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Long-term *in vivo* wear of different bearing types used for the Oxford Unicompartmental Knee Replacement

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Objectives
The aim of this study was to determine the polyethylene wear rate of Phase 3 Oxford Unicompartmental Knee Replacement bearings and to investigate the effects of resin type and manufacturing process.

Methods
A total of 63 patients with at least ten years' follow-up with three bearing types (1900 resin machined, 1050 resin machined, and 1050 resin moulded) were recruited. Patients underwent full weight-bearing model-based radiostereometric analysis to determine the bearing thickness. The linear wear rate was estimated from the change in thickness divided by the duration of implantation.

Results
The wear rate for 1900 resin machined (n = 19), 1050 machined (n = 21), and 1050 moulded bearings (n = 23) were 60 µm/year (SD 42), 76 µm/year (SD 32), and 57 µm/year (SD 30), respectively. There was no significant difference between 1900 machined and 1050 machined ($p = 0.20$), but 1050 moulded had significantly less wear than the 1050 machined ($p = 0.05$). Increasing femoral ($p < 0.001$) and tibial ($p < 0.001$) component size were associated with increasing wear.

Conclusion
Wear rate is similar with 1050 and 1900 resin, but lower with moulded bearings than machined bearings. The currently used Phase 3 bearings wear rate is low (1050 moulded, 57 µm/year), but higher than the previously reported Phase 2 bearings (1900 moulded, 20 µm/year). This is unlikely to be due to the change in polyethylene but may relate to the minimally invasive approach used with the Phase 3. This approach, as well as improving function and thus increasing activity levels, may increase the risk of surgical errors, such as impingement or bearing overhang, which can increase wear. Surgeons should aim to use 4 mm thick bearings rather than 3 mm thick bearings in young patients, unless they are small and need conservative bone resections.

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Keywords: Mobile bearing unicompartmental knee replacement, Polyethylene, Long-term wear

Article focus
- To determine the polyethylene wear rate of the Phase 3 Oxford Unicompartmental Knee Replacement bearings.
- To determine if the polyethylene resin type or manufacturing process influences the wear rate.

Key messages
- The wear rate of currently used Oxford Unicompartmental Knee Replacement bearings, which are moulded from 1050 resin, is very low (0.06 mm/yr) but is higher than that of the previous Phase 2 bearings.
- The wear rate is the same for bearings made of 1050 and 1900 resin, but is less when moulded rather than machined.
- With machined bearings, the wear rate increased with component size; with moulded bearings, it appeared to be

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independent of size. Further study is needed to understand this.

Strengths and limitations

- The wear rate was determined *in vivo* with a minimum of ten years' follow-up, using weight-bearing model-based radiostereometric analysis.
- We were unable to determine the amount of polyethylene creep, but it is likely to be relatively small and would result in an overestimation of wear.

Introduction

Unicompartmental knee arthroplasty (UKA) is a popular alternative to total knee arthroplasty (TKA) due to its minimally invasive approach, superior functional outcomes, and reduced complication rates.[1] Polyethylene wear is an important failure mechanism for fixed-bearing UKA due to the small contact area and high contact stress from incongruent surfaces.[2-4] To minimize wear and allow normal kinematics, the Oxford Unicompartmental Knee Replacement (Zimmer Biomet, Swindon, United Kingdom) has a fully congruent and mobile polyethylene bearing. Despite this, there are reports of wear resulting in bearing fracture.[5]

Polyethylene wear can be quantified either by volumetric loss or linear penetration of the femoral component into the polyethylene relative to the tibial component. Linear wear is more relevant for UKA, given that failure due to wear is usually catastrophic polyethylene failure or fracture due to linear wear rather than particulate debris-induced osteolysis resulting from volumetric wear.[5] Linear wear of the Oxford Unicompartmental Knee Replacement bearings has been assessed by wear simulation, retrieval analysis, and radiostereometric analysis (RSA).[6-11] Although these three methods have produced similar results, only the RSA method quantifies the wear that occurs in functioning knees.

There have been three main iterations of the Oxford Unicompartmental Knee Replacement. Phase 1 was used between 1976 and 1987, Phase 2 between 1987 and 1998, and Phase 3 between 1998 and present. An RSA study of the Phase 1 with approximately 20 years' follow-up found that the mean linear bearing wear rate was 0.07 mm/year (0.02 to 0.1).[6] Similar studies of wear of Phase 2 bearings at both ten and 20 years found a mean linear wear rate of about 0.02 mm/year (0.00 to 0.05).[6,10] Although there are small design differences between the Phase 2 and 3 bearings, such as the plan shape of the tibial component, the main difference was that the Phase 2 bearing was implanted using a TKA approach, whereas the Phase 3 bearing was implanted with a minimally invasive approach.

Since the introduction of the Phase 3 bearing in 2005, there was a change in the polyethylene resin used to manufacture the bearing from Hi-Fax 1900 (Montell Polyolefins, Wilmington, Delaware) to GUR 1050 (Ticona, Oberhausen, Germany),[12] as the manufacture of the 1900 resin was discontinued. The main difference between the resins is the molecular weight, which is 4.4 $\times 10^6$ g/mol to 4.9 $\times 10^6$ g/mol for the 1900 resin and 5.5 $\times 10^6$ g/mol to 6.0 $\times 10^6$ g/mol for the 1050 resin. Although wear simulations in TKA have shown no difference between these resins, they have never been compared clinically for any knee design.[13] In addition, although the Oxford bearings are usually manufactured by a direct compression moulding process (DCM), some bearings were machined from bar stock around the time of the transition from 1900 to 1050 resin, which may have influenced wear.[12]

The main aim of our study was to determine the wear rate of the Phase 3 bearings using an accurate and validated RSA method.[7,14,15] In addition, we aimed to compare the wear rates of bearings made from different resin types (1900 *vs* 1050) and to compare bearings manufactured by moulding and machining.

Patients and Methods

Patient recruitment. All patients gave informed consent for participation in the study, which was approved by the local ethics committee (South Central – Oxford B Research Ethics Committee, REC reference 16/SC/0456). Bearing code numbers from patients with follow-up of ten years or more and well-functioning knees were identified from our database of medial Phase 3 Oxford Unicompartmental Knee Replacements.[16,17] An appropriate number of patients with 1900 machined, 1050 machined, and 1050 moulded bearings were recruited. Insufficient 1900 moulded bearings were identified to be worth studying, as bearing code numbers were not available on most of these early bearings.

Measuring wear. Patients attended a research clinic where their Oxford Knee Scores (OKS) were measured and simultaneous stereo pairs of anteroposterior radiographs were taken obliquely at 30° with the patient fully weight-bearing for RSA, as has previously been described.[6,10] Each patient stood within a calibration frame with 0.8 mm tantalum markers embedded within it at known locations. The fiducial and control markers in front and behind the frame, respectively, allowed for image calibration of the stereo images. Previously validated model-based RSA software version 3.21 (Medis Specials, Leiden, The Netherlands) was used to estimate the position of the tibial and femoral component in space based on each implant's outline using a Canny detection algorithm.[7,18] For each component, a virtual silhouette could be created from the photogrammetric relationship from the calibration and the computer-aided design (CAD) models. This allowed virtual representation of the components in 3D space.

Once the implants were posed, their coordinates were inputted into MATLAB (Version 7.0.4.287; The MathWorks, Natick, Massachusetts), which allowed for the closest

Table I. The baseline characteristics in the three bearing types. No significant differences were detected between groups

Baseline parameter	1900 machined bearing (n = 19)	1050 machined bearing (n = 21)	1050 moulded bearing (n = 23)	p-value
Mean age, yrs (SD)	65.2 (9.1)	58.8 (8.6)	63.9 (7.6)	0.06*
Mean BMI, kg/m² (SD)	28.4 (3.8)	28.3 (3.5)	27.8 (4.5)	0.88*
Sex, n (%)				0.54†
Male	9 (*47*)	12 (*57*)	15 (*65*)	
Female	10 (*53*)	9 (*43*)	8 (*35*)	
Femoral component sizes, n (%)				0.28†
Small	7 (*37*)	7 (*33*)	4 (*17*)	
Medium	6 (*32*)	4 (*19*)	10 (*43*)	
Large	5 (*26*)	10 (*48*)	9 (*39*)	
Extra-large	1 (*5*)	0 (*0*)	0 (*0*)	
Tibial component sizes, n (%)				0.52†
A	1 (*5*)	0 (*0*)	0 (*0*)	
B	2 (*11*)	2 (*10*)	1 (*4*)	
C	7 (*37*)	6 (*29*)	7 (*30*)	
D	3 (*16*)	4 (*19*)	6 (*26*)	
E	5 (*26*)	2 (*10*)	4 (*17*)	
F	1 (*5*)	7 (*33*)	5 (*22*)	
Bearing sizes, n (%)				0.91†
3	6 (*32*)	6 (*29*)	5 (*22*)	
4	9 (*47*)	9 (*43*)	12 (*52*)	
5	3 (*16*)	5 (*24*)	6 (*26*)	
6	1 (*5*)	1 (*5*)	0 (*0*)	

*One-way analysis of variance
†Fisher's exact test
BMI, body mass index

linear distance between the femoral component and tibial tray to be calculated and taken as the bearing thickness at follow-up.[6,7,10]

As the bearing has fully congruous contact on both upper and lower surfaces, the overall bearing linear wear was calculated by subtracting the closest linear distance at follow-up between femoral component and tibial tray from the estimated thickness of the bearing at implantation. The estimated bearing thickness was determined by adding 0.5 mm to the nominal bearing thickness and then adding a further 0.05 mm for manufacturer tolerance, as previously described.[6,10] This additional thickness had previously been determined from measurement of unused bearings.[11] The overall bearing wear was then divided by the time between implantation and RSA to determine the bearing linear wear rate. The accuracy of our RSA system is approximately 0.1 mm, so the linear wear rate can be assessed relatively accurately using RSA, particularly with follow-up of ten years or more.[6,7,10]

Statistical analysis. A power calculation was conducted using a power of 0.8, significance of 0.05, a SD of 0.02 from the Phase 2 implant, and a minimally significant clinical difference of 0.02 mm/year.[10] The study required 18 participants per group for meaningful comparison.

To determine if resin type affected wear rate, we compared the wear rate of 1900 machined and 1050 machined bearings. To determine if manufacturing process affected wear rate, we compared the wear rate of 1050 machined and 1050 moulded bearings. Given that the annual wear rate data were normally distributed, we used the unpaired *t*-test to conduct these comparisons.

To compare baseline characteristics between groups, the one-way analysis of variance (ANOVA) was used for age, body mass index (BMI), and OKS. Sex and femoral and tibial component sizes between groups were compared with the Fisher's exact test. To analyze the relationship of factors with annual wear rate, each factor was correlated using the Spearman's rank test and plotted graphically. If a linear relationship was evident, a linear regression model was utilized with 95% confidence intervals (CIs) reported. The effect of bearing type on the linear relationship was evaluated using an interaction term.

All statistical tests were conducted using Stata (Version 13.1; College Station, Texas). A p value of $\leqslant 0.05$ was deemed as statistically significant.

Results

The number of patients recruited with RSA radiographs that could be analyzed were 19, 23, and 21 for the 1900 machined, 1050 moulded, and 1050 machined bearings, respectively. The mean patient BMI at final follow-up was 28.2 kg/m² (SD 4.0) and the mean age at surgery was 62.6 years (SD 8.7). The mean OKS recorded at the time of RSA was 42.6 (SD 6.1), corresponding to excellent long-term functional outcomes.[19]

Comparison of wear between groups. There were no differences in baseline characteristics between groups (Table I). As anticipated, there was a significant difference in mean follow-up ($p < 0.001$, one-way ANOVA) for each group, given the different time periods in which the bearing types were used. Mean follow-up was 14.1 years (SD 0.4), 12.1 years (SD 1.1), and 10.0 years (SD 0.5)

Table II. The total wear and bearing wear rates for each bearing type

Group	Mean follow-up, yrs (SD)	Mean linear penetration, µm (SD)	Mean bearing wear rate, µm/yr (SD)
1900 machined (n = 19)	14.1 (0.4)	847 (589)	60 (42)
1050 machined (n = 21)	12.1 (1.1)	908 (353)	76 (32)
1050 moulded (n = 23)	10.0 (0.5)	563 (290)	57 (30)

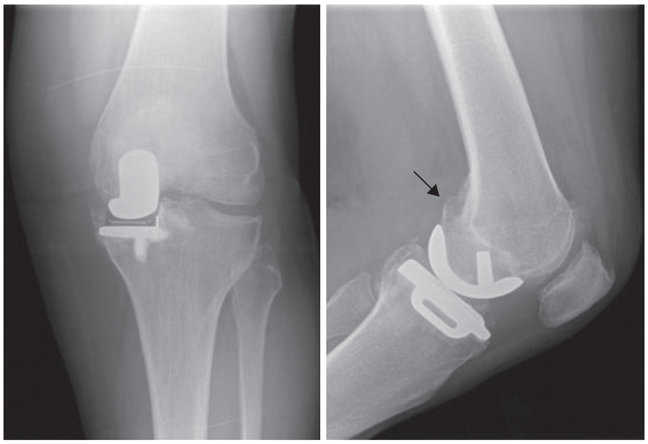

Fig. 1a Fig. 1b

a) Anteroposterior and b) lateral radiographs of a wear outlier patient in the 1050 moulded group. Note that there is a posterior osteophyte, marked by an arrow, that would impinge on the bearing in flexion and cause increased wear.

for the 1900 machined bearings, 1050 machined bearings, and 1050 moulded bearings, respectively. Long-term OKS (ten years or more) were 42.7 (SD 5) in 1900 machined, 42.6 (SD 6.4) in 1050 machined, and 42.4 (SD 6.7) in 1050 moulded groups with no differences ($p = 0.98$, one-way ANOVA).

The mean linear penetration rate was 60 µm/year (SD 42) for the 1900 machined group, 76 µm/year (SD 32) for the 1050 machined group, and 57 µm/year (SD 30) for the 1050 moulded group (Table II). There was one patient outlier in the 1050 moulded group, who had an annual wear rate of 151 µm/year. On inspection of this patient's radiographs, there was a large posterior osteophyte that would have impinged on the bearing, which perhaps explains this elevation of wear rate (Fig. 1).[11]

When analyzing the effect of resin type by comparing the two machined bearings, there was no significant difference in the wear rate of the 1900 resin or the 1050 resin (60 µm/year and 76 µm/year, respectively; $p = 0.20$, unpaired *t*-test). When analyzing the effect of manufacturing process by comparing the two 1050 resins, the wear rate for the moulded bearings was significantly lower than for the machined bearings (57 µm/year and 76 µm/year, respectively; $p = 0.05$, unpaired *t*-test).

The influence of component size on wear. When all bearing types were combined, the wear rate was 44 µm/year (SD 32) for small femoral components (n = 18), 59 µm/year (SD 22) for medium femoral components (n = 20), 79 µm/year (SD 32) for large femoral components (n = 24), and 178 µm/year (n = 1) for extra-large femoral components. Using a linear regression model, there was found to be a significant linear relationship between femoral component size and bearing wear; for each increase in femoral component size, the wear rate increased by 21 µm/year (95% CI 12 to 30; $p < 0.001$). The strength of this relationship was influenced by bearing type ($p = 0.01$). For both machined bearings, there was increased wear with increased femoral component size; the wear increased by 35 µm/year (95% CI 21 to 49) in the 1900 machined bearings ($p < 0.001$), and by 23 µm/year (95% CI 10 to 35) in the 1050 machined bearings ($p = 0.001$). However, with the moulded bearings there was no significant increase in wear with increased size, at -0.5 µm/year (95% CI -19 to 18; $p = 0.96$) (Fig. 2).

When all bearing types were combined, the mean wear rate was 22 µm/year for tibia A size components (n = 1), 46 µm/year (SD 5) for tibia size B components (n = 5), 52 µm/year (SD 32) for tibia size C components (n = 20), 57 µm/year (SD 25) for tibia size D components (n = 13), 83 µm/year (SD 32) for tibia size E components (n = 11), and 84 µm/year (SD 43) for tibia size F components (n = 13). Using a linear regression model, there was found to be a significant linear relationship between tibial component size and bearing wear; for each increase in tibial component size, the wear rate increased by 12 µm/year (95% CI 6 to 18; $p < 0.001$). The strength of this relationship was influenced by bearing type ($p = 0.003$). For both machined bearings, there was increased wear with increased tibial component size; the wear increased by 23 µm (95% CI 12 to 35) in the 1900 machined bearings ($p = 0.001$) and increased by 14 µm (95% CI 6 to 22) in the 1050 machined bearings ($p = 0.002$). However, with the moulded bearings, there was no significant increase in wear with increased size, at -2 µm/year (95% CI -13 to 9; $p = 0.72$) (Fig. 3).

Male sex was associated with significantly higher wear rates in the 1900 and 1050 machined groups, but not in the 1050 moulded groups (Table III). This is explained by the observation that men had larger component sizes (Table IV) and that the wear rate increases with increased size with machined bearings, but does not with moulded bearings.

Other factors related to wear. When data from all bearings (n = 63) were combined, the mean wear rate was 64 µm/year (SD 35) at a mean follow-up of 12 years (SD 1.9). There was no significant correlation between OKS

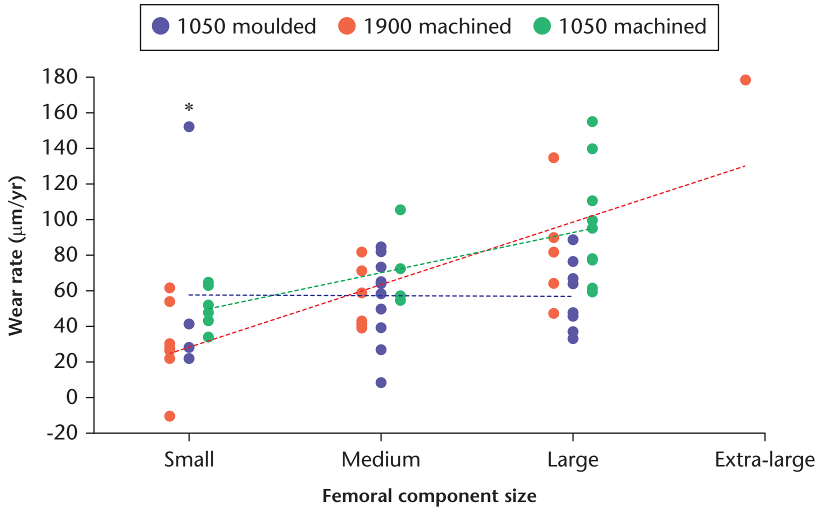

Fig. 2

Chart showing the relationship between femoral component size and wear rate for different bearing types. *This bearing is the outlier with much higher wear than expected.

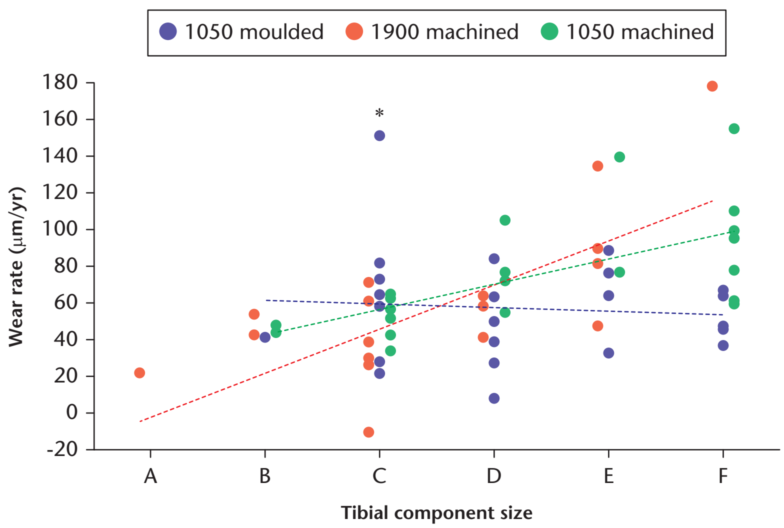

Fig. 3

Chart showing the relationship between tibial component size and wear rate for different bearing types. *This bearing is the outlier with much higher wear than expected.

and annual wear rate (Spearman's coefficient 0.15; p = 0.23, Spearman's rank correlation coefficient) (Fig. 4).

No significant relationship existed between wear rate and age, although there was a trend towards increased wear in younger patients. At the time the RSA radiographs were taken, patients under 70 years of age (n = 53) had a wear rate of 68 µm/year (SD 34), while those over 70 years of age (n = 10) had a wear rate of 46 µm/year (SD 35; p = 0.08, unpaired *t*-test). Spearman's correlation coefficient was -0.22 (p = 0.08, Spearman's rank correlation coefficient) (Fig. 5).

Furthermore, no significant relationship between wear rate and BMI was observed. Patients with BMIs under 25 kg/m^2 (mean 23.3 kg/m^2 (21.2 to 24.8)) had wear rates of 71 µm/year (SD 33, n = 11) and those with BMIs of 30 kg/m^2 or greater (mean 33.8 kg/m^2 (30.1 to 39.9)) had wear rates of 72 µm/year (SD 40, n = 16). Spearman's coefficient was 0.05 (p = 0.69, Spearman's rank correlation coefficient).

The annual wear rate of 75 µm/year (SD 36) observed for men (n = 36) was significantly higher than the wear rate of 50 µm/year (SD 29) observed for women (n = 27; p = 0.004, unpaired *t*-test). This difference is explained by the fact that men had larger component sizes than women and larger component sizes were, overall, associated with increased bearing wear (Table III). The mean age of men and women was 63.0 years (SD 8.2; 40.0 to 80.8) and 62.1 years (SD 9.4; 40.9 to 84.7), respectively, with no significant differences (p = 0.69, unpaired *t*-test). The mean BMIs of men and women were 28.4 kg/m^2 (SD 3.5; 22.7

Table III. A comparison of wear rates between sexes within each bearing group

Bearing type	Mean bearing wear rate, μm/yr (SD)		
	Men	**Women**	**p-value***
1900 machined	84 (46); n = 9	38 (24); n = 10	0.01†
1050 machined	93 (31); n = 12	53 (12); n = 9	0.002†
1050 moulded	55 (21); n = 15	60 (43); n = 8	0.72

*Unpaired *t*-test
†Statistically significant

Table IV. The sizes of components stratified by sex

Component size	Men (n = 36)	Women (n = 27)
Femoral, n (%)		
Small	0 (*0*)	18 (*67*)
Medium	11 (*31*)	9 (*33*)
Large	24 (*67*)	0 (*0*)
Extra-large	1 (*3*)	0 (*0*)
Tibial, n (%)		
A	0 (*0*)	1 (*4*)
B	0 (*0*)	5 (*19*)
C	4 (*11*)	16 (*59*)
D	8 (*22*)	5 (*19*)
E	11 (*31*)	0 (*0*)
F	13 (*36*)	0 (*0*)

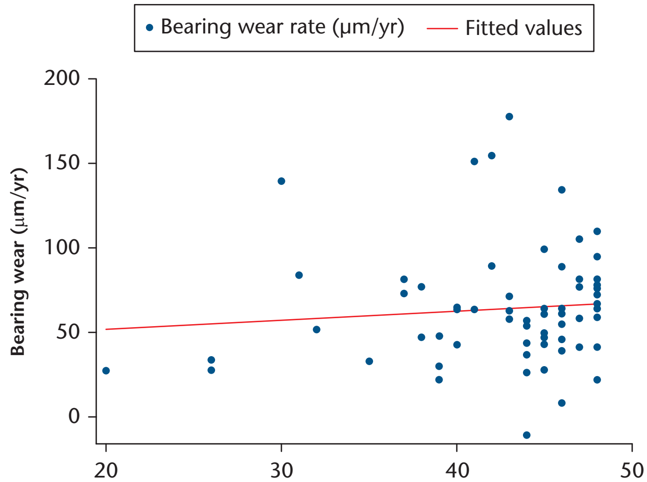

Fig. 4

Scatter plot of Oxford Knee Score and bearing wear.

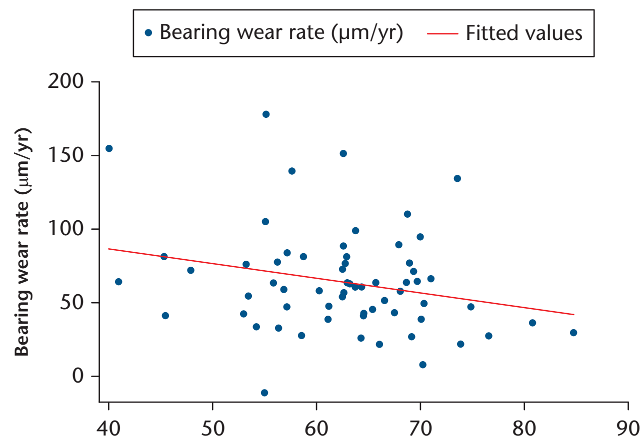

Fig. 5

Scatter plot of bearing wear rate and age for Oxford Phase 3 implant.

to 35.6) and 27.9 kg/m^2 (SD 4.6; 21.3 to 39.9), respectively, with no significant differences (p = 0.69, unpaired *t*-test).

The nominal bearing thickness varied from 3 mm to 6 mm. The mean linear wear rates of the thin (3 mm; n = 17) and thick (5 mm to 6 mm; n = 16) bearings were 59 μm/year (SD 28) and 56 μm/year (SD 27), respectively, with no significant difference between them (p = 0.76, unpaired *t*-test). Direct correlation analyses between thickness and wear rate showed a Spearman's rho correlation coefficient of 0.02 (p = 0.87, Spearman's rank correlation coefficient), showing no correlation.

Discussion

This is the first long-term RSA wear study of the Phase 3 Oxford Unicompartmental Knee Replacement and the first to compare the different resin materials and manufacturing processes used to make polyethylene bearings. Our main findings were that there was no difference between the wear rate of the two resin types (1900 and 1050) with the same manufacturing process. However, different manufacturing processes did impact wear, with the moulded bearings having significantly lower wear rates than the machined. We also found that with machined bearings, the wear rate increased with component size but, surprisingly, with moulded bearings there was no relationship between size and wear rate.

Approximately 15 years ago, the polyethylene resin used for the Phase 3 bearings was changed from 1900 to 1050. Both 1900 and 1050 resin bearings have been routinely manufactured using direct compression moulding but during the transition some bearings were produced by machining from bar stock.[12] These changes could potentially result in changes to the wear properties of the bearings. With the same resin, the wear rate of the machined bearings was significantly higher than that of the moulded bearings. This difference was expected, as previous studies have shown that direct compression-moulded polyethylene wears more slowly than machined polyethylene.[20] We found no significant difference between the wear rates of the 1900 machined and the 1050 machined resins. This demonstrates, for the first time *in vivo*, that there is no difference in wear properties of the two resins. This is an important finding, as all the new bearings are now made of the 1050 resin, whereas the good long-term results of the Phase 2 Oxford Unicompartmental Knee Replacement were achieved using the 1900 resin.

We found that, overall, the wear rate increased with increasing component size, with the largest sizes having over twice the wear rate of the smallest. Larger patients tend to be heavier so apply larger loads, and have larger components, which have larger surface areas and have larger sliding distances for the same amount of knee flexion. All these factors are known to increase wear.[21,22] When the different types of bearing were studied, it was found that for both types of machined bearings, the wear rate increased with both tibial and femoral component size. However, it was found that, with the moulded bearing, the wear rate did not increase with increasing femoral or tibial component size, which was unexpected. This explains the anomaly that men, who tend to be larger, have greater wear with machined bearings than women, whereas with moulded bearings there was no significant differences in wear rate between sexes. It also suggests that the moulding process produces a material with different tribological properties to the machined process, perhaps because a surface skin is produced that reduces wear and oxidation. Further study is needed to understand this surprising difference between machined and moulded bearings.

Our study found no statistically significant relationship between wear rate and age, which is similar to the conclusions of Kendrick et al.[6] We also found no significant relationship between wear rate and OKS or BMI. These findings, particularly relating to age and OKS, are surprising and difficult to explain, given that wear is related to the number of cycles and load, and young active patients will use their knees more often and apply greater loads. Although obese patients will apply greater loads, they tend to be less active. It is therefore likely that age and activity do influence the wear rate, but their effect is masked by other, more important, variables. Indeed, there was a trend towards increasing wear in younger patients and those with higher OKS.

Our study has shown that the mean linear wear rate of the 1050 resin-moulded bearings, which are the bearings in current use, is 57 μm/year (SD 30). This linear wear rate, measured *in vivo*, is substantially lower than that of other knee arthroplasties, whether unicompartmental or total.[23-25] It is also independent of bearing thickness. It is for this reason that the Oxford Unicompartmental Knee Replacement can safely use thinner bearings, which is particularly important in UKA to preserve bone stock.

The mean linear wear rate of the current Phase 3 bearings (57 μm/year) is higher than that reported for Phase 2 bearings (20 μm/year) but lower than that reported for Phase 1 bearings (70 μm/year) determined in the same way.[6] Impingement of the bearing on bone anteriorly to the femoral component was common in Phase 1 and uncommon in Phase 2, as surgeons were aware of the problem and therefore able to prevent it. Impingement is known to increase wear and is probably the reason why the wear in Phase 1 was higher than that in Phase 2. With Phase 3, like Phase 2, surgeons were aware that they should avoid impingement; however, it is possible that surgical errors that could contribute to wear, such as impingement, might be more common with the minimally invasive approach. This could possibly contribute to the higher wear of Phase 3 than Phase 2. Given that Phase 2 used 1900 moulded bearings, we suspected that the increased wear with Phase 3 might be due to the change in polyethylene resin from 1900 to 1050, but this study suggests otherwise. The Phase 3 bearing and tibial plateau plan shape are slightly different from the Phase 2 bearing, as they are more anatomical, but the difference is small so it is unlikely to be the explanation. There was also no change to the finish of the metallic bearing surfaces. Due to the minimally invasive approach with Phase 3, patients tend to have higher levels of function and a better range of movement than those with Phase 2. The higher function (mean OKS in this study 42.6 (SD 6.1)) is likely to increase activity levels which will probably increase wear. With increased movement, the bearings may overhang the tibial and femoral component more, which might increase wear. Further study is needed to understand why the wear is higher with Phase 3.

Bearing fractures rarely occur after Oxford Unicompartmental Knee Replacement. When they were studied they were found to occur most commonly in the third decade after implantation of Phase 1 bearings.[5] They can easily be treated by inserting a new bearing and ensuring there is no impingement. In a detailed study of ten fractured bearings, it was found that the aetiology of fracture was multifactorial.[5] However, evidence of impingement and associated abnormally high wear, as well as oxidation, were observed in all fractured bearings.[5] A good example of impingement causing marked wear is evident in our study from the 1050-moulded outlier patient with very high wear; this patient had a retained posterior osteophyte, which would have caused impingement (Fig. 1). New instrumentation, known as Microplasty (Zimmer Biomet, Swindon, United Kingdom), is now routinely used for the Oxford Unicompartmental Knee Replacement and includes instruments designed to prevent impingement. A finite element study[26] demonstrated that thinner bearings were more likely to fracture, and approximately half of the retrieved fractured bearings in a retrieval study by Pegg et al[5] were less than 2 mm thick. With the current Phase 3 bearings, the wear rate is a mean of 57 μm/year (SD 30), which would equate to about 1.1 mm wear at 20 years. Therefore, the thinnest bearings available, which are size 3 with minimum thickness of 3.5 mm, will be, on average, 2.4 mm thick at 20 years. A small proportion of these will be substantially thinner than 2 mm and, if there happened to be marked oxidation, would be at risk of fracture. In contrast, if the bearing was initially 4.5 mm thick (size 4), it would be very unlikely to be worn thinner than 2 mm. Therefore, we would recommend that with young active patients, unless they are small and require a conservative resection, surgeons should aim to implant a size 4 rather than a size 3 bearing. This can easily be done with the Microplasty instrumentation. It would also be sensible to consider having available bearings made with highly crosslinked polyethylene to decrease wear[27,28] and with vitamin E to decrease oxidation.[29,30]

A limitation of the study is that we assume that the change in bearing thickness between implantation and RSA was due to bearing wear, when it was actually due to both wear and creep. With a single RSA measurement, we cannot calculate the relative contributions of creep and wear; however, creep mainly occurs in the first three months and has minimal effect in the long term.[31-33] Therefore, it is not unreasonable to assume, over a ten-year period, that the change in thickness was due to wear. Furthermore, had there been marked creep, this would have resulted in us overestimating, rather than underestimating, the wear. We also did not know the precise thickness of the bearing at implantation. However, we have previously found that when we measured bearing thickness with RSA soon after implantation, it was virtually the same as that estimated from the bearing size using the methodology used in this study, for both 1900 bearings[10,11] and 1050 bearings (unpublished). The accuracy of the RSA system was about 100 μm. As the minimum follow-up was ten years, the accuracy of the system for measuring the wear rate would be about 10 μm/year. This is substantially less than the SD of the wear rate measurements, suggesting most of the variability in measurements was due to differences between the patients rather than the measurement accuracy. Another limitation is that we did not match patients having the different bearing types. Instead, we studied patients who were due to attend for routine follow-up and who had available bearing codes so we could identify the bearing type. However, there were no significant differences between the three groups in the baseline characteristics (age, sex, BMI, and OKS). Additionally, given that the three bearing types were used at slightly different time periods, this resulted in an inevitable difference in mean follow-up for each group. However, given that all exceeded ten years and we analyzed annual wear rate, this should not have influenced our results. Finally, there was one outlier with high wear from the 1050 moulded group and the data from this might have influenced the conclusion. We therefore carried out a sensitivity analysis, in which we excluded this patient, and found that this did not affect the conclusion.

The Oxford Unicompartmental Knee Replacement polyethylene bearing linear wear rate is similar with 1050 and 1900 resin, but is lower with direct compression-moulded rather than machined bearings. The wear rate of the Phase 3 bearings in current use is low (1050 resin moulded, 57 μm/year) but is higher than that reported for the Phase 2 bearings (1900 resin moulded, 20 μm/year), and lower than that reported for Phase 1 bearings. Therefore, the fracture rate of Phase 3 bearings may be higher than that of Phase 2 bearings, but lower than that of Phase 1 bearings. It is not clear why the wear rate of Phase 3 is higher than Phase 2, but it may be due to the minimally invasive approach, which improves function and probably increases activity levels, but may also increase the risk of surgical errors, such as impingement, that can increase wear. However, with the new Microplasty instrumentation, these errors should be avoided. In addition, it is simpler to select bearing thickness and it would be sensible to aim for 4 mm bearings rather than 3 mm bearings in young active patients, in all but small patients who need conservative bone cuts.

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- All patients gave informed consent for participation in the study, which was approved by the local ethics committee (South Central – Oxford B Research Ethics Committee, REC reference 16/SC/0456).