markings) on the undersurface of the IB II® and Advance® implants (Fig. 4).

Discussion

Wear in modular total knee replacements is dependent on a number of variables, including the bearing materials, articular surface design, surface finish, joint kinematics and loads, and locking mechanism design. Although all of these factors are important, the suggestion that the majority of wear from knee implants comes from the backside [25] highlights the importance of examining the effect of locking mechanisms. One hundred percent of both IB-II® and Advance® inserts and 80% of the Optetrak® implants showed evidence of backside wear, confirming that this unintentional source is increasing implant wear, the release of particulate debris, and, therefore, the potential for osteolysis and implant failure.

The predominant wear mode in all three designs was burnishing, consistent with micromotion leading to adhesive and abrasive wear mechanisms, even in the more contemporary Optetrak® design. Although some pitting, scratching, and surface deformation was evident, more severe damage modes such as delamination were absent. The finding by Crowninshield et al. [35] of bone cement debris leading to pitting on the back surface was not observed in this study. Instead, the pits had a similar appearance to those found on the articular surfaces of many tibial components, consistent with material removal from fatigue wear mechanism.

The designs we chose to examine, IB II®, Optetrak®, and Advance®, have very similar condylar articulating surface geometries, but very different locking mechanisms.

The result that both the IB II® and Advance® implants had significantly higher wear scores can be explained by design differences. Whereas the large anterior/posterior dovetails of the IB II® greatly minimized motion in these directions, the use of an interlocking pin did not eliminate medial-lateral motion. This locking pin was designed to be inserted anteriorly, compressed, and snapped into place. Medial-lateral loads could compress the pin, allowing motion between the polyethylene insert and the metallic tray.

The Advance® uses a posterior locking rail and two centrally placed anterior metallic locking posts. Whereas posterior movement is minimized by the rail, the anterior central locking posts do not fully restrain the polyethylene insert under high loads. Instances were found in which the posts had deformed the surrounding polyethylene, consistent with such loading.

Both the IB II® and Advance® designs use a partial capture mechanism, restraining motion in one plane, but providing only partial restraint in other planes. The Optetrak® design, however, uses a full peripheral capture to restrain motion in all directions. The result is a significant reduction in the amount of backside wear compared with the other two implants examined in this study.

This study was focused on the effect of locking mechanism design. This is not to diminish the impact of other manufacturing factors, such as surface finish of the metallic tibial tray, which can profoundly influence backside wear. For example, many other contemporary designs have a polished finish. Reducing the roughness of the tray surface by polishing should reduce polyethylene wear, provided the locking mechanism is sufficient to restrain the tibial insert. Otherwise, the reduced coefficient of friction between a polished metallic surface and polyethylene (compared to between a matte surface and polyethylene) might have the unintended effect of increasing micromotion and wear. Nonetheless, the results of this study suggest that locking mechanism is indeed an important consideration for the orthopedic surgeon in choosing a knee implant design that will minimize the potential for polyethylene wear.

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