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The wear of the taper junction of the stem trunnion with the femoral head of a total modular hip prosthesis

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KEYWORDS

Total modular hip prosthesis
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ABSTRACT

The introduction of total modular hip prostheses has led to notable facilities, as well as micro-movement problems and fretting wear of modular junctions. The wear of the stem trunnion taper junction with the femoral head of the modular total hip prosthesis is a less well-researched or less published. The total ceramic-on-ceramic hip replacement (CoC) has a substantially lower wear rate than the metal-on-polyethylene (MoP) joints, as shown in many papers. However, the revision rates of the CoC and MoP are comparable. To try to explain this discrepancy, wear on both bearing surfaces and the taper - trunnion interface of a 36 mm CoC BIOLOX delta, mounted on titanium trunnions (Ti6Al4V) 12/14, was studied. After 5 million cycles, the total average wear of the ceramic joint surfaces was 0.25 mm^3, and the titanium trunnion was 0.29 mm^3. This metal wear can provide an explanation for the adverse reaction to the metal debris found in contemporary CoC hip joints. Therefore, it is essential to take into account taper - trunnion wear in the pre-clinical testing of artificial hip joints.

1.0 INTRODUCTION

Specialized international literature has published a lot of papers on the wear problems of total hip prostheses. Thus, Krishnan et al., (2013) published a review that aims to provide surgeons an updated summary of the clinically relevant issues of introducing modularity. "The development

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of femoral modularity and a classification system is described. The theoretical reason for modularity is needed to determine whether femoral stems with modular neck will be used in the future and how patients who already have implants should be monitored".

Goldberg et al., (2002) reported an analysis of 231 hip modular implants retrieved, to investigate the effects of materials combination, metallurgical condition, bending stiffness, head and neck moment arm, neck length and implantation time, corrosion and fretting of modular taper surfaces. The results of this study suggest that in vivo corrosion of hip modular taper interfaces is attributed to a mechanically assisted corrosion process. The higher diameter necks will increase their rigidity and reduce the fretting and subsequent corrosion of the taper interface, regardless of the alloy used. However, the increase in neck diameter must be balanced, taking into account the decrease in the resulting range of motion (ROM) and the stability of the joint.

Hussenbokus et al., (2015), and Grupp et al., (2011), have shown that the THP retrievals and biomechanical simulation tests have shown that the primary micro-motions initiated the fretting within the modular connexion of taper neck. Titanium oxide layers of 10-30 μm were observed on the surface. Surface cracks caused by fretting or fretting corrosion eventually lead to fatigue fracture of titanium alloy modular neck adapters. Cobalt-chromium alloy neck adapters have significantly reduced micro-motions, especially in the case of contaminated taper connection. With a cobalt-chromium neck, micro-motions can be reduced three times compared to the titanium neck. The incidence of fretting corrosion was also substantially lower in the case of cobalt-chromium neck.

Jauch et al., (2011) studied modular prosthesis neck adapter failures for a number of different models. It has been speculated that micro-motions from the stem – neck interface were responsible for these implant failures. The purpose of the study was to investigate the influence of materials combinations and assembly conditions on the size of micro-motions at the stem – neck interface during cyclic loading. The largest observed micro-motions were located at the lateral side of the taper neck, which is consistent with the location of clinically impaired prosthetic cracks. Titanium neck adapters showed significantly higher micro-motions than cobalt-chromium neck adapters. The contaminated interfaces also showed significantly higher micro-motions. The authors concluded that since excessive micro-motions from the stem – neck interface could be involved in the implant failure process, particular attention should be paid to the cleaning of the interface before assembly, and caution should be exercised when using the titanium neck adapters and titanium stems.

In another paper, Jauch et al., (2014) investigated micro-motions at the stem – neck interface of two different models: a model (Metha, Aesculap AG) demonstrated a substantial number of in vivo fractures for Ti-Ti couplings, but no fractures documented for Ti-CoCr couplings. In contrast, for a comparable design (H-Max M, Limacorporate) with a Ti-Ti coupling, only clinical failure was reported. The prostheses were mechanically tested, and micro-motions were recorded using a non-contact measurement system. The authors showed that "for Ti-Ti couplings, the Metha's prosthesis showed a tendency towards higher micro-motions compared to the H-Max M (6.5 ± 1.6 μm vs. 3.6 ± 1.5 μm). Independent of the design, prostheses with Ti neck adapter have caused significantly higher micro-motions at the interface than those with a CoCr adapter (5.1 ± 2.1 μm vs. 0.8 ± 1.6 μm). There were no differences in micro-motions between the Metha prosthesis with CoCr neck and H-Max M with Ti neck (2.6 ± 2.0 μm)".

Ellman et al., (2013) have shown that a possible complication of modularity increase is components fracture. The authors presented a case of fracture of the modular femoral neck, which required a review surgery to treat this complication. "The combined effects of cracking and fretting corrosion of the large diameter femoral head, long metal-on-metal modular neck, patient size and activity have all played integral roles in creating an environment that is susceptible to this classic fatigue fracture model".

Hallab et al., (2004) studied the corrosion differences by fretting corrosion of metal-metal modular junctions and metal-metal and ceramic-metal hip replacements. They assumed that modular ceramic-metal junctions in total hip arthroplasty (THA) release more metal by fretting corrosion than traditional metallic modular connections. This was investigated using an in vitro comparison of ceramics femoral head fretting (zirconia, ZrO_2) and metal (Co alloy) on Co alloy stem components. The in vitro fretting corrosion test consisted in the potential and dynamic analysis of the metal loss in 28 mm zirconium and Co alloy femoral heads, with similar surface roughness (S_a = 0.46 μm) on identical stems from Co alloy at 2.2 kN for 1 x 10^6 cycles at 2 Hz. Unlike their initial hypothesis, the authors found a greater release of metal (about 11 times in Co and a 3-fold increase in Cr) and the potentiodynamic fretting of metal-metal modular junctions, compared to ceramic-metal.

McTighe et al., (2015) published a paper on modular taper junctions in THA, which is designed to review the risk factors and benefits of modular junctions in THA, as well as some basic engineering principles that can reduce risk factors and improve the functionality of modular junctions. The authors have shown that the decline in clinical acceptance of hip modular implants has recently been attributed to fretting corrosion. This was also the reason for the withdraw of two products (Rejuvanate ™ and ABGII ™) by Stryker Ortopedics, Mahwah, NJ. A main mechanism behind the fretting corrosion is the stress or load. Increasing the stress at the modular junction will increase proportional the fretting corrosion. Stryker recall products had reduced tapered support (13 mm vs. 15 mm and 17 mm) with high bending and torsional moments, which produced much greater stress at the modular junction and potentially lead to a faster corrosion speed, compared to the style of stems that keep the neck. Since taper lengths and reports have changed over the years, the standardization of the Euro-Ceramtec 12/14 "off-the-shelf", allows more standard review options compared to using a neck sleeve adapter. Taper neck adapters may have design constraints in that they have skirts that can interfere with the range of motion or cause pressure, generating particles and/ or remnants dislocations.

Kop and Swarts, (2012) have shown that the clinical advantages of the modular neck include the intraoperative adjustment of leg lengths and femoral anteversion through neck – head taper. In this regard, sixteen cases of double tapers cones of recovered Margron hip prostheses were inspected, their necks exhibiting significant fretting and a corrosive cracking of taper with a median duration of 39 months after implantation. These were compared with the remaining recoveries, which showed no corrosion after an average of 2.7 months in situ. This recovery study demonstrates that even in the case of modern taper design and corrosion-resistant materials, increased modularity can lead to fretting corrosion and cracking, metal ions and debris that can contribute to periprosthetic osteolysis and loss of fixation.

Dos Santos et al., (2016) made a characterization of fretting corrosion behaviour of the surface and debris from the head – taper interface, of two different hip modular prostheses. The authors have found that micro-motions associated with modular components can lead to fretting corrosion and therefore the release of debris, that can cause local tissue reactions in the human body. They studied two models of modular hip prostheses: the cementless SS/ Ti model whose stem was made of ASTM F136 Ti6Al4V alloy and whose metal head was made of ASTM F138 austenitic stainless steel; and the SS/ SS model cemented, with both components made of ASTM F138 stainless steel. Micro-motions during the test caused mechanical wear and loss of material in the head – taper interface, resulting in fretting and corrosion. The SS/ SS model showed a higher degree of corrosion. Different morphologies of debris predominated in each studied model. Small and crowded particles were observed in the SS/ Ti model, and in the SS/ SS model, irregular particles. After 10 million cycles, the SS/ Ti model was more resistant to fretting corrosion than the SS/ SS model.

Grunert et al., (2018) have also shown that modality in THA allows orthopaedic surgeons to accurately reconstruct hip biomechanical parameters, particularly in tumour revision and arthroplasty. Models of femoral stems structured using taper junctions have shown an increase in implant rupture in the recent past. The authors assumed that a new modular neck – stem interface may result in lower implant breakage compared to conventional femoral stems. For this purpose, a new modular stem for the THA was designed and produced. As a result, three different variants of the interface mechanisms have been developed that provide a simple connection between the stem and the modular neck and allow the intraoperative adjustment. Three prototypes were manufactured and then tested for dynamic fatigue (ISO 7206-6). The authors have shown that modular implants are used with caution because of the high risk of breaking. Another risk in this context is the fretting of tapering, corrosion and disconnection. With the new design, it should be possible to detach the stem and neck module from the intraoperative to adapt to the anatomical situation.

Oladokun et al., (2018) published a paper on the fretting of CoCrMo and Ti6Al4V alloys in modular prostheses, investigating the fretting behaviour of CoCr - CoCr and CoCr - Ti couples, and investigating their destruction mechanisms. An in-situ electrochemical ball on plate tribometer was instrumented to characterize tribocorrosion damage due to the contact of the two material couplings. The fretting movements amplitudes of 10, 25 and 50 μm were evaluated at an initial contact pressure of 1 GPa. The results revealed a greater loss of metal in CoCr - CoCr alloy couplings compared to CoCr - Ti alloys, and the open circuit potential indicates an overlap of the protective oxide layer at displacement amplitudes > 25 μm. In conclusion, the damage mechanisms of the CoCr - CoCr and CoCr -Ti contacts have been identified as the mechanisms of wear and fatigue prevalence.

Bhalekar et al., (2019) have experimentally tested the resistance to shock and hydrothermal aging of ceramic hip joints. It was established that shocks lead to main degradation through wear on the bearing surfaces, alumina toughened zirconia implants (ZTA) do not exhibit hydrothermal degradation, in vitro shock effects allow reproduction of the best wear mechanism in vivo. The authors have developed a new procedure that combines friction, shocks and hydrothermal aging, establishing that shocks lead to main degradation through wear on ZTA bearing surfaces.

Bhalekar et al., (2019) focused on investigating the material loss, if any, at the junction of the taper of 36 mm BIOLOX delta CoC components, mounted on titanium trunnions. These components have been tested for wear in a multistation hip simulator for over 5 million cycles. In addition, a CoC sample was used in a dynamically loaded station with no articulated motion, to investigate the material losses, if there exist, at the bearing surfaces and at the taper junction. Furthermore, it was appreciated that both the assembly and the disassembly of the femoral head in the trunnion, could produce wear at the taper - trunnion junction, therefore this important concern was also investigated.

Pastides et al., (2013) showed that metal-on-metal (MoM) hip replacements have proven to be a modern-day orthopaedic failure. The early enthusiasm and promise of a hard, durable bearing were quickly quashed following the unanticipated wear rates. The release of metal ions into the blood stream has been shown to lead to surrounding soft tissue complications and early failure.

The devastating destruction caused has led to a large number of revision procedures and implant extractions. The resulting research into this field has led to a new area of interest; that of the wear at the trunnion of the prosthesis. It had been previously thought that the metal debris was generated solely from the weight bearing articulation, however with the evolution of modularity to aid surgical options, wear at the trunnion is becoming more apparent. The phenomenon of "trunnionosis" is a rapidly developing area of interest that may contribute to the overall effect of metallosis in MoM replacements but may also lead to the release of metal ions in non-MoM hip designs. The aim of this paper is to introduce, explain and summarise the evidence so far in the field of trunnionosis. The evidence for this phenomenon, the type of debris particles generated and a contrast between MoM, non-MoM and resurfacing procedures are also presented.

2.0 EXPERIMENTAL PROCEDURE

Generally, total hip prostheses are tested on hip simulators in dynamic motion and physiological stress conditions. The walking cycle applied in the simulator combines the sine wave flexion-extension and abduction-adduction steps of 46^0 and 12^0 respectively, resulting in an elliptical wear path.

The term "wear test on the hip simulator" corresponds to components that are subject to dynamic loading (DL) and joint movement. In this study, three ceramic on ceramic (CoC) bearings BIOLOX delta hip replacement, Pinnacle (DePuy Synthes, UK) were tested under dynamic load and joint movements. Newborn calf serum diluted with deionized water was used as a lubricant to obtain a protein concentration of 21 g/l. The tests were conducted on the simulator at the Institute of Solid Mechanics of the Romanian Academy, in Bucharest.

The lubricant was changed every 500,000 cycles when the components were cleaned and weighed in accordance with the relevant international standard, ISO 14242-2.26. In addition, a neutral detergent was used to eliminate any visual trace seen after disassembly on the inner taper of the femoral heads and the back of the liners. To study the wear of the stem trunnion taper junction with femoral head, a CoC joint sample was tested on a DL station with a minimum charge of 400 N and a maximum charge of 2000 N, but without the articulation movement, hereinafter referred to as the "DL test station", Figure 1(A, B).

All other testing conditions were used, such as assembling - disassembly procedures, the same lubricant, etc., as in Saikko and Pfaff, (1998). It is important to note that the trunnion in the DL station was not loaded along its axis so that the head load was shifted relative to the trunnion, reproducing that observed when an artificial hip is implanted.

The test lasted 5 million cycles. A double-peak was applied to the three articulated samples, with a minimum value of 400 N and a maximum value of 2000 N, as in Matthies et al., (2013). A replica of the one used in surgery, on a 12/14 titanium (Ti6Al4V) trunnion was mounted with a femoral head plastic impacter. When the trunnion was hit by at least two strokes, the axial blows aligned in the sense of the femoral head impact on the trunnion (Heiney et al., 2009).

In turn, each trunnion was placed in a femoral head holder – see Figure 2(A-C). The 12/14 taper trunnions with a 34.5 mm neck length were manufactured by Phoenix Tribology Limited, UK, based on the Corail stem (DePuy Synthes, UK) which, when used with 36 mm ceramic heads, give the CoC hip joint most commonly implanted in the UK.

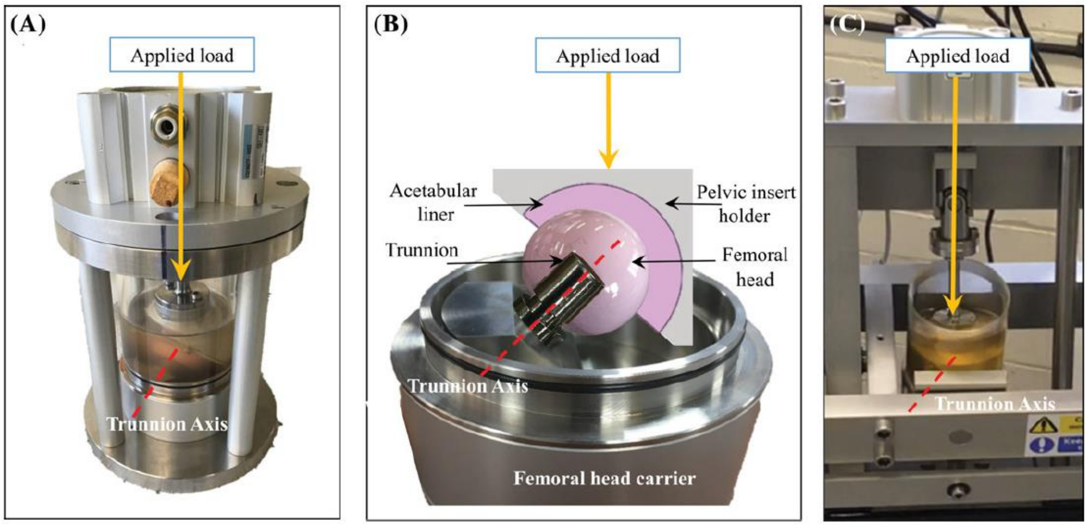


Figure 1: (A) A DL station. (B) Scheme of the femoral head, acetabular and trunnion liner in the test and in the DL station. (C) A test station (Bhalekar et al., 2018).

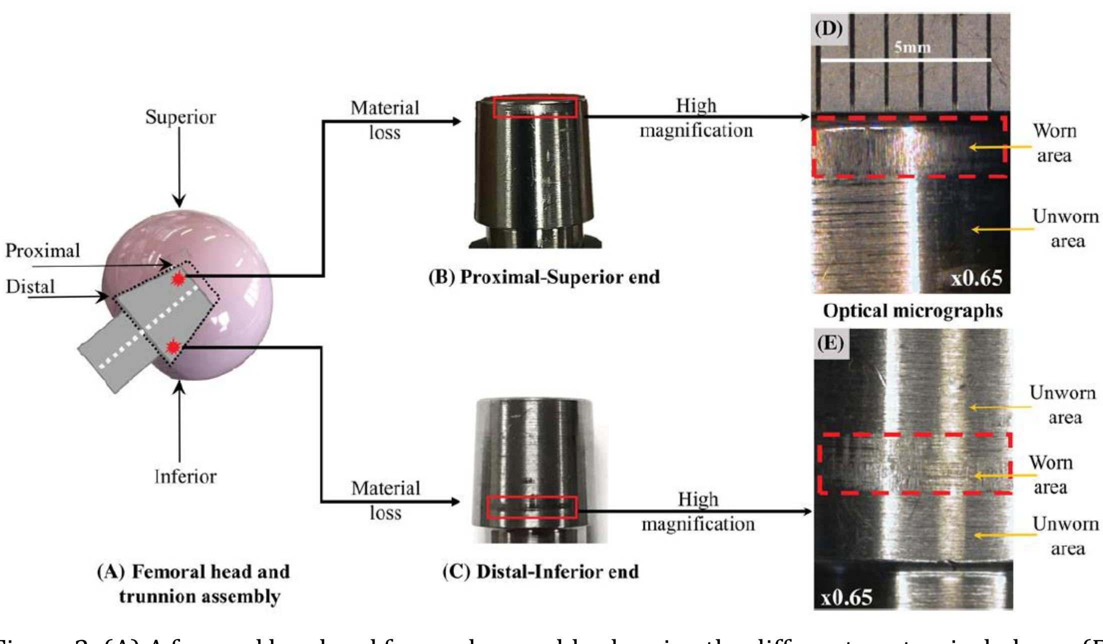


Figure 2: (A) A femoral head and femoral assembly showing the different anatomical planes (B, C) a test trunnion indicating wear at the proximal – superior end and at the distal – inferior end, respectively (D, E) optical microscopic images captured at a 0.65x magnification showing worn and unworn areas of the superior – proximal end and the distal – inferior ends (Bhalekar et al., 2018), respectively.

All trunnions and femoral head holders have been marked before testing to allow for correct repositioning after cleaning and measuring intervals. Each ceramic acetabular cup was stored in a pelvis insert holder of aluminium alloy 3105, with a simulator cup abduction angle of 45^0 and an anteversion angle of 15^0.

This arrangement is different from the clinical situation in which a titanium shell would serve to bind the acetabular liner, but it is customary not to use a shell in the hip simulators, where the emphasis has been put on testing the wear of the bearing surfaces.

3.0 RESULTS

The head and trunnion assembly are shown in Figure 2(A). On the trunnions, the loss of material (as indicated by the reduction of the mass and the decrease of the roughness) was seen opposite the superior – proximal end and the distal – inferior end, respectively, as shown in Figure 2(B, C).

Unworn and worn out areas are clearly visible, and the original circular machining marks are evident in unworn areas. The proximal – superior end of a test trunnion can be seen in Figure 3(A) at a magnification of 2.5x, using an optical microscope and at a magnification of 500x with a SEM in Figure 3(B). In figure 3(B), considering the use of a more advanced microscopic system and a larger magnification, it is observed that even in the unworn area, small traces of wear appear. There are several small areas, where the loss of material is observed, as pronounced as in the worn areas.

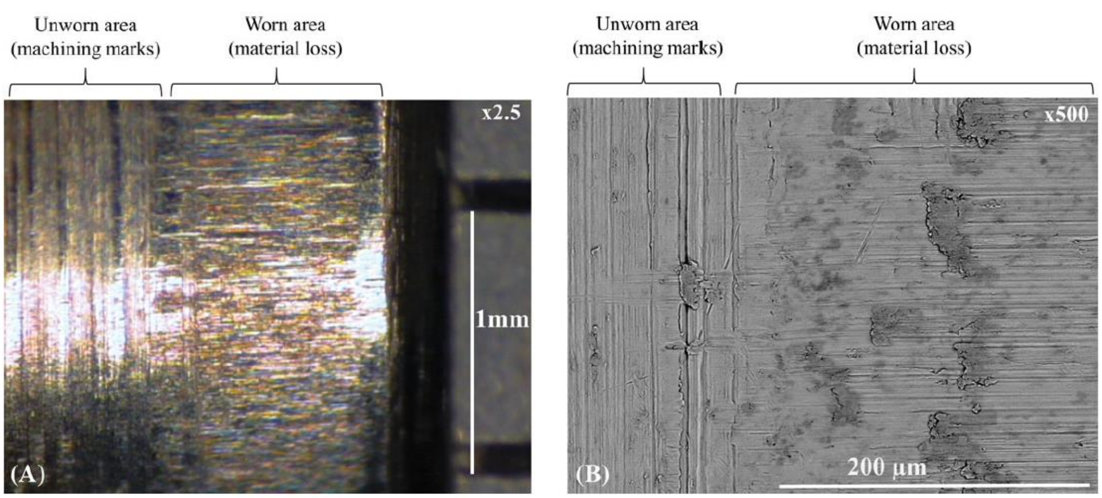


Figure 3: (A) An optical microscopic image at 2.5× magnification and (B) the microscopic scanning electronics (SEM) image at 500× magnification of test trunnion, showing worn and unworn areas (Bhalekar et al., 2018).

Figure 4 shows femoral head and a trunnion – head assembly, showing the various anatomical planes and internal taper of a tested femoral head showing a grey ring (Bhalekar et al., 2018).

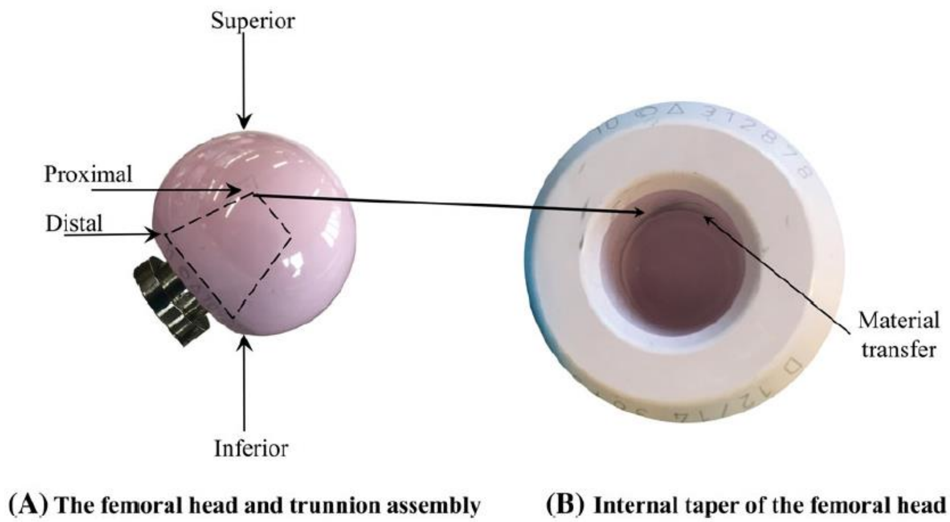


Figure 4: (A) A femoral head and a trunnion – head assembly, showing the various anatomical planes. (B) Internal taper of a tested femoral head showing a grey ring (Bhalekar et al., 2018).

There were no pre-test and post-test statistical differences (p = 0.210) for femoral taper surfaces with R_a (mean ± standard deviation) of 0.351 ± 0.142 and 0.302 ± 0.071 µm, respectively. However, the R_a of the tapers showed a statistically significant decrease ($p < 0.001$) from 0.612 ± 0.070 to 0.527 ± 0.090 µm in the measurements before and after the tests.

Figure 5 shows an evaluation profile of a trace obtained on the distal – inferior end of a test area, which shows the worn area.

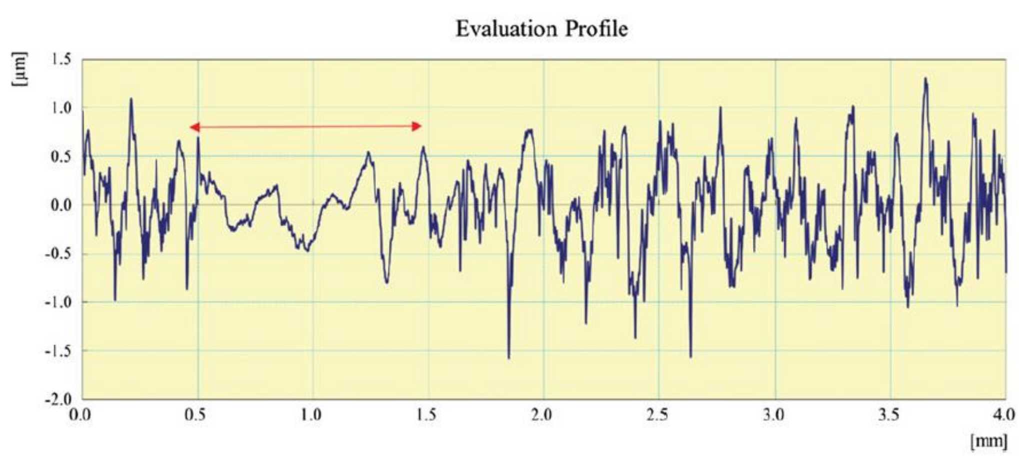


Figure 5: An evaluation profile obtained at the distal – inferior end of a test trunnion (R_a = 0.321 µm). The red arrow marks the worn area.

Figure 6(A, B) shows profile images acquired with the non-contact profilometer on (A) unworn and (B) worn areas from the superior – proximal end of a tested trunnion.

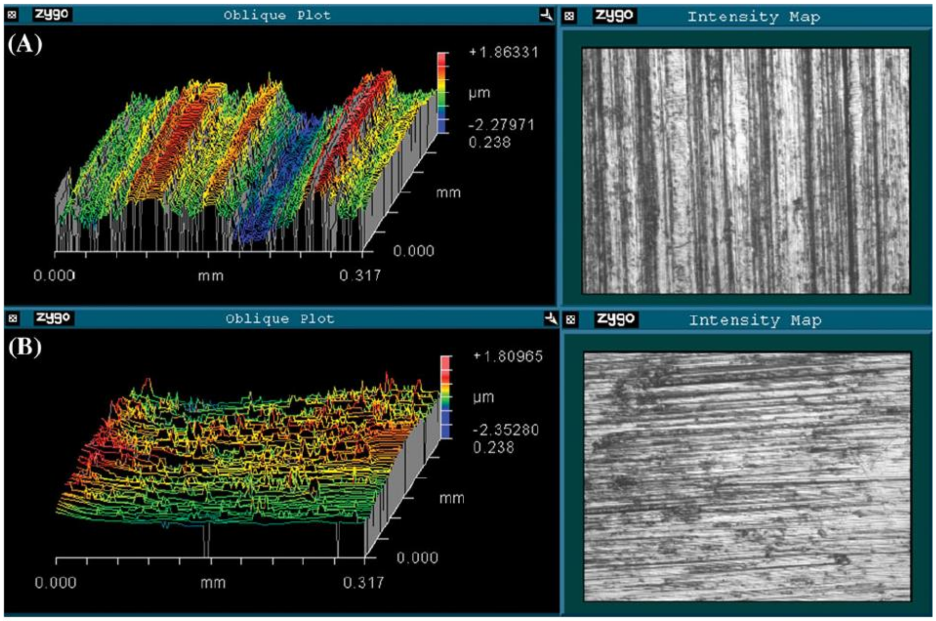


Figure 6: Images of surface topography of a titanium trunnion (A) surface with no visible machining marks (R_a = 0.565 µm) and (B) worn (R_a = 0.284 µm) (Bhalekar et al., 2018).

In the unworn area, the original marks of processing can be observed, but no such marks have been observed on the unworn area. The R_a roughness of the trunnions in the unworn and worn areas showed a statistically significant decrease from 0.558 ± 0.060 to 0.312 ± 0.028 µm ($p < 0.001$), respectively.

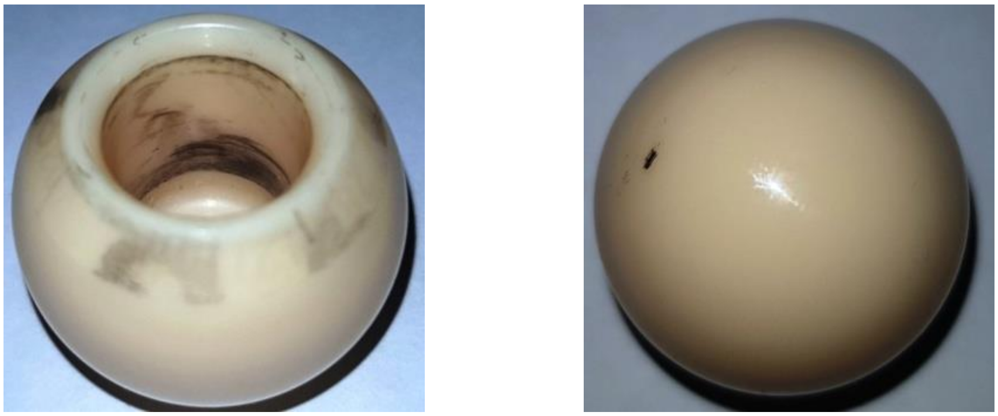
If changes in trunnion weight due to assembly and disassembly were noted, they were below the sensitivity (0.1 mg) of the analytical balance. In addition, there was no statistically significant difference in the pre-test and post-test R_a values, either for the trunnion ($p = 0.187$) or the femoral taper ($p = 0.193$).

Table 1 shows the pre - and post - impact average roughness test (R_a) for femoral and trunnion taper.

Table 1: The average roughness of the femoral taper and femoral trunnion used for an impact test.

R_a (µm)	Before testing (average ± SD)	After testing (average ± SD)
Femoral taper	0.324 ± 0.084	0.254 ± 0.054
Trunnion	0.602 ± 0.068	0.598 ± 0.042

The dark grey traces of the inner taper of the femoral head during this test, as well as the transfer of the material, are shown more clearly in Figure 7. They illustrate micro-movement and wear through fretting, and a metal wear particle embedded in the outer surface of the ceramic femoral head.



(a) (b)

Figure 7: (a) An internal taper of the femoral head tested at impact on the stem, showing grey marks of micro-movement and fretting wear, prior to cleaning, and (b) a metallic wear particle embedded in the outer surface of the ceramic head.

This is the first long-term study on the hip simulator, which reports the wear generated by the trunnion – taper junction of a modern CoC hip joint. Hip prosthesis recovery studies have shown that material loss and debris formation are not limited to joint surfaces, they also result from the trunnion – taper junction, as reported in (Langton, 2010) and (Langton, 2012).

Some may suggest that it is not possible to test both the trunnion – taper junction and the bearing surfaces in a single test. The authors of the present paper believe that this is not only possible, but it is essential. If the bearing surfaces have a low wear, however, the trunnion wear occurs, and then it must be identified so that the patients are protected and the surgeons are not convinced to believe in a "low wear", in fact, due to loss of material elsewhere. However, these assertions are based on setting the test, reproducing the clinical situation as close as possible. The authors consider that the hip simulator does this, due to the fact that DL is applied to the test samples, Figure 2(B, C), so that femoral head behaviour can be replicated on the trunnion, as seen on the explanted hip prosthesis, in (Langton, 2012).

4.0 DISCUSSION

4.1 Wear of Contact Taper – Trunnion Junction of CoC Prosthesis Used in Hip Simulator Wear Test

Currently, the authors did not find in the literature a theoretical approach to fretting wear. Archard's classic approach is applied to quantify the wear rates. This classical approach reports the amount of wear as the product between the sliding distance and the normal load. A wear coefficient is then extrapolated and it is assumed that it determines the wear resistance of the studied material. This approach does not work when the friction coefficient is not constant. Consequently, it seems more relevant to consider a significant wear parameter, the mechanical work of interfacial shearing.

By identifying the wear energy coefficients, the wear quantification can be rationalized and the wear resistance of the studied tribosystems can be quantified.

This seems to be a convenient approach to interpret different wear mechanisms. The energy balance confirms that a small part of the dissipated energy is consumed through plasticity, while most of it participates in the heat flow and debris through the interface. When introducing a load energy approach, an accumulated density of dissipated variable energy is considered, to quantify the formation of the tribological transformed structure (TTS).

Based on the wear data of the hip simulator, the metal trunnions (total wear = 0.29 mm^3) were worn with a quantity similar to that of the bearing surfaces (total wear = 0.25 mm^3). Trunnion surfaces measured with a 2D contact profile showed a statistically significant decrease in surface roughness (R_a) after testing (see Figure 5). In addition, the worn area showed a statistically significant decrease of the 3D surface roughness (R_a) compared to the area of the unworn area (see Figure 6).

After the analysis of the position of the taper damage (Langton., 2012) during a recovery study of MoM hips, it was suggested that the damage from the surface of the taper was caused by an overturning effect of the femoral head.

Overturning of the cobalt chromium head (CoCr) on the stem of MoM modular hip was also the cause of the wear at the taper – trunnion junction. Because a similar wear pattern was observed in this simulation study, it suggests that "there is a similar change in the position of the ceramic femoral head" as shown in Figure 8.

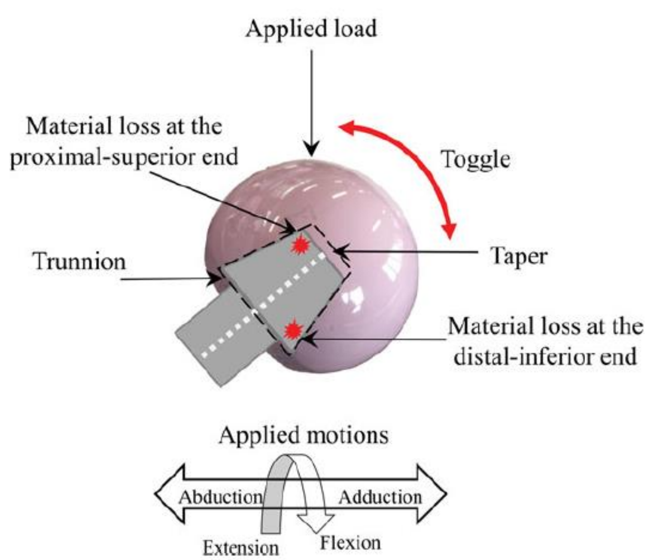


Figure 8: A ceramic and beaded femoral head test set with applied load and applied movements indicating the overturn and loss of the material in two distinct areas (shown in red).

The femoral head position changes due to the loss of material on the taper junction of the head and trunnion. The wear of the trunnion is probably due to the relative hardness of ceramics compared to titanium or may be the result of shocks due to micro-separation. After this process, wear stripes formed on the surfaces of the femoral head, a result similar with another obtained by Langton et al., (2017).

Femoral head tapers showed a statistically insignificant change of the surface roughness, indicating a minimal loss of material in the form of a grey ring visible at the proximal end of the femoral taper. This probably indicates the adhesive wear transferred from the titanium trunnion to the taper of the ceramics. Besides the adhesive transfer, was not observed any loss of ceramic material or fretting corrosion. This is consistent with an explant study, in which the transfer of metallic material to the taper surface of the CoC and CoP recovery ceramics was observed, without any other wear signs.

The explant study also quantified the volumetric loss of material from the recovered trunnions with a wear rate of 0.0 - 0.37 mm^3/ year. If one million cycles in the hip simulator are equivalent to 1 year in vivo, then the average wear rate (0.061 mm^3/ year) of the titanium trunnions obtained in the in vitro test reported here is in the range obtained in this recovery study.

In order to determine if there is a difference between the wear of the taper – trunnion junction of the CoC and CoP hips, it should be started experiments considering the wear on the bearing surfaces.

A much lower wear on the CoC hips would be expected here than with CoP hips. However, this result is not reflected in the data from the world's largest joint registry, NJR. Here, CoP hips show review rates lower than CoC hips.

It is speculated that a possible cause could be greater damage to trunnion – taper surfaces in CoC hips compared to CoP. The reason is that the PE liner could act in the sense of "softening the blow" of peak power while walking and other activities. An engineering comparison of a CoP hip with a CoC hip, could be a wooden hammer, compared to a normal hammer. While both carry loads, the wood hammer is deliberately softer to reduce damage to the materials.

4.2 Adverse Reactions to Metal Debris (ARMD) in CoC Hip Implants

After many researches it has been shown that CoC hip joints have shown lower wear both in in vitro studies, (Smith et. al., 2001), (Nevelos et al., 2001), (Essner et al., 2005), (Spinelli et al., 2009), (Affatato et.al., 2011) and in recovery studies (Lusty et al., 2007), (Walter, 2004) compared to conventional MoP joints.

However, the overall revision risks for a 13-year uncemented THR are similar – 5.69% and 5.90% for CoC and MoP, respectively. The authors accept that the reasons for the review are multifactorial, including infections, dislocations and fractures. However, they ask why, especially in the case of longer monitoring in the established joints registers, it does not seem to be possible to see the wear-related benefits of ceramic joints.

Titanium trunnion that was mounted in the ceramic femoral head of failed prostheses presented an extensive wear (Ratner et. al., 2004).

The residual particles isolated from the periprosthetic tissue are the same as those of the metal trunnion alloy.

More adverse reactions to metal debris (ARMD) in the CoC hips than in the MoP hips were also found in clinical trials, like the one published by (Matharu et al., 2016). Even if in a CoC hip there are fewer metal components than in a MoP hip, it has been shown that the taper-trunnion junction is the one that produces metal debris in the CoC hip.

Although CoCr wear particles may be more cytotoxic than titanium alloy wear particles, it has been demonstrated that the generation of residual waste volumes should be avoided.

There are also studies that show no correlation between the movement of the modular components of the prosthesis (femoral head, femoral stem) and loss of material (Esposito et al., 2014). This was demonstrated on the trunnion – taper junction of the CoC, CoP and MoP hip prostheses.

Therefore, additional investigations may be necessary in this area. In this wear test, the same type of CoC hip prosthesis with identical neck lengths was used.

4.3. The Importance of the DL Test and Impact Test

In this study the movement was applied to the hip simulator wear test, and no joint movement was applied to the DL test sample. Archard wear equation was used, and it was not found a significant loss of material on the articulated surfaces of the wear test samples, rather than those of the DL specimen. But this was not the case. Taking into account this result, it can be concluded that the loss of material on the bearing surfaces of the DL sample may be due to the fretting wear. A similar result was reported by Joyce et al., (2009) for alumina friction against alumina.

The impact test results confirmed that the assembly/ disassembly process had no effect on the gravimetric or surface roughness measurements for the titanium trunnion or for the taper of the ceramic femoral head.

5.0 CONCLUSION

Based on the gravimetric measurements, the bearing surface wear rate was similar to that of the hip simulator wear test trunnions.

The metal debris that appear can provide an explanation for the adverse reaction reported in the CoC hip arthroplasty and for the similarity of clinical performance between CoC and MoP hips.

Until now, no long-term hip simulator study has measured the trunnion – taper junction wear.

This in vitro study confirms the need to measure taper – trunnion junction wear in preclinical testing to fully understand the mechanisms of material loss. The authors of the present study believe that such wear needs to be measured and that ISO 1424246 needs to be modified to take into account this wear.

Following in vitro tests, the morphologies and microstructures of the zirconia rigidized alumina (ZTA) femoral head surface were studied to simulate in vivo damage. Three phenomena have been investigated that could lead to damage: shocks, friction and hydrothermal aging.

Shocks due to micro-separation have created the main damage with the formation of wear stripes on the surfaces of the femoral head. AFM images have suggested the release of wear residues of various shapes and sizes through inter-granular and intra-granular cracks. Some debris may be smaller than 100 nm. It was measured by nano-indentation technique a decrease in Young's hardness and modulus in wear stripes, and was attributed to the presence of surface and sub-surface micro-cracks. Such micro-cracks mechanically triggered the transformation of the zirconia into those worn areas, which probably reduced crack propagation. Compared to shocks, friction caused reduced wear degradation, as seen from AFM images, by the rare pulling of grains. The long-term resistance of ZTA composite material to hydrothermal aging is confirmed by the present observations.

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