Rotating-platform Has No Surface Damage Advantage Over Fixed-bearing TKA

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Abstract

Background Rotating-platform TKA, although purported to have superior kinematics, has shown no clinical advantages over those of fixed-bearing TKA. Our design-matched retrieval study aimed to investigate if differences in bearing wear damage exist between fixed- and mobile-bearing TKAs with similar condylar geometry.

Questions/purposes We asked whether (1) the rotating platform's more conforming tibiofemoral articulation

would be associated with less severe damage; (2) the location of damage and wear would be similar on the tibiofemoral or backside surfaces of two contemporary designs with similar condylar geometry; and (3) the combined damage and deformation measured as thickness would differ between the two designs.

Methods We performed damage grading and damage mapping on 25 rotating-platform and 17 fixed-bearing inserts. The patient demographic data from each of these cohorts were comparable. Inserts were also laser-scanned from which we obtained thicknesses, and inferior surface three-dimensional scans, from which we determined dimensional changes.

Results Rotating-platform and fixed-bearing inserts had similar tibiofemoral damage scores. However, the scores on the inferior surface of rotating platforms were greater, often as a result of third-body debris scratching observed on both damage mapping and three-dimensional scans. The extent of damage as a function of surface area was greater for rotating platforms, consistent with the greater tibiofemoral conformity. Dimensional changes on the inferior surfaces of the fixed bearing followed loading areas of the knee. However, no differences were seen in the thicknesses between fixed- and rotating-platform bearings.

Conclusions The increased total damage score on the rotating platform, coupled with increased surface area damaged and the propensity for third-body debris, indicates no damage advantage to this mobile-bearing design.

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Introduction

TKA design is challenged by the perceived need to maximize conformity between joint surfaces to reduce contact

stresses and, hence, wear and the need to have less conforming surfaces that reduce load transfer to the fixation interfaces and mitigate possible loosening [1, 15, 25]. The development of the mobile-bearing knee arthroplasty was an attempt to meet both objectives by maximizing conformity at the tibiofemoral surfaces, thus lowering polyethylene stresses but allowing free motion of the polyethylene tibial insert relative to its metallic tray, thereby reducing fixation interface stresses. An initial study following patients with mobile-bearing platforms reported that the majority of patients scored good to excellent in their scoring system, which assessed pain, function, ROM, stability, deformity, and strength [3]. The design concept subsequently evolved from meniscal-bearing designs to include rotating-platform versions. A report on rotating-platform TKAs at 9 to 12 years showed no cases of loosening or osteolysis [4]. However, with longer followup beyond 20 years, osteolysis occurred in 23% of the remaining patients, raising concerns for wear-related failures [5].

A modern version of the rotating platform was introduced in 2000 as the Press Fit Condylar (PFC®) Sigma rotating-platform knee (DePuy, Warsaw, IN, USA). The posterior-stabilized version of this implant has a mobile-bearing implant intended to produce greater femoral rollback afforded by the cam-post interaction [12]. In vivo fluoroscopy of patients undergoing TKA demonstrated this design appears to achieve greater rollback and although motion patterns during daily activities were variable among patients, rotations and displacements were similar to those associated with moderately to highly constrained fixed-bearing knees [26]. Like with earlier mobile-bearing designs, this implant was associated with no observed loosening, bearing complications, or osteolysis [21].

Enthusiasm for the mobile-bearing concept led investigators to determine whether a clinical advantage exists in mobile-bearing over fixed-bearing designs. Randomized clinical trials [17, 19] and recent meta-analyses [22, 27] failed to demonstrate the purported advantages in its use. Specifically, no difference was seen between fixed and rotating bearings in ROM and clinical and functional scoring. These studies were limited as a result of their short followup times. In a previous retrieval analysis [14], we found the extent of polyethylene damage and wear patterns on retrieved mobile-bearing TKAs, even after short implantation, was similar to that seen in historical controls of fixed-bearing implants [11, 28, 29] and rotating platforms [8, 10]. However, this study was and those reported historically are limited by the fact that all mobile-bearing designs, including meniscal and rotating-platform designs with a variety of constraints, were part of the analysis.

In the present study, we limited our analysis to a single design, the PFC® Sigma rotating-platform and fixed-bearing

knees, thus allowing comparison of implants within the same commercial system with the same femoral component geometry. Our research focused on three important questions: (1) is the severity of damage and wear the same on either the tibiofemoral articular or inferior surface between these two implant groups given the similar condylar geometry? (2) Does the more conforming tibiofemoral articulation in the rotating-platform implant change the locations of damage at the inferior surface? (3) Are the combination of wear and deformation measured as component thickness different between the two types of implants?

Materials and Methods

We analyzed 25 rotating-platform and 17 fixed-bearing PFC® polyethylene tibial inserts from our institutional review board-approved retrieved implant program. The 25 rotating-platform inserts were a subset of a cohort in our previous study [14]. Three of the 25 rotating-platform and four of the 17 fixed-bearing inserts were cruciate-retaining; all others were posterior-stabilized. All implants were retrieved from a failed primary TKA. All rotating-platform and fixed-bearing polyethylene was manufactured from GUR 1020 polyethylene and sterilized using gamma sterilization and packed in air-impermeable foil (GVF, gamma vacuum foil sterilization). All rotating-platform and fixed-bearing inserts had cemented tibial and femoral components.

All patients' clinical demographic data are summarized (Table 1). We were unable to obtain demographic data for one of the fixed-bearing implants. Average length of implantation (LOI) for the rotating platforms was 2.0 ± 1.0 years (mean $\pm$ SD; range, 0.4–3.8 years) and 5.4 ± 3.9 years (range, 0.5–11.2 years) for the fixed bearings. Patients who received rotating platforms had an average BMI of 29.8 kg/m^2 (range, $16.2\text{--}43.3 \text{ kg/m}^2$); fixed-bearing patients had an average BMI of 28.0 kg/m^2 (range, $17.7\text{--}36.6 \text{ kg/m}^2$). The highest percentage of rotating platforms were revised for stiffness (32%) followed by infection (28%), osteolysis/loosening (20%), instability (16%), and malpositioning (4%). Fixed-bearing implants were revised mostly for osteolysis/loosening (44%) followed by infection (31%), stiffness (19%), and fracture (6%) (Table 1).

Prerevision radiographs were available for all rotating-platform cases and 14 of the 17 fixed-bearing cases. Flexion/extension and varus/valgus alignment were measured from the lateral and AP films, respectively, by two observers, one for the rotating platform (RF) and one for the fixed bearing (NN) using Picture Archiving and Communication Systems (PACS). Interobserver correlation in lower extremity alignment using PACS is reportedly above 0.93 [18]. Rotating platforms had an average femorotibial

angle of $4.4^\circ \pm 7.4^\circ$ valgus and AP femoral and tibial angles of $7.0^\circ \pm 3.4^\circ$ valgus and $2.5^\circ \pm 5.9^\circ$ varus, respectively. Fixed bearings had an average femorotibial angle of $4.6^\circ \pm 4.4^\circ$ valgus and AP femoral and tibial angles of $5.8^\circ \pm 3.4^\circ$ valgus and $1.0^\circ \pm 1.6^\circ$ varus, respectively. Rotating platforms had average lateral

femoral and tibial angles of $2.8^\circ \pm 4.4^\circ$ flexion and $2.6^\circ \pm 6.7^\circ$ flexion, respectively. Fixed bearings had average lateral femoral and tibial angles of $6.4^\circ \pm 4.7^\circ$ flexion and $6.6^\circ \pm 6.6^\circ$ flexion, respectively (Table 1). The groups were similar with the exception of femoral lateral angle; rotating platforms had lower angles ($p = 0.01$).

Wear damage on both the tibiofemoral and insert tray surfaces of the retrieved polyethylene liners was assessed using light microscopy at $\times 6$ to $\times 32$ magnification. Damage on the tibiofemoral and insert tray surfaces was assessed using our previously published Hood grading score [11, 28]. Briefly, tibiofemoral and insert tray surfaces of the implant were divided into 10 regions (Fig. 1). Within each region, seven damage modes are assessed: burnishing, pitting, scratching, delamination, surface deformation, abrasion, and third-body debris. A scale of 0 to 3 is used to reflect the extent and severity of each damage mode. Scoring was done by two independent observers (SEJ, ST); if scores were markedly different for each scorer, a third independent scorer (KES) was used as a tiebreaker.

Wear damage area was determined by manually replicating the identified damage modes on two-dimensional digital projections of the tibiofemoral and inferior insert surfaces. The total available bearing area and the areas for the individual modes were determined using ImageJ (National Institutes of Health, Bethesda, MD, USA); the areas were recorded as a percentage of the total articular area [14].

To determine the damaged location on the inferior surface, we obtained three-dimensional scans for each insert using a NextEngine 3D Laser scanner (NextEngine Inc, Santa Monica, CA, USA). The implants were first sprayed with aerosol talc. The implants were positioned in the specimen holder of the scanner such that the insert's mediolateral axis was perpendicular to the laser beam. Fixed-bearing implants were aligned perpendicular to the scanner, requiring only one scan. Rotating platforms,

Table 1. Demographic and radiographic patient data for rotating-platform and fixed-bearing cohorts

Variable	Rotating platform	Fixed bearing	p value
Number	25 (3 CR)	17 (4 CR)	0.413
Number of females	15	9	0.812
Length of implantation (years)	2.0 ± 1.0	5.4 ± 3.9	0.019
BMI (kg/m^2)	29.8 (range, 16.2–43.3)	28.0 (range, 17.7–36.6)	0.530
Age (years)	64 (range, 47–85)	66 (range, 47–86)	0.612
Stiffness	8 (32%)	3 (19%)	0.198
Infection	7 (28%)	5 (31%)	0.198
Osteolysis/loosening	5 (20%)	7 (44%)	0.198
Instability	4 (16%)	0 (0%)	0.198
Malposition	1 (4%)	0 (0%)	0.198
Fracture	0 (0%)	1 (6%)	0.198
AP femorotibial (degrees)	4.4 ± 7.4	4.6 ± 4.4	0.999
AP femoral (degrees)	7.0 ± 3.4	5.8 ± 3.4	0.890
AP tibial (degrees)	-2.5 ± 5.9	-1.0 ± 1.6	0.999
Lateral tibial (degrees)	2.6 ± 6.7	6.6 ± 6.6	0.055
Lateral femoral (degrees)	2.8 ± 4.4	6.4 ± 4.7	0.010

Negative radiographic angles represent varus or extension angles where positive angles represent valgus or extension angles. Comparisons were made using Mann-Whitney U tests for continuous variables and chi-square or Fisher's exact tests for categorical variables; CR = cruciate-retaining.

Fig. 1A–B A photograph of the tibiofemoral (A) and inferior (B) surfaces of a rotating-platform insert depicts the 10 damage grading regions.

because of the backside post protruding from the inferior surface, required two scans approximately 45° from the perpendicular of the scanner beam. Multiple images were aligned and merged using the manufacturer's software. In preliminary work, mediolateral posterior-stabilized post widths were measured with digital calipers and then calculated from the meshed digital scans using Geomagic Qualify (Geomagic, Morrisville, NC, USA). We found no difference between the two measurements by a paired t-test, although the calipers have a higher resolution than that of the NextEngine scanner (± 0.064 mm).

The xyz point clouds representing the three-dimensional scans were meshed and analyzed in Geomagic Qualify. Best-fit flat contact planes were fit to the inserts' inferior surfaces. Care was taken to exclude rotating-platform posts and obvious tool marks made during revision surgery. Deviations of the surfaces from the best-fit planes were mapped using the same colorimetric scale for each insert.

Pristine rotating-platform and fixed-bearing inserts were obtained from the manufacturer to compare condylar thicknesses for never implanted inserts with those measured on retrieved inserts of the same sizes. The most common sizes and thicknesses were chosen: size 3 with a 10-mm thickness for rotating platform and size 4 with a 10-mm thickness for fixed-bearing inserts. From our retrieved implants, four rotating-platform inserts and two fixed-bearing inserts were of these respective sizes and thicknesses. Laser scans of the tibiofemoral and inferior surfaces were taken; a best-fit plane was again fit to the inferior surface. The thickness was measured as the perpendicular distance between the minimum of the point cloud of the tibiofemoral surface of each condyle and the inferior plane. This corresponds to the location at which the manufacturer defines the thickness. Standard thickness dimensions and tolerances were also obtained from the manufacturer for both rotating-platform and fixed-bearing inserts; these were 6.68 ± 0.130 mm for the 10-mm thick rotating platform and 8 ± 0.130 mm for the 10-mm thick fixed bearing.

To determine differences in demographic variables between the cohorts, we used nonparametric Mann-Whitney U tests for continuous variables and chi-square or Fisher's exact test for categorical variables. A series of bivariate correlation analyses were run to determine if there were any correlations among damage scores, radiographic femorotibial alignment angles, and continuous demographic variables (age, BMI, LOI). Spearman's rho coefficients were calculated because our data were nonparametric. A Mann-Whitney U test was used to determine differences in wear scores and radiographic images between males and females. To determine differences in damage scores and wear damage areas, nonparametric Mann-Whitney U tests were used. Because we found no difference in our analysis

with or without the inclusion of the cruciate-retaining inserts, data are presented for all of the retrieved implants. Analysis of variance and Mann-Whitney rank sum tests were used to determine if the femorotibial alignment differed between observed scanning patterns in fixed-bearing and rotating-platform designs, respectively. Finally, we compared the measured thicknesses of the two designs with the respective manufacturing standards using a t-test. We also used a two-sample t-test to compare fixed- and rotating-platform insert thicknesses normalized by their respective manufacturing standards.

Results

The average total damage for rotating platforms was greater ($p < 0.001$) than of fixed bearings (Table 1). Rotating platforms had an average total damage score of 77 ± 22 (range, 49–131) and the fixed bearing had an average total damage score of 53 ± 18 (range, 30–99). The tibiofemoral damage scores were not different between the designs. The average rotating-platform tibiofemoral damage score was 38 ± 10 (range, 20–64). The average fixed-bearing tibiofemoral damage score was 43 ± 15 (range, 26–85). On the tibiofemoral surface, burnishing, pitting, and scratching were the dominant damage modes for both designs (Table 2). Rotating platforms had higher average inferior surface damage scores ($p < 0.001$) than fixed bearings. The average rotating-platform inferior surface damage score was 40 ± 14 (range, 22–67). The average fixed-bearing inferior surface damage score was 11 ± 7 (range, 0–25). Like with the tibiofemoral surface, the primary damage modes were burnishing, pitting, and scratching (Table 2).

Table 2. Total average damage scores for each of the seven damage modes as seen on the tibiofemoral and inferior surfaces of rotating-platform and fixed-bearing inserts

Damage mode score	Rotating platform		Fixed bearing	
	Tibiofemoral	Inferior surface	Tibiofemoral	Inferior surface
Burnishing	18.1 ± 5.2	14.4 ± 6.9	17.1 ± 3.1	5.9 ± 5.2
Pitting	9.9 ± 6.1	10.3 ± 7.4	11.5 ± 6.2	3.1 ± 4.7
Scratching	8.8 ± 4.6	14.3 ± 6.6	8.5 ± 4.7	1.2 ± 3.3
Third-body debris	0.6 ± 1.1	0.4 ± 1.1	2.4 ± 4.9	0.0 ± 0.0
Abrasion	0.5 ± 1.3	0.0 ± 0.0	0.8 ± 1.4	0.0 ± 0.0
Deformation	0.1 ± 0.6	0.1 ± 0.4	1.9 ± 1.3	0.0 ± 0.0
Delamination	0.0 ± 0.0	0.0 ± 0.0	0.7 ± 1.5	0.0 ± 0.0
Surface total	38 ± 10	40 ± 14	43 ± 15	11 ± 7
Implant total	77 ± 22		53 ± 18	

Data are presented as mean $\pm$ SD.

Table 3. Regional damage scores of the tibiofemoral and insert tray surfaces for both rotating-platform and fixed-bearing inserts

	Region	Rotating platform		Fixed bearing	
		Tibiofemoral	Inferior surface	Tibiofemoral	Inferior surface
Medial plateau	0	4.9 ± 1.4	4.3 ± 1.4	5.0 ± 2.4	1.1 ± 0.7
	1	4.5 ± 1.3	3.9 ± 1.5	4.4 ± 2.5	1.0 ± 0.9
	2	4.6 ± 1.3	3.8 ± 1.7	4.5 ± 1.9	1.1 ± 0.9
	3	4.7 ± 1.3	4.2 ± 1.5	5.2 ± 1.9	1.2 ± 0.7
Lateral plateau	4	4.2 ± 1.4	4.0 ± 1.7	4.5 ± 2.0	1.0 ± 0.9
	5	4.5 ± 1.2	4.0 ± 1.7	4.5 ± 1.7	1.3 ± 0.9
	6	4.8 ± 1.7	4.0 ± 1.6	5.6 ± 1.3	1.1 ± 0.9
	7	4.8 ± 1.5	4.2 ± 1.6	5.2 ± 2.3	1.1 ± 0.9
Post	8	0.3 ± 1.0	3.7 ± 1.5	1.9 ± 2.0	0.8 ± 0.9
	9	0.4 ± 0.9	3.2 ± 1.8	1.9 ± 1.3	0.8 ± 0.8

Data are presented as mean ± SD.

Fig. 2 Graph of the average damage scores for each of the individual tibiofemoral grading regions of both fixed- and rotating-platform (RP) inserts shows that the post regions (8 and 9) had lower ($p < 0.001$) damage scores than all other regions regardless of design. Rotating-platform post regions had lower ($p < 0.001$) damage scores than fixed-bearing regions.

The individual damage scores of regions 0 to 9 for both the tibiofemoral and inferior surfaces were investigated for regional differences (Table 3). When comparing within a design, tibiofemoral damage scores did not differ among regions located in the medial and lateral plateaus (regions 0–7). In both designs, tibiofemoral regions 8 and 9, located at the post, had lower damage scores ($p < 0.001$) than the plateau regions (Fig. 2). When comparing between the two designs, the tibiofemoral post damage scores were lower ($p < 0.001$) for the rotating platform than the fixed bearing. On the inferior surface, no differences were found between the same regions within the same design; however, rotating-platform inferior surfaces had higher damage scores ($p < 0.001$) than fixed-bearing surfaces.

Fig. 3A–B Graphs of the damage score versus length of implantation are shown for rotating-platform (A) and fixed-bearing inserts (B). The reason for revision is depicted by different colored markers.

The two cohorts were similar with the exception of LOI; rotating platforms had shorter LOI ($p = 0.019$) and femorolateral angle; rotating platforms had lower angles ($p = 0.01$). BMI correlated with ($p = 0.006$) the femorolateral angle and LOI correlated with ($p = 0.042$) tibiofemoral damage scores. Distribution of damage score, LOI, and reason for revision of both cohorts are depicted (Fig. 3).

The extent of tibiofemoral surface damage, seen as area covered by burnishing, was greater ($p < 0.001$) (Fig. 4A). The extent of inferior surface damage was also greater ($p < 0.001$) for the rotating platform than the fixed bearing (Fig. 4B). Scratching was more common ($p < 0.001$) on the inferior surface of the rotating-platform than the fixed-bearing inserts (Fig. 4B), primarily as a result of entrapment of third-body debris. Scratching observed on the inferior surfaces as concentric rings was reflected dimensionally on the laser scans (Fig. 5).

Laser scans revealed distinct patterns of dimensional changes that differed between rotating-platform and

Fig. 4A–B Graphs of the percent of projected area covered by specified damage modes are shown for the tibiofemoral (A) and inferior surfaces (B) of fixed-bearing and rotating-platform (RP) inserts. Rotating-platform inserts had more burnishing ($p < 0.001$) on both tibiofemoral and inferior surfaces.

fixed-bearing inserts. Rotating platforms showed mostly uniform dimensional changes across the inferior surface (Fig. 6), consistent with the broad, flat, highly conforming bearing between this polyethylene surface and the polished superior surface of the metallic tray. The exceptions were the components with severe concentric rings described (Fig. 5A). Fixed bearings showed more concentrated areas of dimensional changes underneath the medial and lateral plateaus (Fig. 7A). Exceptions were the fixed-bearing implants that had been retrieved after longer implantation times for osteolysis and loosening, where asymmetric patterns of change were noted (Fig. 7B). We found no differences in pre-implantation femorotibial angles between any of observed dimensional patterns for either insert design.

We observed no difference in medial or lateral thickness measurements when compared with the manufacturer's standard dimensions for either fixed-bearing or rotating-platform designs. Additionally, no differences were seen in the normalized thicknesses between fixed-bearing and rotating-platform inserts.

Discussion

We sought to compare the performance of rotating-platform and fixed-bearing knee implants on the basis of wear damage and dimensional changes experienced by the polyethylene tibial inserts. Previous studies have compared rotating-platform and fixed-bearing knee implants but have not compared implants of similar design from the same product line. This minimizes design differences between

Fig. 5A–B Laser scan image (A) and the corresponding damage map (B) are shown for the inferior surface of a rotating-platform insert. Concentric rings of dimensional change on the laser scan coincide with concentric scratching (blue lines) on the damage map. Scale bar applies to (A) only with units in millimeters; negative values indicate removal or deformation of material.

the two cohorts allowing us to focus on how the differences in conforming tibiofemoral geometry plays a role in polyethylene damage when paired with a rotational bearing. Given clinical studies [17, 19, 22, 27] have not

demonstrated superiority of rotating platforms compared with fixed bearings, we specifically were interested in determining if the rotating platform had favorable damage characteristics by (1) having less severe total damage; (2) a more uniform distribution of dimensional changes on the inferior surface; and (3) having less thickness changes than the fixed-bearing inserts.

This comparison is limited by a number of factors. First, we relied on retrieved implants, some of which were removed for mechanical failure and therefore might not represent well-functioning implants. Conversely, retrieved implants reflect the damage accrued during in vivo use, providing a better reflection of performance than that obtainable by in vitro knee simulator tests that typically look at only one simplified loading condition like walking. Another limitation is that our cohorts have short LOI, which does not allow us to make any predictions regarding longitudinal data. However, this does not negate the importance of understanding how these two implants perform differently even in short implantation periods. Second, because most of the primary surgeries were not performed at our institution, we have no information regarding patient activity. In both simulator and retrieval studies, higher levels of activity can lead to higher polyethylene damage [6, 16]. Because we have a large cohort of implants, we hope to capture a representative sample of patient demographics. Third, we have no information regarding shelf time of these implants because they were not implanted at our institution. It is possible that some implants were stored longer before implantation than

Fig. 6 A laser scan of the inferior side of a rotating-platform insert shows diffuse dimensional changes. Scale is in millimeters; negative values depict removal or deformation of material.

Fig. 7A–B Laser scans of the inferior side of fixed-bearing inserts show concentrated medio-lateral (A) and asymmetrical (B) dimensional changes. Scale is in millimeters; negative values depict removal or deformation of material.

others, which reportedly increases damage [20]. However, all of these implants have been sterilized in foil packaging to minimize degradation resulting from air exposure. Fourth, our comparison is also limited in that the articular surfaces are slightly different as a result of the more conforming design of rotating platforms. However, because we compared a fixed and rotating platform from the same company and same product line, we have removed factors such as femoral component variation, which may affect damage. Additionally, we did not see differences between posterior-stabilized and cruciate-retaining designs. Subtle changes in damage resulting from differences in conformity between these two inserts may be present but undetectable with our small sample size of cruciate-retaining inserts. Damage scoring reflects both occurrence and severity, so when damage is spread over a larger area as is the case with more conforming surfaces, damage scores can remain high although the severity in any one subregion is lower. Fifth, there were limitations in our scanning and thickness assessments. To assess dimensional differences, we obtained pristine implants of the most common sizes, but we did not make comparisons across all sizes and thicknesses. These pristine implants are representative and, given manufacturing tolerances, may not be the exact same size as the implanted liners. Similarly, the laser scanner has limitations in terms of resolution, but so do other imaging techniques such as microcomputed tomography [2, 24]. This combined with the lack of dimensional information for the retrieved implant before implantation made it difficult to truly determine thickness changes. Finally, our damage mapping is based on two-dimensional projections of three-dimensional surfaces, but the inferior surfaces are nearly flat and overlaying our maps with our scanner data showed good correlation.

As to our first question, concerning differences in damage and wear between the rotating-platform and fixed-bearing implants, the answers differed between the tibiofemoral and inferior surfaces. For the tibiofemoral surfaces, damage modes and severity did not differ appreciably, which would be expected given the common femoral component geometry between the two designs and the similar geometries for the tibial bearing surfaces. The exception was for the posterior-stabilized tibial post, which was less damaged than the rotating platform. This difference might reflect the greater conformity of the tibiofemoral bearing in the rotating-platform design with the conformity dictating the knee's kinematics, thus reducing the role played by the post-cam mechanism. However, it might also reflect an advantage in that the rotating implants could find their own axis of internal-external rotation as has been seen in the *in vivo* fluoroscopic studies of rotating-platform patients [26]. This should reduce the chances of edge loading on the post that is common in fixed-bearing

designs [7, 9], including the PFC® inserts in our current study. The low occurrence of more severe damage modes such as delamination and pitting is most likely the result of higher conforming surfaces and short implantation times, which decrease the likelihood of damage caused by fatigue mechanisms. For the inferior surface, although the modes were similar, the damage was more severe for the rotating-platform inserts, which follows previous work [8, 14]. Although the presence of extensive third-body wear on some of these inserts contributed to the overall increased average score, our results reflect that the broad, flat, conforming bearing between the insert and the polished surface of the tray was capable of damage more severe than the fixed bearing. This held true although the bearing in the latter case includes a grit-blasted metallic surface. From a biomechanics viewpoint, the somewhat lower contact stresses that result from the greater conformity are likely more than offset by the markedly larger sliding distances afforded by the rotating platform. The resulting abrasive/adhesive wear mechanisms, for which wear is proportional to the product of stress and sliding distance [13], would contribute more wear (and hence more damage) under such conditions.

Our second question, concerning potential advantages of the more conforming tibiofemoral articulation in the rotating-platform implant, can be answered by considering our damage mapping results. Indeed, the result of the greater conformity was seen in the increased tibiofemoral contact area (Fig. 4A). However, again, although contact area was larger, meaning contact stresses were most probably lower, the resulting lower stresses were not reflected in lower damage scores. This may be the result of increased burnishing, which is a function of area and sliding distance. Similarly, the corresponding larger contact areas for the inferior surface (Fig. 4B) did not have the intended advantage of lowering damage on this surface, as already discussed. Additionally, the finding that tibiofemoral damage scores increase with LOI but insert tray damage scores do not is intriguing. It supports the findings of our group and others that although the tibiofemoral surface can perform well, the introduction of a second bearing surface paired with third-body debris can accelerate wear, leading to early implant failure. A benefit of including the laser scanning could be seen by comparing the surfaces generated from the point clouds from the scanner with the damage maps, which for the first time allowed us to compare observed damage modes with the corresponding dimensional changes on a location-by-location basis. The most striking example was for the concentric scratching seen on the inferior surfaces of the rotating platform inserts (Fig. 5A), but similar correspondence was found between burnishing and the asymmetric patterns of wear on the fixed-bearing inserts with longer

lengths of implantation. We intend to pursue this technique further by developing automated registration techniques that integrate two-dimensional images with three-dimensional scan data; such techniques are finding use in a number of nonmedical applications, including large-scale scenes such as urban structures and archeological sites [23].

The answer to our third research question, whether the amount of wear differed between the rotating-platform and the fixed-bearing design, is hampered by a combination of: the inability to distinguish between deformation of polyethylene implant surfaces and the removal of material through wear mechanisms; the limitations in the laser scans; the lack of dimensional information for the retrieved implant before implantation; and the machining tolerances set by the manufacturer and low numbers of compared implants. The resolution of the scanner is similar to that reported by others who used microcomputed tomography to measure thickness changes [2, 24]. When this resolution is combined with the range of initial dimensions that are possible within the manufacturer's tolerances, the ability to know the true amount of dimensional change that occurred in any one retrieved implant with sufficient accuracy to make comparisons across a number of implants is insufficient to make such comparisons meaningful. Unfortunately, this is a practical issue from a manufacturing standpoint and is a function of setting the tolerances within the ability to machine a soft, elastic material like polyethylene. If unique identifiers were available for each insert, then the manufacturer's records for the individual insert could be culled for starting insert thicknesses and compared with measurements from the same retrieved implant. Such a system of identification is underway by the FDA with support from the AAOS and other organizations, making such future studies a promising development.

In summary, our study of retrieved rotating-platform and fixed-bearing inserts from the same commercial system with similar femoral component geometry suggests no inherent damage benefit to the rotating-platform concept. Specifically the introduction of a more conforming surface and rotating bearing does not appear to decrease stress concentrations across the polyethylene enough to decrease damage seen through damage scores and dimensional changes, even at short lengths of implantations. This coupled with no apparent clinical benefits over fixed-bearing designs suggests this design may not be as beneficial to the patient as originally intended.

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