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TITLE PAGE

A comparative surface topographical analysis of explanted Total Knee Replacement prostheses: Oxidised Zirconium vs Cobalt Chromium femoral components

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ABSTRACT

It has been proposed that an increased surface roughness of the femoral components of Total Knee Replacements (TKRs) may be a contributing factor to the accelerated wear of the polyethylene (PE) bearing and ultimately prosthesis failure. Oxidised Zirconium was introduced to the orthopaedic market in an attempt to reduce PE wear associated failures and increase the longevity of the prosthesis.

In this study, non-contacting profilometry was used to measure the surface roughness of the femoral components of 6 retrieved TKRs (3 Oxidised Zirconium (OxZr) and 3 Cobalt Chromium alloy (CoCr) femoral components) and 2 as-manufactured femoral components (1 OxZr and 1 CoCr). A semi-quantitative method was used to analyse the damage on the retrieved PE components.

The S_a values for the retrieved OxZr femoral components (S_a = 0.093μm ±0.014) and for the retrieved CoCr femoral components (S_a = 0.065μm ±0.005) were significantly greater ($p<0.05$) than the roughness values for the as-manufactured femoral components (OxZr S_a = 0.061μm ±0.004 and CoCr S_a = 0.042μm ±0.003). No significant difference was seen between the surface roughness parameters of the retrieved OxZr and retrieved CoCr femoral components. There was no difference between the PE component damage scores for the retrieved OxZr TKRs compared to the retrieved CoCr TKRs.

These results agree with other studies that both OxZr and CoCr femoral components roughen during time *in vivo* but the lack of difference between the surface roughness measurements of the two materials is in contrast to previous topographical reports. Further analysis of retrieved OxZr TKRs is recommended so that a fuller appreciation of their benefits and limitations be obtained.

Keywords: Total Knee Replacement; retrieval; Oxidised Zirconium (OxZr); surface roughness; profilometry.

1. INTRODUCTION

Total Knee Replacement (TKR[*]) offers improved mobility and pain relief for many people suffering with the debilitating disease of osteoarthritis [1-4]. In the longer-term, wear of the polyethylene (PE) component and PE wear-debris associated problems continue to limit TKR longevity. The 2016 Australian Orthopaedic Association National Joint Replacement Registry (AOANJRR) [1] and the National Joint Registry (NJR) Annual Report for England, Wales, Northern Ireland and the Isle of Man [3] both cite aseptic loosening as the main reason for TKR revision at 10 years and beyond. Whilst there are many factors that influence PE wear within TKR, an increased surface roughness of the counter-face femoral component has been reported as one of the causative mechanisms of accelerated PE wear [5-10].

In 2004, Oxidised Zirconium (OxZr) (a surface-modified metal comprising a uniform ceramic surface with a gradual transition from ceramic oxide to substrate metal alloy) was introduced for TKR femoral components in an attempt to reduce PE wear associated failures [11, 12]. With a greater surface hardness and wettability than cobalt-chromium alloy (CoCr) [13], OxZr femoral components should theoretically lead to the reduction of PE wear. While *in-vitro* wear testing of OxZr TKRs has shown significant wear reduction when compared to CoCr TKRs [13-15], the 10-year clinical follow-up reviews reported no difference in survivorship or patient-reported

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[*] List of Abbreviations: Total Knee Replacement (TKR); polyethylene (PE); Australian Orthopaedic Association National Joint Replacement Registry (AOANJRR); National Joint Registry (NJR) Oxidised Zirconium (OxZr); Cobalt Chromium (CoCr); Body Mass Index (BMI); Anterior – posterior (AP).

outcome measures [16-19]. Further, the revision rates reported in both the NJR and the AOANJRR for Genesis II Oxinium are higher at 12 years than that of the standard CoCr Genesis II [1, 3]. Vertullo et al [20] analysed data presented in the 2016 AOANJR report [1] and concluded that OxZr femoral components did not reduce revision rates compared with the same CoCr femoral components across all age groups.

While laboratory simulation can provide important data, the analysis of retrieved TKR components provides invaluable insights into the *in-vivo* tribological performance of the prostheses. Two previous retrieval studies [21, 22] reported on the measurement of roughness parameters of as-manufactured and retrieved OxZr and CoCr femoral components. Using contact profilometry, Brandt et al [21] analysed the surface damage of 26 pairs of retrieved OxZr and CoCr TKRs. All roughness parameters were found to be significantly lower on an as-manufactured CoCr femoral component when compared to retrieved CoCr femoral components but no significant difference was found between the roughness parameters measured on an as-manufactured OxZr femoral component compared to retrieved OxZr femoral components. The surface roughness parameters for the as-manufactured CoCr femoral component were significantly lower than for the as-manufactured OxZr femoral component, however there was no significant difference between the results for the retrieved CoCr femoral components and the retrieved OxZr femoral components.

Non-contacting profilometry is a preferable method of surface roughness measurement as it is not limited by errors induced by the physical profile of the stylus and potential damage to the sample as the stylus drags across the surface [23]. Heyse et al [22] used non-contacting profilometry to compare the roughness measurements of as-manufactured OxZr and CoCr femoral components and 10 retrieved OxZr and CoCr femoral components. The overall roughness for the retrieved CoCr implants was 83% greater than that of the retrieved OxZr implants and, in agreement with Brandt et al [21], the as-manufactured CoCr femoral component had a lower surface roughness than the as-manufactured OxZr femoral component. In contrast to Brandt et al, the retrieved OxZr components measured by Heyse et al had a significantly greater surface roughness than the as-manufactured OxZr component.

Gascoyne et al [16] used observer damage scoring and microcomputed tomography to quantify the damage observed on the articular surface of the PE inserts from the same cohort used by Brandt et al [21]. No significant difference was found between the PE damage of the two groups.

The purpose of this study was to use non-contacting profilometry to investigate the *in vivo* changes in surface roughness of OxZr TKRs and CoCr TKRs in order to add to the limited literature available on this topic. It was hypothesised that both OxZr and CoCr femoral components will roughen *in vivo* when comparing retrieved to as-manufactured prostheses; further, the extent of the roughening would be greater on retrieved CoCr femoral components compared with retrieved OxZr femoral components.

2. MATERIALS & METHODS

Ethical approval was obtained for the retrieval of 6 explanted TKRs (3 with OxZr and 3 with CoCr femoral components) from the Freeman Hospital, Newcastle upon Tyne, UK. All prostheses were implanted with cemented fixation with modular fixed PE bearings. The 3 retrieved CoCr TKRs (DePuy PFC Sigma Bicondylar) were selected to match the OxZr TKRs (3 Smith & Nephew Oxinium TKRs – 2 Genesis II; 1 Legion) based on time *in vivo*. The mean time *in vivo* for the OxZr retrievals was 58 (±24.8) months and 47 (±14.3) months for the CoCr retrievals. The mean BMI for the OxZr retrievals was 30.2 (±3.3) and 33.4 (±5.4) for the CoCr retrievals; the mean age at primary surgery was 51 (±14.0) years for the OxZr prostheses and 60 (±8.5) years for the CoCr prostheses. The patient and implant variables are shown in Table 1.

An as-manufactured Smith & Nephew Genesis II Oxinium femoral component and an as-manufactured DePuy PFC Sigma Bicondylar femoral component were available for analysis. Before the commencement of any analyses, all retrieved explanted components were sterilised in formaldehyde solution for at least 48 hours, rinsed with water and air-dried.

2.1 Qualitative and semi-quantitative damage assessment

A macroscopic visual assessment of damage was performed for each retrieved femoral component. A Mitutoyo QuickScope vision measuring system with a x25 magnification (x50 lens and x0.5 zoom) was used to perform the semi-quantitative Hood analysis technique [24] and a surface damage score was calculated for the articulating surface of each PE component. The articulating surface of the PE component was divided into sections and a grade assigned for each section corresponding to the estimated percentage area covered by 7 damage modes (surface deformation, pitting, embedded debris, scratching, burnishing, abrasion and delamination). The sum of the grades for each damage mode in each section gives the PE damage score with the maximum possible being 210.

2.2 Non-contacting profilometry

Surface roughness measurements for the retrieved and the as-manufactured femoral components were performed on a Zygo NewView 5000 non-contacting white light interferometric profilometer as used in previous explant studies [25-27]. The x10 lens was used with a x2 zoom, giving an area of view of 317 x 238 μm. The Zygo has a vertical resolution of greater than 1 nm. Measurements were taken of mean surface roughness S_a (the mean of the variation in peaks and valleys from the centreline of the sampling area), root-mean-square surface roughness S_q (the root-mean-square of the variation in peaks and valleys from the centreline of the sampling area), maximum peak height S_p, maximum valley depth S_v, peak to valley S_z (sum of the maximum peak height and the maximum valley depth of the sampling area) and surface skewness S_{sk} (the symmetry of the profile about the mean line) [28]. Fifteen measurements were taken at approximately 30^0 flexion on each femoral condyle (see Figure 1).

2.3 Statistical Analysis

Statistical software programme Minitab® 17 was used to perform two-sample Student's t-tests to compare the roughness measurement results. A p-value of <0.05 was considered to show significant difference. Sample sizes for the roughness values were n=30 and n=90 for the as-manufactured and retrieved components respectively. Normality was not checked as the sample sizes were great enough for the tests to be accurate for non-normal data.

3. RESULTS

Macroscopic visual assessment showed the damage to the retrieved OxZr femoral components to be minimal but there were obvious scratches in the anterior –posterior (AP) direction; the retrieved CoCr femoral components showed light to moderate scratching also in the AP direction.

The roughness parameters, S_a, S_q, S_z and S_p were greater, and S_v and S_{sk} were more negative, for the retrieved than for the as-manufactured for both OxZr and CoCr femoral components. There were no significant differences between any of the surface roughness parameters measured on the retrieved OxZr femoral components compared to those measured on the retrieved CoCr femoral components (see Table 2 and Figures 2 and 3). The S_a and S_q were both significantly greater ($p<0.001$) for the as-manufactured OxZr femoral component than for the as-manufactured CoCr femoral component.

All six of the retrieved PE components displayed *in vivo* damage with burnishing being the most prevalent damage mode observed; there was no embedded debris or delamination detected. Figure 4 shows a retrieved PE component with an area of burnishing and a pit approximately 1mm in size. The Hood damage scores are given in Table 1.

4. DISCUSSION

The results show that both OxZr and CoCr femoral components roughen *in vivo* which is in agreement with other reports of retrieved TKRs components [22, 27]. Further, in agreement with Scholes et al [27], femoral component roughening does not appear to be correlated to length of time *in vivo*.

The mean S_a values for the as-manufactured OxZr femoral component (S_a = 0.061μm ±0.004), the as-manufactured CoCr component (S_a = 0.042μm ±0.003) and the retrieved OxZr femoral components (S_a = 0.093μm ±0.014) are comparable to the mean S_a values reported by Heyse et al [22] for an as-manufactured OxZr femoral component (S_a = 0.05μm ±0.00), an as-manufactured CoCr femoral component (S_a = 0.04μm ±0.01) and retrieved OxZr femoral components (S_a =0.15μm ±0.39). However, the mean S_a value for the retrieved CoCr femoral components (S_a = 0.065μm ±0.005) is much lower than that reported by Heyse et al (S_a = 0.21μm ±0.21). In contrast to the data presented by both Brandt et al [21] and Heyse et al [22], no difference was found between the surface roughness measurements for the retrieved OxZr femoral components and the retrieved CoCr femoral components. When reviewing these results, it must be considered that the as-manufactured and retrieved CoCr femoral components used in this study are a different design to those reported on by Brandt et al and Heyse et al which may go towards explaining the differences seen.

The mean S_a and S_q were significantly less for the as-manufactured CoCr femoral component than for the as-manufactured OxZr femoral component which has been reported previously [21, 22]. Simulator studies report that the PE wear rate increases with increasing counter-face surface roughness [5, 13, 14] and so it would be expected that the rougher as-manufactured OxZr component would result in a greater PE wear rate than the as-manufactured CoCr component. However, the results from this study show that both OxZr and CoCr femoral components roughen after time *in vivo* (minimum time *in vivo* in this study is 35 months) and that there is no difference between the surface roughness parameters of the retrieved OxZr and CoCr femoral components. Kim et al [19] reported that the PE wear particles from CoCr TKRs were not different in weight, size or shape than those from OxZr TKRs which would be expected if the femoral components of both materials roughened to the same extent after a period of time *in vivo.* The results in this study and in Kim et al [19] support the findings that report no clinical difference between TKRs with OxZr femoral components and TKRs with CoCr femoral components at the 10 year follow up period [12, 17, 18].

All the retrieved PE components were observed to have undergone *in vivo* damage but there was no noticeable difference between the damage observed on the OxZr TKRs compared with the CoCr TKRs. There was no relationship found between the Hood scoring system of the PE component damage and the femoral component roughness measurements. These results match those presented in a recent study [16].

In TKR, PE wear and failure due to debris related aseptic loosing and osteolysis is influenced by multiple contributing factors that are a combination of surgeon, patient and implant variables [29, 30]. Surface roughness of the femoral component is just one of these factors and differentiating out individual effects continues to be challenging. Data from retrieval studies can add to the long-term clinical follow-up studies and *in vitro* wear analyses to help provide a clearer understanding of the interdependencies influencing wear *in vivo*.

It is acknowledged that this study is limited by the small number of retrieved OxZr TKRs that were available for analysis. However, there is a limited literature on retrieved OxZr TKRs and the recent history of orthopedics has shown the vital role that explant analysis can provide in understanding why some implants fail [31]. There are inherent limitations associated with the analysis of ‘failed’ prostheses as opposed to those which are still *in vivo* and may be functioning ‘well’. However, such ‘failed’ implants have arguably undergone the truest test of all in the human body, and this unique data should be shared. The surface roughness data of this retrieval study contributes to the current literature within this area [16, 20-22, 27]. In time, with longer clinical follow-up periods reported in arthroplasty registries and the further analysis of more explanted samples, the benefits and limitations of OxZr femoral components may become clearer. Ultimately the aim of the interdisciplinary evaluation of retrieved prostheses is to lead to future improvements in TKRs and a concomitant reduction of failures.

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5. CONCLUSIONS

Both OxZr and CoCr femoral components show increased surface roughness parameters following time *in vivo*. No significant difference was seen between the surface roughness parameters of the retrieved OxZr and CoCr femoral components. Further analysis of retrieved OxZr TKRs is recommended so that a fuller appreciation of their benefits and limitations be obtained.

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COMPETING INTERESTS

Author, DJW has received monies from Stryker with regards to lecturing not related to this work; author JH has received monies from Zimmer Biomet and Stryker for education not related to this work; and, author TJJ has received monies paid to Newcastle University for expert testimony not related to this work. All other authors certify that she or he has no commercial associations (e.g consultancies, stock ownership, equity interest, patent/licensing arrangements, etc.) that might pose a conflict of interest in connection with the submitted article.

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ETHICAL COMMITTEE REVIEW STATEMENT

This study is approved by Ethical Committee Review REC 09/H0906/72.

REFERENCES

[1] Australian Orthopaedic Association National Joint Replacement Registry. *Annual Report. 2016.*

[2] Bae DK, Song SJ, Park MJ, Eoh JH, Song JH, Park CH. Twenty-year survival analysis in total knee arthroplasty by a single surgeon. *Journal of Arthroplasty. 2012;* 27(7): 1297-304

[3] National Joint Registry for England, Wales and Northern Ireland. *The 13th Annual Report. 2016.*

[4] Swedish Knee Arthroplasty Register. *Annual Report. 2015*.

[5] Muratoglu OK, Burroughs BR, Bragdon CR, Christensen S, Lozynsky A, Harris WH. Knee simulator wear of polyethylene tibias articulating against explanted rough femoral components. *Clinical Orthopaedics & Related Research. 2004;* 428: 108-13.

[6] Puloski SK, McCalden RW, MacDonald SJ, Bourne RB, Rorabeck CH. Surface analysis of posterior stabilized femoral components used in total knee arthroplasty. *Journal of Arthroplasty. 2003;* 18(7): 822-6.

[7] Puloski SK, McCalden RW, MacDonald SJ, Rorabeck CH, Bourne RB. Tibial post wear in posterior stabilized total knee arthroplasty. An unrecognized source of polyethylene debris. *Journal of Bone & Joint Surgery - American Volume. 2001*; 83-A(3): 390-7

[8] Que L, Topoleski LD, Parks NL. Surface roughness of retrieved CoCrMo alloy femoral components from PCA artificial total knee joints. *Journal of Biomedical Materials Research. 2000;* 53(1): 111-8.

[9] Siddique MS, Rao MC, Deehan DJ, Pinder IM. Role of abrasion of the femoral component in revision knee arthroplasty. *Journal of Bone & Joint Surgery - British Volume. 2003;* 85(3): 393-8

[10] Saikko V, Vuorinen V, Revitzer H. Effect of CoCr Counterface Roughness on the Wear of UHMWPE in the Noncyclic RandomPOD Simulation. *Journal of Tribology. 2016;* 139(2):

[11] Laskin RS. An oxidized Zr ceramic surfaced femoral component for total knee arthroplasty. *Clinical Orthopaedics & Related Research. 2003;* 416:191-6.

[12] Schuttler KF, Turgay E, Heyse TJ, Haas SB. Oxidized Zirconium Bearing Surfaces in Total Knee Arthroplasty: Lessons Learned. *Journal of Knee Surgery. 2015;* 28(5): 376-381

[13] Spector BM, Ries MD, Bourne RB, Sauer WS, Long M, Hunter G. Wear performance of ultra-high molecular weight polyethylene on oxidized zirconium total knee femoral components. *Journal of Bone and Joint Surgery-American Volume*. *2001;* 83-A: 80–86

[14] DesJardins JD, Burnikel B, LaBerge M. UHMWPE wear against roughened oxidized zirconium and CoCr femoral knee components during force-controlled simulation, *Wear, 2008*; 264: 245–56

[15] Ezzet KA, Hermida JC, Colwell CW, D'Lima DD. Oxidized zirconium femoral components reduce polyethylene wear in a knee wear simulator. *Clinical Orthopaedics & Related Research. 2004;* 428: 120-24.

[16] Gascoyne TC, Teeter MG, Guenther LE, Burnell CD, Bohm ER, Naudie DR. In vivo wear performance of cobalt-chromium versus oxidized zirconium femoral total knee replacements. *Journal of Arthroplasty*. *2016;* 31(1): 137-41.

[17] Hofer JK, Ezzet KA. A minimum 5-year follow-up of an oxidized zirconium femoral prosthesis used for total knee arthroplasty. *Knee*. *2014*; 21(1): 168-71.

[18] Innocenti M, Matassi F, Carulli C, Nistri L, Civinini R. Oxidized zirconium femoral component for TKA: a follow-up note of a previous report at a minimum of 10 years. *Knee. 2014;* 21(4): 858-61

[19] Kim YH, Park JW, Kim JS. Comparison of the Genesis II total knee replacement with oxidised zirconium and cobalt-chromium femoral components in the same patients: a prospective, double-blind, randomized controlled study. *J Bone Joint Surg Br. 2012;* 94(9): 1221-7.

[20] Vertullo CJ, Lewis PL, Graves S, Kelly L, Lorimer M, Myers P. Twelve-Year Outcomes of an Oxinium Total Knee Replacement Compared with the Same Cobalt-Chromium Design. *J Bone Joint Surg Am 2017;* 99: 275-83

[21] Brandt JM, Guenther L, O'Brien S, Vecherya A, Turgeon TR, Bohm ER. Performance assessment of femoral knee components made from cobalt-chromium alloy and oxidized zirconium. *Knee. 2013;* 20(6): 388-96

[22] Heyse TJ, Elpers ME, Nawabi DH, Wright TM, Haas SB. Oxidized zirconium versus cobalt-chromium in TKA: profilometry of retrieved femoral components. *Clinical Orthopaedics & Related Research*. *2014;* 472(1): 277-83.

[23] Hutchings IM. *Tribology: Friction and Wear of Engineering Materials.* 1st ed. Butterworth-Heinemann; 1992

[24] Hood RW, Wright TM, Burstein AH. Retrieval analysis of total knee prostheses: A method and its application to 48 total condylar prostheses. *Journal of Biomedical Materials Research*. *1983*; 17(5): 829-42.

[25] Holleyman RJ, Scholes SC, Weir D, Jameson SS, Holland J, Joyce TJ, Deehan DJ. Changes in surface topography at the TKA backside articulation following in vivo service: a retrieval analysis. *Knee Surgery Sports Traumatology Arthroscopy*. *2015;* 23(12): 3523-31.

[26] Joyce TJ, Langton DJ, Jameson SS, Nargol AV. Tribological analysis of failed resurfacing hip prostheses and comparison with clinical data. *Proceedings of the Institution of Mechanical Engineers Part J Journal of Engineering Tribology*. *2009;* 223(3): 317-323.

[27] Scholes SC, Kennard E, Gangadharan R, Weir D, Holland J, Deehan D, Joyce TJ. Topographical analysis of the femoral components of ex vivo total knee replacements. *Journal of Materials Science-Materials in Medicine*. *2012;* 24(2): 547-54

[28] ISO 4287, Geometric Product Specification (GPS). Surface texture: Profile method – terms, definitions and surface texture parameters. 2009.

[29] Gallo J, Goodman SB, Konttinen YT, Wimmer MA, Holinka M. Osteolysis around total knee arthroplasty: A review of pathogenetic mechanisms. *Acta Biomaterilia 2013;* 9: 8046-8058

[30] Vandekerckhove PTK, Teeter MG, Naudie DDR, Howard JL, MacDonald SJ, Lanting BA. The Impact of Coronal Plane Alignment on Polyethylene Wear and Damage in Total Knee Arthroplasty: A Retrieval Study. *Journal of Arthroplasty 2017;* 32: 2012-2016

[31] Langton DJ, Jameson SS, Joyce TJ, Gandhi JN, Sidaginamale R, Mereddy P, Lord J, Nargol AVF. Accelerating failure rate of the ASR total hip replacement. *JBJS(Br) 2011;* 93-B(8): 1011-1016

FIGURE LEGEND

Figure 1: Profilometer measurements were taken at approximately 30° flexion in the boxed areas as shown on this femoral component

Figure 2: Surface roughness parameters S_a, S_q and S_p measured on as-manufactured OxZr and CoCr femoral components and retrieved OxZr and CoCr femoral components.

Figure 3: Surface roughness parameters S_v, S_z and S_{sk} measured on as-manufactured OxZr and CoCr femoral components and retrieved OxZr and CoCr femoral components.

Figure 4: A retreived PE component from an OxZr TKR

Table 1. Patient and Implant Variables

Implant No.	Make & Model of retrieved prosthesis	Gender	Side	BMI	Indication for primary surgery	Indication for Revision	Time *In Vivo* (Months)	Age at implantation of retrieved prosthesis	PE Articular Surface Hood Damage Score
1	S&N Genesis II Oxinium	Female	Right	28.4	Osteoarthritis	Pain / Hypermobility	40 months	37 years	22
2	S&N Genesis II Oxinium	Male	Right	28.2	First revision of primary TKR indicated for osteoarthritis.	Instability	86 months	51 years	35
3	S&N Legion Oxinium	Male	Left	34	Osteoarthritis	Chronic infection and instability / Pain	47 months	65 years	44
4	DePuy PFC Sigma	Female	Right	33	Osteoarthritis	Component malalignment	44 months	50 years	25
5	DePuy PFC Sigma	Male	Left	28.3	Osteoarthritis	Component malalignment	35 months	66 years	15
6	DePuy PFC Sigma	Female	Left	39	Osteoarthritis	Instability / Pain	63 months	63 years	33

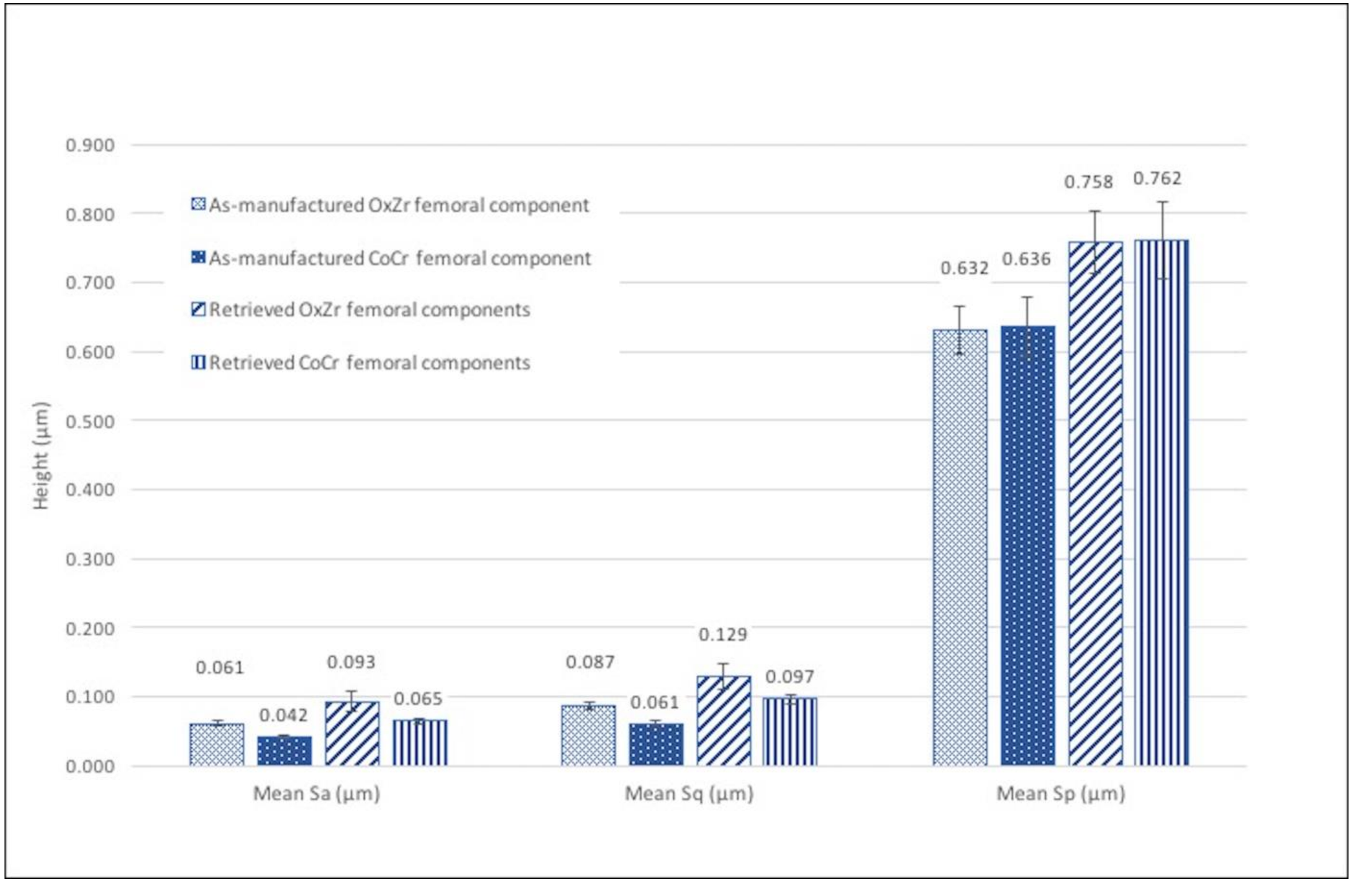
Table 2. Femoral component surface roughness measurements

	As-manufactured OxZr femoral component (n = 30, 1 component x 30 points)	Retrieved OxZr femoral components (n = 90, 3 components x 30 points per component)	As-manufactured CoCr femoral component (n = 30, 1 component x 30 points)	Retrieved CoCr femoral components (n = 90, 3 components x 30 points per component)	p-value 1 OxZr As-manufactured vs Retrieved	p-value 2 CoCr As-manufactured vs Retrieved	p-value 3 Retrieved OxZr vs Retrieved CoCr	p-value 4 As-manufactured OxZr vs As-manufactured CoCr
Mean S_a (μm)	0.061 (±0.004)	0.093 (± 0.014)	0.042 (± 0.003)	0.065 (±0.005)	0.033	<0.001	0.059	<0.001
Mean S_q (μm)	0.087 (± 0.005)	0.129 (± 0.017)	0.061 (± 0.004)	0.097 (±0.006)	0.021	<0.001	0.079	<0.001
Mean S_p (μm)	0.632 (± 0.035)	0.758 (±0.045)	0.636 (± 0.042)	0.762 (±0.056)	0.029	0.075	0.960	0.937
Mean S_v (μm)	-0.613 (± 0.028)	-1.000 (±0.078)	-0.831 (± 0.211)	-1.145 (±0.087)	<0.001	0.178	0.218	0.314
Mean S_z (μm)	1.245 (± 0.053)	1.758 (±0.115)	1.467 (± 0.222)	1.918 (±0.112)	<0.001	0.077	0.322	0.337
Mean S_{sk}	0.6194 (± 0.105)	0.118 (±0.129)	0.806 (± 0.515)	-0.466 (±0.345)	0.003	0.045	0.116	0.725

* The mean value ± standard error is given for each surface roughness parameter. P-value 1 corresponds to the difference between the results for the retrieved OxZr femoral components compared to those for the as-manufactured OxZr femoral component. P-value 2 corresponds to the difference between the results for the retrieved CoCr femoral components and the as-manufactured CoCr femoral component. P-value 3 corresponds to the difference between the results for retrieved OxZr femoral components compared to those for retrieved CoCr femoral components. P-value 4 corresponds to the difference between the results for the as-manufactured OxZr femoral component and the as-manufactured CoCr femoral component

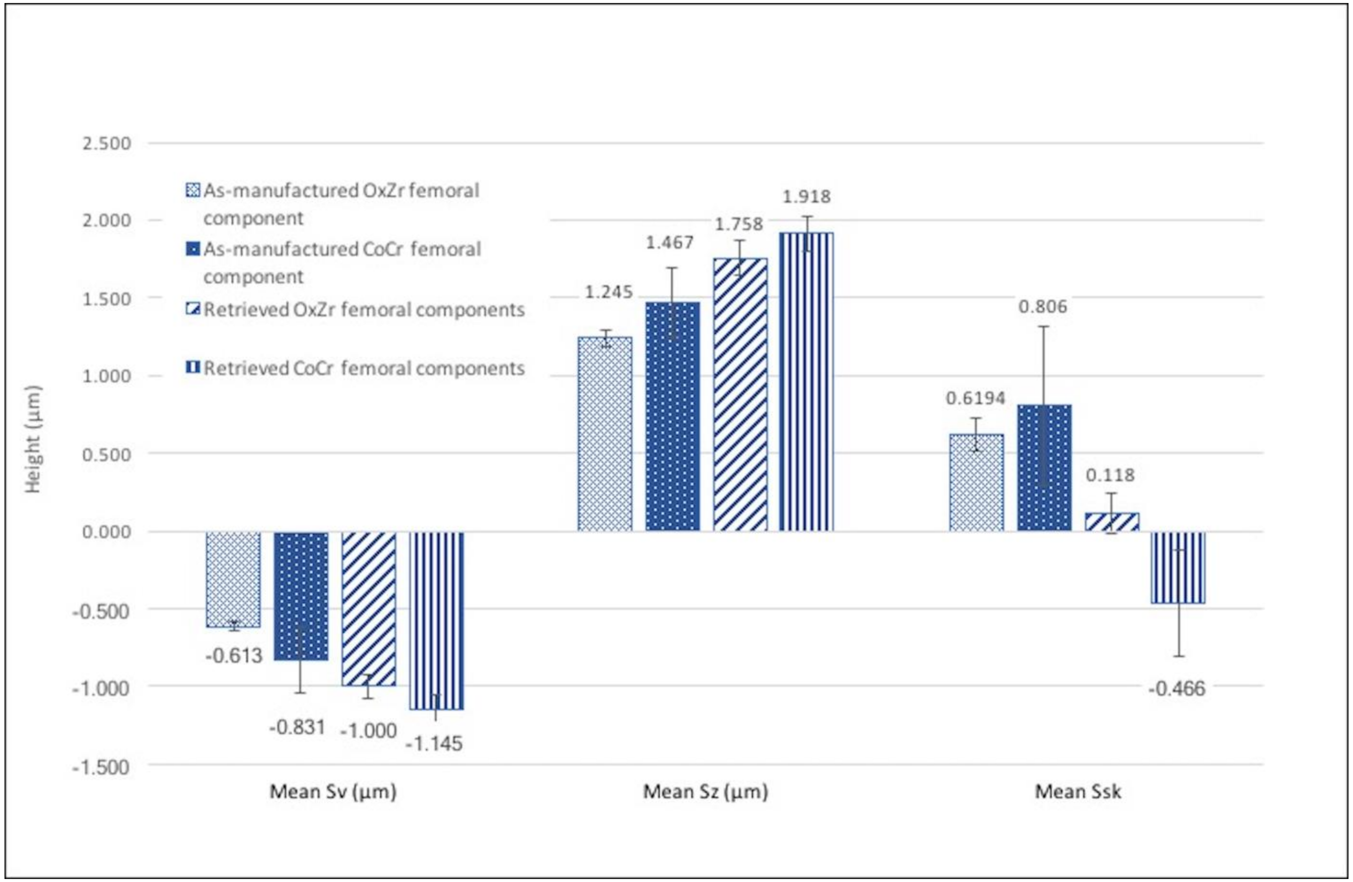
Figure 1.

Figure 2.



As-manufactured OxZr femoral component
As-manufactured CoCr femoral component
Retrieved OxZr femoral components
Retrieved CoCr femoral components
Height (µm)
0.900
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
0.061
0.042
0.093
0.065
0.087
0.061
0.129
0.097
0.632
0.636
0.758
0.762
Mean Sa (µm)
Mean Sq (µm)
Mean Sp (µm)

Figure 3.



As-manufactured OxZr femoral component
As-manufactured CoCr femoral component
Retrieved OxZr femoral components
Retrieved CoCr femoral components
Height (µm)
2.500
2.000
1.500
1.000
0.500
0.000
-0.500
-1.000
-1.500
-0.613
-0.831
-1.000
-1.145
1.245
1.467
1.758
1.918
0.6194
0.806
0.118
-0.466
Mean Sv (µm)
Mean Sz (µm)
Mean Ssk

Figure 4.