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In Vivo Wear Performance of Cobalt-Chromium Versus Oxidized Zirconium Femoral Total Knee Replacements

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ABSTRACT

This study examines the damage and wear on the polyethylene (PE) inserts from 52 retrieved Genesis II total knee replacements to identify differences in tribological performance between matched pairs of cobalt-chromium (CoCr) and oxidized zirconium (OxZr) femoral components. Observer damage scoring and microcomputed tomography were used to quantify PE damage and wear, respectively. No significant differences were found between CoCr and OxZr groups in terms of PE insert damage, surface penetration, or wear. No severe damage such as cracking or delamination was noted on any of the 52 PE inserts. Observer damage scoring did not correlate with penetrative or volumetric PE wear. The more costly OxZr femoral component does not demonstrate clear tribological benefit over the standard CoCr component in the short term with this total knee replacement design.

Reducing the amount polyethylene (PE) bearing wear in total knee replacements (TKRs) has received significant attention over the past decades. The use of ethylene oxide instead of gamma radiation or electron beam as a sterilization method in the manufacturing process of PE inserts has been proven to be effective in eradicating delamination wear in vivo [1-4] and was associated with a 98% survivorship in individual studies at a follow-up at the 5-year [5] and 10-year interval [6]. Other measures to reduce clinical PE wear have included the development of different types of cross-linked PE [7-9]. However, its use has been limited in TKRs thus far due to altered mechanical properties compared with conventional non–cross-linked PE [10]. These reduced properties risk fracture of the post in posterior stabilized designs after long implantation periods [11].

Genesis II TKR prostheses (Smith & Nephew, Memphis, TN) are a well-functioning joint replacement with excellent clinical results [12]. The Genesis II PE bearing is a machined, ram-extruded, ultra-high-molecular-weight PE insert, which is sterilized by ethylene oxide to prevent damaging free radical production. The PE inserts, therefore, have no molecular cross-linking. The Genesis II femoral components are available in highly polished cobalt-chromium (CoCr) and oxidized zirconium (OxZr) surface finishes. The OxZr components are a "premium" implant with increased cost compared to CoCr implants and, as such, are generally indicated with a specific clinical benefit in mind. Oxidized zirconium components are well functioning [13] and are often indicated for patients with a suspected nickel sensitivity, in which a CoCr component might create a local allergic reaction.

Neither survivorship nor patient-reported outcomes are different between CoCr and OxZr components [14,15], with marginally more patients preferring their CoCr knee to their OxZr knee in bilateral cases [16]. As well, the PE wear particles generated in vivo are reportedly identical in shape and size between CoCr and OxZr femoral components [14]. The benefit of OxZr components potentially lies in the theoretical reduction of PE wear thanks to a tribologically superior zirconia surface. Retrieval analysis of Genesis II TKRs has shown that OxZr components retain their initial surface smoothness better than CoCr components which scratch, gouge, and abrade to a greater extent in vivo [17-19]. Increased surface roughness in CoCr components has been linked to higher associated PE damage compared to OxZr components [17]. In vitro tests, in particular, have shown significant wear reduction with the OxZr components [20,21], but in vivo wear has been previously examined via retrieval analysis in only 1 study that examined solely CoCr components [22]. Polyethylene insert wear has not been compared between CoCr and OxZr femoral component materials via retrieval analysis.

The purpose of this study was to examine the damage and wear (and associated plastic deformation) of the PE inserts from matched pairs of

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CoCr and OxZr Genesis II TKRs to determine if there is a difference in tribological performance.

Materials and Methods

An implant retrieval study by Brandt et al [19] examined the surface damage on the femoral components of 26 matched pairs of CoCr and OxZr Genesis II TKRs. These 26 pairs of retrieved TKRs were matched based on their implantation period, body mass index, sex, and PE type insert (posterior stabilized [PS] or cruciate retaining [CR]). The details of this cohort of retrieved TKRs have been previously reported [19] and have been included for reference in Table 1. Of the 52 TKRs selected, 14 were a CR-type insert, whereas 38 were a PS-type insert. There were 28 male patients and 24 female patients in total.

Damage Assessment

Surface damage on the retrieved PE inserts was assessed using a modified semiquantitative grading method as described by Brandt et al [23]. This method assesses the area and severity of surface damage to allow for more precise identification of PE insert damage compared to previous methods [24,25]. Three independent observers performed the damage scoring, and an average score was calculated. The inserts were subdivided into distinct surface areas, including the articulating surface and backside for both the PS and CR inserts, as well as the post in the 38 PS-type inserts. The following damage features were identified and graded for each region of the PE inserts: burnishing, grooving, indentations, deformation, pitting, striations, embedded particles, and extra-articular damage. The mean damage scores across all 3 observers for each damage feature were summed to obtain a total damage score per region of the PE insert. These regional damage scores were again summed to obtain a total damage score for each PE insert.

Radiographic Assessment

The pre-revision surgery plain films of the study patients were obtained and used to calculate the varus/valgus alignment as well as the posterior tibial slope of the primary implants from as near to the time of revision surgery as was available. Plain films were not available for 9 of the OxZr patients in this study. A total of 17 of 26 CoCr patients and 16 of 26 OxZr patients had plain films suitable for mechanical axis measurement, whereas 16 of 26 CoCr and 15 of 26 OxZr patients had plain films suitable for tibial posterior slope measurement.

A standardized technique was used to measure the mechanical axis on the full-length limb plain films [26]. For the femoral angle, a line was drawn from the center of the femoral head to the femoral condylar midpoint. For the tibial angle, a line was drawn from the center of the tibial plafond to the center of the tibial plateau. In the event that the tibial plafond was not visualized on the plain film, this technique was modified by drawing the line from the center of the distal tibial intermedullary canal to the center of the tibial plateau. The resulting intersection of these 2 lines was then measured and described as being varus or valgus.

A modified version of a standardized technique described by [27] was used to measure the tibial posterior slope. On the lateral knee plain films, a line was drawn along the center of the tibial intermedullary canal. A second, perpendicular line was drawn along the cross-sectional diameter of the tibial component of the implant. The resulting angle from the intersecting lines was subtracted from 90° to calculate the tibial posterior slope. In the event of anterior subluxation of the component, a negative value was assigned to the value.

Table 1
Retrieval Characteristics of Patients That Received a CoCr Alloy Femoral Component and OxZr Femoral Component (Mean ± 95% Confidence Interval).

Retrieval Characteristics	CoCr (n = 26)	OxZr (n = 26)	*P*
Implantation period (mo)	23.10 ± 4.99	21.93 ± 4.58	.725
Body mass index (kg/m^2)	34.71 ± 2.72	35.43 ± 3.10	.719
Mass (kg)	97.61 ± 8.15	100.79 ± 9.86	.611
Height (cm)	167.53 ± 2.59	168.67 ± 5.11	.683
PE insert thickness (mm)	11.77 ± 1.55	11.92 ± 1.44	.882
Patient age at revision surgery	66.15 ± 3.78	59.79 ± 3.43	.013
Reason for revision	Infection, n = 8 Loosening, n = 1 Instability, n = 9 Stiffness, n = 4 Pain, n = 2 Periprosthetic fracture, n = 1 Patellar issue, n = 1	Infection, n = 8 Loosening, n = 2 Instability, n = 4 Stiffness, n = 8 Pain, n = 3 Malposition, n = 1	

Wear Assessment

Microcomputed tomography was used to obtain the surface geometry of the retrieved PE inserts and approximate the in vivo wear and plastic deformation from the top and backside surfaces of the inserts. All 52 retrieved PE inserts were scanned using microcomputed tomography (Vision 120; GE Health Care, London, Canada) to obtain the precise surface geometry. Scans were performed with an isotropic voxel spacing of 50 μm, using a previously described protocol [28], and the surface geometries were reconstructed at the maximum quality settings. New, never-implanted PE inserts covering the range of sizes matching the retrieved PE inserts were obtained from the manufacturer and scanned with the same protocol to serve as unworn reference geometries. The articular and backside surfaces of the surface geometries were coregistered between each retrieved PE insert and the appropriate reference PE insert, using a previously described registration method [29]. Deviations between the reference and retrieved PE insert surfaces, representing wear and creep, were calculated and mapped across the surface geometries (Fig. 1). Maximum linear penetration within each worn area identified on the surface geometry deviation map was measured on the medial and lateral condyles and on the backside surface. Wear volume within these locations was also measured. Wear rates were calculated by dividing the penetration by implantation time (millimeters per year) and by dividing the volume by implantation time (cubic millimeters per year). Never-implanted inserts were unavailable to match 2 PE inserts from the OxZr group, and therefore, these 2 were excluded from the analysis.

Statistical Analyses

The Kolmogorov-Smirnov test was used to assess normality of the data. For nonparametric data, Wilcoxon 2-sample tests were used to determine statistical significance between groups, whereas Spearman tests were used to determine correlation between variables. Finally, multiple regression analysis was performed to determine if patient age was a significant contributor to penetration depth and wear volume while controlling for the effect of implantation period.

Results

Damage Assessment

No significant differences in surface damage features were found between the CoCr and OxZr PE inserts, with the exception of articulating surface and backside deformation (Fig. 2A and B) ($P < .05$). All retrieved PE inserts displayed evidence of in vivo damage, with the majority of damage being burnishing of the articulating surface. Grooving, indentations, pitting, and striations were also commonly seen on the articulating surface of the PE inserts (Figs. 2 and 3).