Effect of impact assembly on the interface deformation and fretting corrosion of modular hip tapers: An in vitro study

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ABSTRACT

Wear and corrosion at the modular head–neck junction has been recognised to be a potential clinical concern, with multiple reports on adverse local tissue reactions and subsequent early failure of metal-on-metal hip replacements. Furthermore, reports on head–neck taper corrosion are also being described with conventional metal-on-polyethylene bearings. Manufacturing tolerances, surgical technique, non-axial alignment, material combination, high frictional torque and high bending moment have all been implicated in the failure process. There is limited guidance on the force of impaction with which surgeons should assemble modular hip prostheses. This study aims to investigate the effect of impaction force on the deformation and corrosion of modular tapers. Short neck tapers with high surface roughness (average $R_z = 16.58$ μm, $R_a = 4.14$μm) and long neck tapers with low surface roughness (average $R_z = 3.82$ μm, $R_a = 0.81$μm), were assembled with CoCrMo alloy heads (smooth finish) under controlled conditions with 2, 4 or 8 kN of impaction force. Material combinations tested included CoCrMo-head/CoCrMo-neck and CoCrMo-head/Ti-6Al-4V-neck. Assessment of surface deformation before and after impaction was made using surface profilometry. Measurement of fretting current during sinusoidal cyclic loading evaluated mechanically assisted corrosion for each assembly load during short-term cyclic loading (1000-cycles) and long-term cyclic loading (5 million-cycles). Deformation on head and neck tapers increased with assembly load. Fretting currents during short term simulation testing showed significantly lower currents ($p < 0.05$), in 8 kN assemblies when compared to 2 and 4 kN, especially for the short-rough tapers. Long-term simulator testing demonstrated a progressive reduction in fretting corrosion for samples impacted with 4 and 8 kN; however, this reduction was greater for samples impacted at 8 kN even at the start of testing. Based on our results, surgeons could minimise mechanically assisted crevice corrosion by using higher impact loads when assembling the head to the stem in total hip arthroplasty.

Introduction

Modular junctions allow for self-locking and resistance to multidirectional loading between the female taper (head component) and male taper (stem component) in total hip replacements and have a number of surgical benefits.1-7 Micromotion can occur between the interfaces,8 which facilitate mechanically assisted crevice (MACC) and fretting corrosion, leading to the production of wear debris and metal ion release.9, 10 These by-products of MACC can migrate locally and systemically resulting in elevated serum metal ion levels thought to initiate a cascade of events leading to the presence of adverse local tissue reactions.11-14 Evidence of corrosion around the head–neck interface indicates that the modular junction is a significant source of metal release.6, 15-19 The effects of metallic wear debris have been well documented, with adverse local tissue reactions and systemic toxicity leading in some cases to pseudotumour formation, necrosis, osteolysis and ultimately implant failure.[13, 20-25]

There is a trend in the industry to manufacture the neck taper with circumferential ridges, which deform during assembly to provide compression and a tight interference fit with the smooth surfaced female taper; however, there is variation in the design and surface finish of the tapers used between different manufacturers but also within the same manufacturer. With greater impaction, the interlock strength of the head–neck taper connection increases linearly.[26] As a result, the load required to initiate micromotion and fretting would increase, reducing the potential for MACC and production of wear debris.[10] Assembly under dry conditions is preferable to wet conditions, with implants assembled in serum or water behaving unpredictably compared to their dry counterparts.[27, 28] Lavernia et al. also demonstrated that tapers contaminated with blood or fat had lower disassembly force than clean tapers.[29]

Mechanical factors affecting taper strength are important to understand. Forces such as frictional torque, bending, shear, etc. will increase with increasing head size as well as with poor lubrication, edge loading and suboptimal component placement during surgery.[30, 31]The relationship between impaction force, number of impaction blows and pull-off strength has been explored.[26, 27, 32, 33] Our study aimed to investigate the effect of three different assembly loads (2, 4 and 8 kN) on the degree of deformation and amount of fretting corrosion of CoCrMo and Ti-6Al-4V neck tapers of different surface finish (smooth vs. rough) and engagement length (standard vs. short). The hypothesis was that increasing impact assembly load affects the deformation at the taper junction resulting in a stronger taper interlock that reduces MACC under high torsion and bending moments.

METHODS

Materials

All head and neck tapers were made to the following specifications: The R_z and R_a values for each component were assessed using a Talyrond 365 (Taylor Hobson, Leicester, UK) roundness instrument. Average roughness R_a is the arithmetical mean of the absolute values of the profile deviations from the mean line. The R_y value is the sum of the highest peak from the mean line and the depth of the deepest valley from the mean line. The $R_z$value is the ten-point height of irregularities obtained from the entire evaluation length. It is the total of two means, which are the average height of the five highest peaks and the average depth of the five deepest valleys. The recommendation by CeramTec for neck taper surface roughness to be used with a ceramic head is between 6 and 20 μm, and the majority of manufacturers have adopted this range for use in both ceramic and metal head. This study focuses on the metal taper junction (i.e., metal head with metal neck). In order to capture the two extreme ends of the neck taper roughness range our 'smooth' surfaces were within an R_z range of 3–6 μm, while 'rough' surfaces fell within a range of 16–20 μm. The average R_z value of the smooth neck tapers used was 3.82 μm, and for rough neck tapers this was 16.58 μm. The average R_a value of the smooth and rough neck tapers was 0.81 and 4.14 μm, respectively. All head tapers were made from wrought CoCrMo alloy and had smooth taper finishes ($R_a$and R_z values 0.58 and 2.8 μm, respectively). All utilised heads had a 36 mm diameter and a +14 mm neck offset to represent a high offset often seen at implantation and also with some large diameter head prostheses. Serrations were cut out of the bearing surface of each femoral head to prevent rotation within the cement mantle and since CoCrMo alloy is a relatively stiff material we did not expect the serrations to interfere with the compliance of the head onto the neck taper. Furthermore, all head coupons used in this comparative study had the same configuration. Half of the neck tapers were CoCrMo and the others were Ti-6Al-4V alloy. For each material, the neck tapers were both a smooth finish and standard length or a rough finish and short length. Figure 1 illustrates the taper angles and locking zones along the tapers, the reference diameters of the head and neck tapers are not the same size and they are referenced at two separate points along the taper axis. What this means is that the taper engages much deeper in relation to the 12 mm dimension mentioned. In fact, when fully impacted, the large diameter of the short taper sits approximately 3.2 mm inside the female bore which is reduced by 0.5 mm due to the small chamfer in the female bore. Therefore, the total engagement length is 14.7 and 12.0 mm for long and short tapers, respectively. This results in just over 18% difference in the amount of taper engaged which is significant difference for such a small area of contact. Prior to the start of the test, all components were passivated through immersion in 20% nitric acid for 30 min as per ASTM F86. Following this, the components were cleaned ultrasonically in distilled water and allowed to dry in air. Rehmer et al. observed a similar relationship between dynamic and quasi-static assembly procedures,26 therefore, combinations were assembled according to the ASTM F2009 at a loading rate of 0.05 mm/s in a materials testing machine to allow for reproducibility throughout the study. Although it is common practice to use multiple blows for intraoperative head-stem assembly, a study by Pennock et al. illustrated that when multiple impacts of varying force were utilised there was no difference in taper strength compared to a single blow of the strongest force.27 Additionally when using multiple impacts of the same force, 50% of the prostheses showed no difference in the taper strength between the first and subsequent impacts, whereas the remaining 50% of their prostheses the first impact accounted for 90% of the overall taper strength and each additional impact contributed to a much lesser extent.27

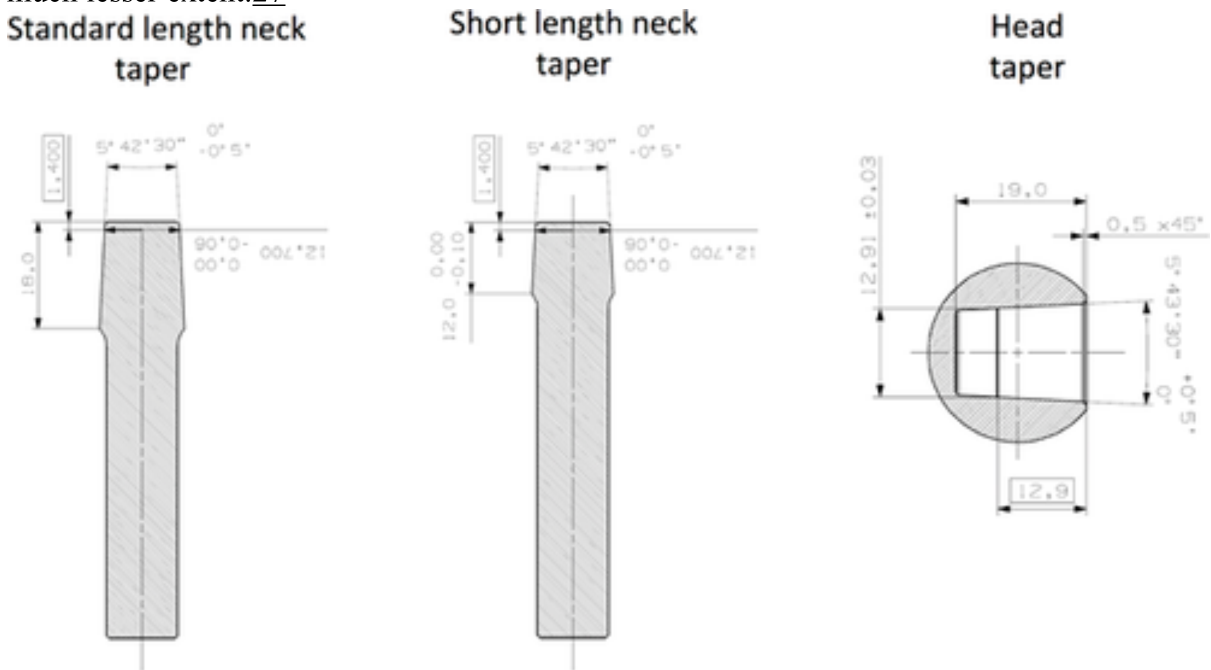

Figure 1
Diagram illustrating dimensions for the standard length neck taper, short length neck taper and head taper used in the study.

Experiment Set Up

In Test 1 (short term) each neck taper material and surface finish combination was impacted onto a CoCrMo head taper using an assembly force of either 2, 4 or 8 kN (Table 1) in line with the taper. The rationale behind our choice of assembly forces to be tested was as follows; 2 kN representing a light tap; 4 kN representing a typical blow32 demonstrated that the average impaction force applied by orthopaedic surgeons was a little over 4 kN and finally 8 kN representing a heavy blow, representative of the largest assembly forces measured in a study of impaction forces from 39 surgeons from German hospitals, which was up to 7848 N.34

Table 1. Overview of Tests Performed

In the first test in order to measure the corrosion currents in accordance with ASTM F1875-98, the head was held in a polyoxymethylene (Delrin) fixture using polymethylmethacrylate (PMMA) bone cement at 45° to the vertical axis (Fig. 2). The neck taper representing a stem of a prosthesis producing head/neck angle of 135° was used. This was mounted in a Perspex chamber to house the lubrication. The cement/head interface and the base of the Delrin were sealed using commercially available silicone paste. Throughout testing, components were immersed in 10% bovine calf serum (Seralab Inc. sterile filtered newborn bovine calf serum) diluted with Phosphate Buffered Saline (PBS) solution with pH 7.4 at room temperature (20 ± 1°C) in an air-conditioned temperature-controlled room. A fatigue-testing machine (manufactured by R.D.P.-Howden), capable of producing sinusoidal cyclical loads, was used as the load application device during testing. External clamps were used to hold the calomel reference electrode (Hg/Hg_2Cl_2) (RE) and platinum/counter electrode (CE) in position, with their tips immersed in test fluid at a constant position within the cell. The RE was held with the tip 2 mm from the head/neck interface, minimising the electrochemical impedance of the fluid medium and allowing for more accurate readings. The working electrode lead was directly connected to the stem.

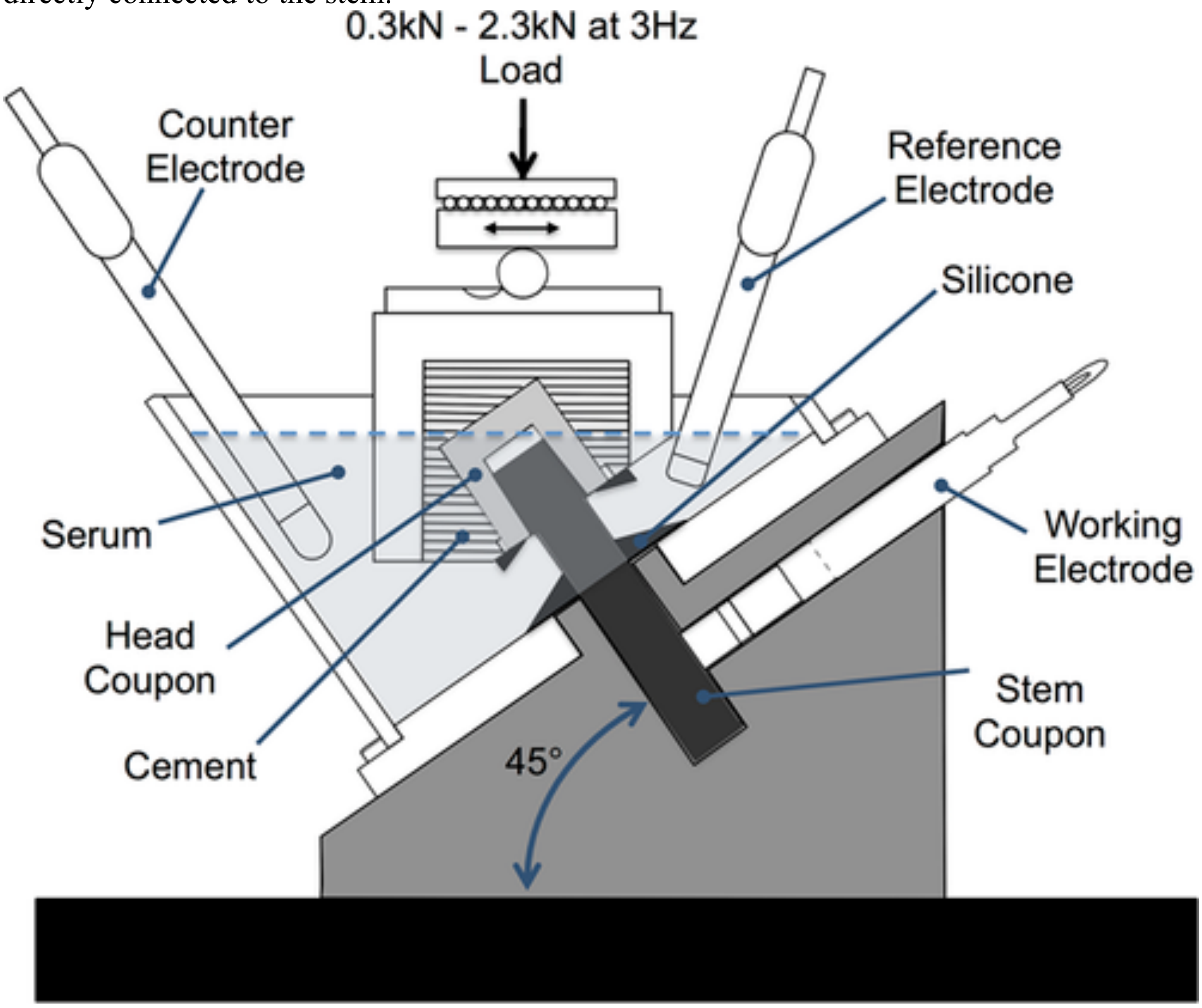

Figure 2

Diagram of experimental setup for assessment of fretting current. A fatigue-testing machine (manufactured by R.D.P.-Howden), was used to apply a sinusoidal cyclic load between 300 and 2300 N at a frequency of 3 Hz.

In Test 2 (long term), the only combinations tested were of CoCrMo heads with Ti rough/short neck tapers; $n = 3$ were impacted at 4 kN and $n = 3$ impacted at 8 kN (Table 1). Prior to testing, the samples underwent assessment using the Talyrond 365 where 180 traces were spaced 2° apart provided a representative baseline volumetric measurement of the taper surface. Once impacted, combinations were then mounted into the fatigue-testing machine.

Electrochemical Parameters and Tests

All electrochemical measurements were performed using the Metrohm Autolab PGSTAT 101 multi-channel modular potentiostat/galvanostat and recorded and analysed with the aid of the NOVA Software supplied by the same company (Metrohm Autolab B.V. Runcorn UK). Initially each sample's Open Current Potential (OCP—rest potential) was recorded for 1 h or, until the rest potential stabilized to a rate of change less than 3 mV/min. Potentiostatic tests were then carried out at a potential of OCP +200 mV. This potential was well below the pitting potential and protection potential observed in potentiodynamic cyclic polarisation scans for the same samples. Samples were held at this potential for 1 h to allow the system to settle and regain a steady passive current before applying the loading regime. The resultant current was the recorded over 1000 loading cycles for the short term test (Test 1) and over 1000 cycles every 1 million cycles over 5 million in total for the long term test (Test 2). An implant alloy spontaneously forms a protective oxide layer on its surface and acts as a semiconductor in the circuit and therefore, if this layer is damaged or removed, a spike in the current is observed (Fig. 3). A sinusoidal cyclic load between 300 and 2300N at a frequency of 3 Hz was employed for both Test 1 (short term) and Test 2 (long term). During the loading regime, this current (referred to as the fretting current) was measured by determining the amplitude of the oscillations and also by the peak fretting current. Each trace produced as in Figure 3 may be broken down into alternating peaks and troughs that directly correspond to the cyclic loading. As can be seen, the current rises immediately as loading begins, and drops back to the baseline when loading is stopped. Each peak represents the point where load is applied, fracturing the passive oxide film (depassivation) covering the taper and enabling current to flow across the interface. Each trough corresponds to the load being removed; at which point the film reforms (repassivation) and current can no longer flow freely across the interface. Thus, with cyclic loading a sinusoidal waveform of current is produced with peak currents at peak loads. In Test 1 (short term), we measured the fretting current for all combinations for the first 1000 cycles of loading. In Test 2 (long term), the experiment test parameters and load application was conducted as with Test 1 (short term), except that it was allowed to run for 5 million cycles where the fretting current was measured every 1 million cycles for 1000 cycles of load.

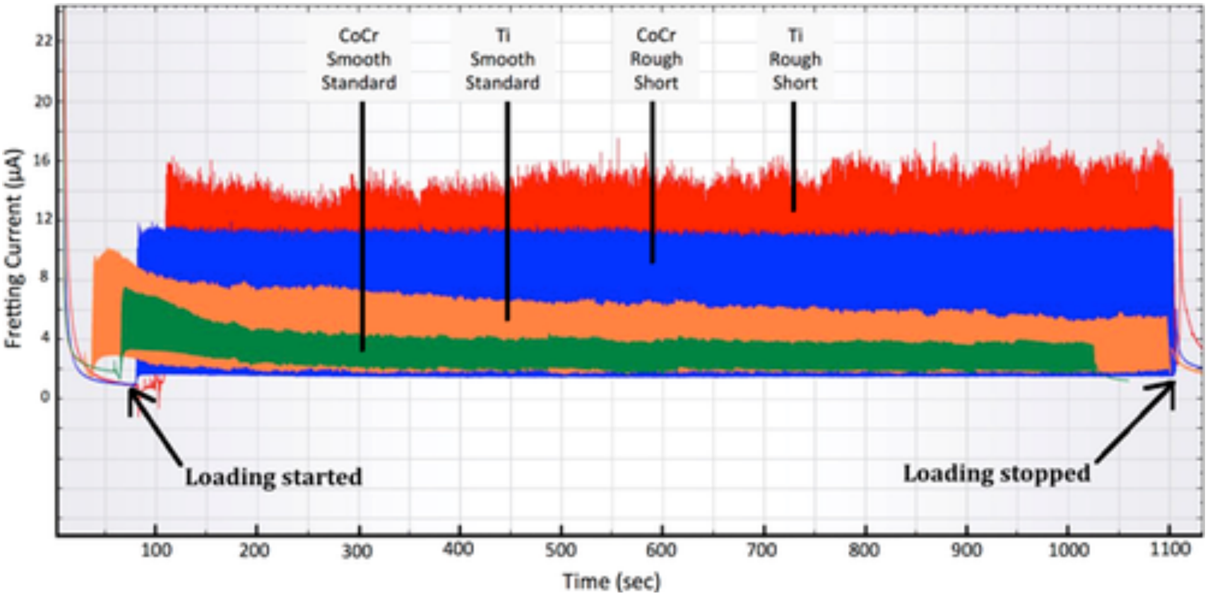

Figure 3

Example of fretting current measurements, superimposed on one another to demonstrate difference in current and amplitude. Red = Ti rough short neck taper, blue = CoCr rough short neck taper, orange = Ti smooth standard neck taper, green = CoCr smooth standard neck taper all coupled with CoCr head tapers. Each trace produced may be broken down into alternating peaks and troughs that directly correspond to the cyclic loading. As can be seen, the current rises immediately as loading begins, and drops back to the baseline when loading is stopped. Each peak represents the point where load is applied, fracturing the passive oxide film (depassivation) covering the taper and enabling current to flow across the interface. Each trough corresponds to the load being removed; at which point the film reforms (repassivation) and current can no longer flow freely across the interface. Thus, with cyclic loading a sinusoidal waveform of current is produced.

Post-Testing Preparation and Analysis

Following 5 million cycles, two of the samples from test 2 (long term) were randomly selected and sectioned in the sagittal plane using a diamond-coated saw (Exact diamond-bladed bone cutting saw—Type 303) to allow disassembly without causing further deformation hence, the disengagement force was not measured. The two halves where then gently pealed apart thus, the surface furthest from the centreline would not be damaged due to shear. However, adhesive damage may be present but assumed negligible. The head and neck tapers were examined under an optical microscope and scored using a previously published method25 and scanning electron microscopy (SEM) to assess the degree of corrosion seen at the interface, and provide an in-depth look at the taper surface. Following this, the remaining four samples were pulled apart in order to keep the taper in one piece, and then underwent volumetric wear analysis using the Talyrond 365. The deformation of the neck tapers at 5 million cycles was compared with the deformation immediately after assembly with 2, 4 and 8 kN.

Statistical Analysis

Data were analysed with the aid of SPSS Statistics Version 22. An initial data analysis on $n = 3$ using Kolmogorov–Smirnov test was carried out showing that the data were non parametric. We therefore carried out Kruskal–Wallis test followed by post hoc Mann–Whitney U test with Bonferroni correction to determine any significant differences ($p = <0.05$) in the generation of fretting current at the modular junction between the different impaction loads and material/surface finish combinations.

RESULTS

Electrochemical Short-Term Cyclic Loading-Test 1 (Short Term)

All modular junctions assembled using 8 kN of force showed significantly lower fretting currents than those assembled with either 2 or 4 kN assembly loads with the exception of CoCrMo smooth-standard neck tapers that showed a slightly higher fretting current when impacted with 8 kN compared to 4 kN (Table 2). For both Ti-6Al-4V surface finishes and the CoCrMo rough-short taper, the lowest fretting current was observed in samples with the greatest force of impaction ($p < 0.05$). At 2 and 4 kN impaction force, the fretting current measured for the CoCrMo with Ti-6Al-4V combination was significantly higher than CoCrMo/CoCrMo ($p < 0.05$). However, at 8 kN assembly load, this effect was reversed and CoCrMo/Ti-6Al-4Vshowed lower fretting currents ($p < 0.05$). Smooth-long tapers generated a significantly lower fretting current than rough-short tapers when impacted with 4 kN of force ($p < 0.05$). However, this was not the case when impacted at 8 kN with the rough-short neck tapers performing better than their smooth-long counterparts when subjected to high impaction loads. This is, seen clearly on the graphs of mean maximum fretting current and amplitude (Fig. 4). However, this effect was only seen on tapers impacted at 8 kN and did not occur when lower impaction forces were used.

Table 2. Maximum Fretting Current and Current Amplitude Values for Each Taper Combination at Three Impaction Loads (Test 1—Short Term)

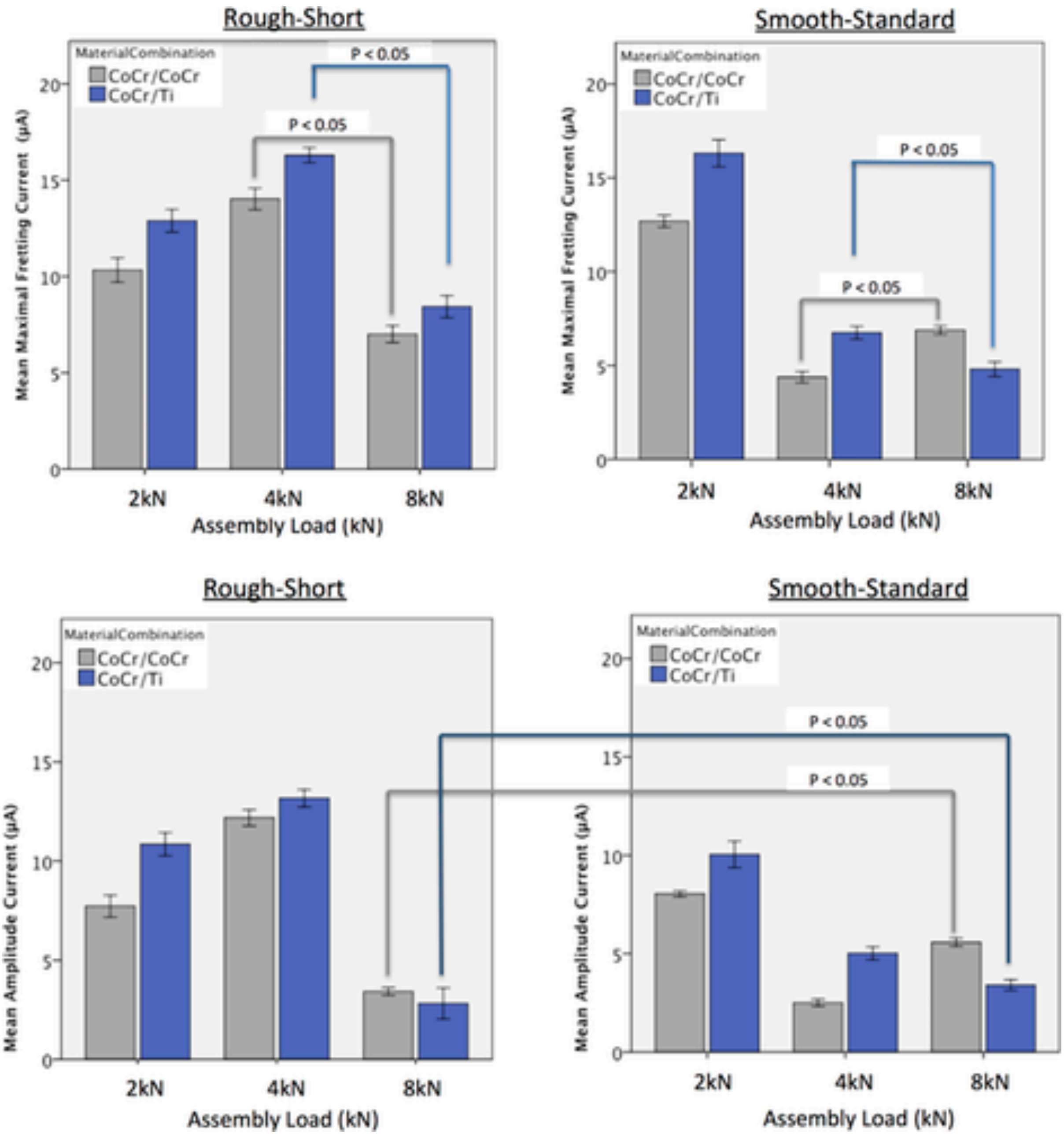

Figure 4

Short-term test results (Test 1). Bar graphs showing the mean maximal fretting and mean amplitude currents at three impaction assembly loads of the different head–neck combinations during 1000 cycles of sinusoidal loading.

Electrochemical Long-Term Cyclic Loading—Test 2

Both maximum fretting current and mean current amplitude decreased with time and the number of cycles. However, in the case of modular junctions impacted at 8 kN this effect is far less pronounced and the fretting current seen after the first one million cycles was lower than those samples impacted at 4 kN ($p < 0.05$). For 4 kN, there was a significant drop in maximum fretting current and amplitude between 1 million and 2 million cycles ($p < 0.05$), but no such change between 2 and 3 million cycles. The downward trend continued at 4 and 5 million cycles (Fig. 5). At 8 kN impaction force, there was no statistically significant difference in current between 1 and 5 million cycles.

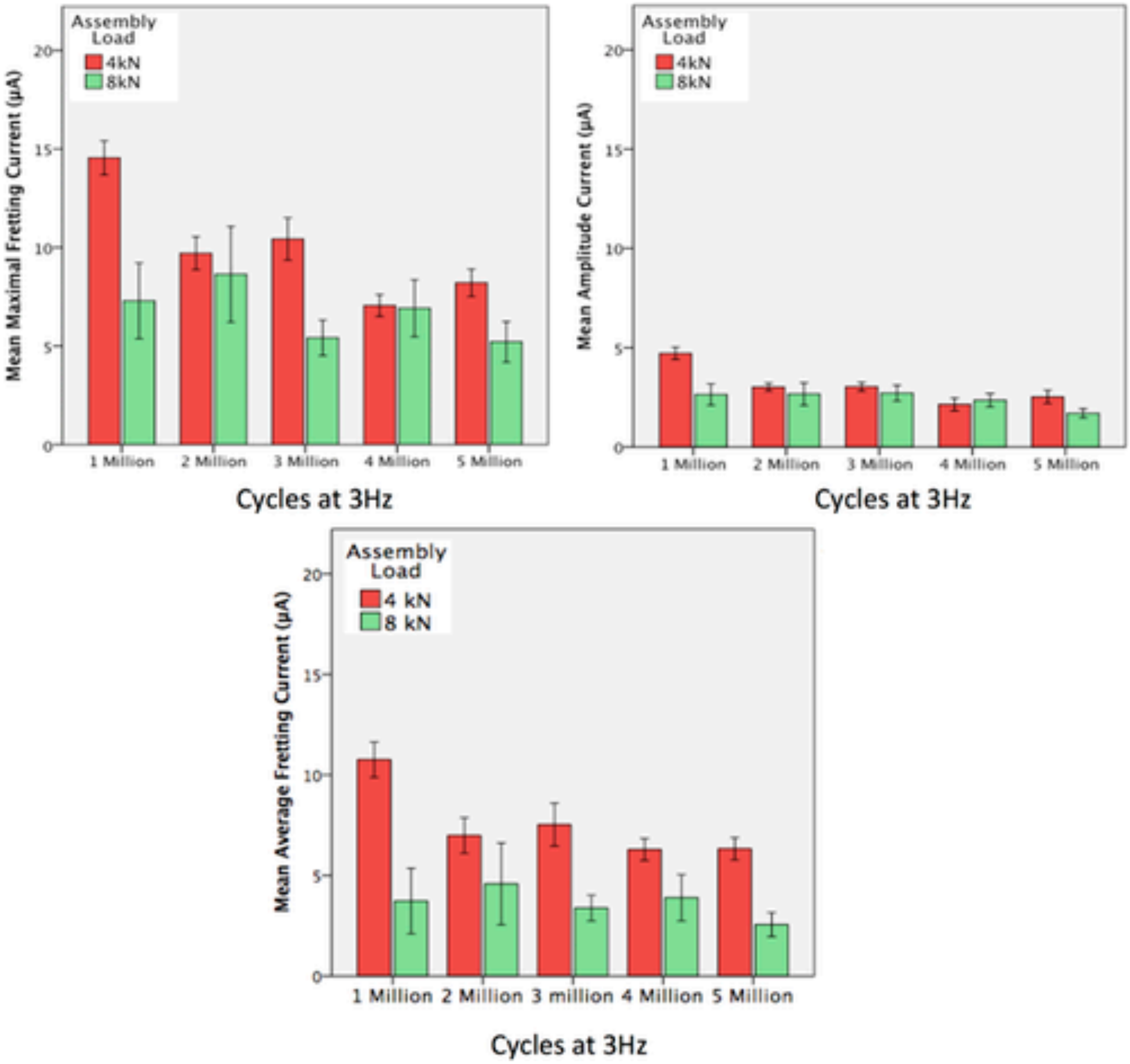

Figure 5

Long-term test results (Test 2). Bar graphs showing the mean maximal fretting current, the mean amplitude of current oscillation and average fretting current up to 5 million cycles, for 4 and 8 kN impaction forces.

Volumetric Wear Analysis—Test 2 (Long Term)

Measurement of surface roughness of the neck tapers at different impaction loads immediately after impaction showed evidence of deformation with flattening of the peaks at the apex in the area of engagement. Increased deformation of the ridges and increased area of taper engagement was seen with increasing impaction loads and was more prominent on neck tapers impacted at 8 kN (Fig. 6). The results showed that tapers become more impacted after cyclic loading. After 5 million cycles the deformation of the ridges on the male taper at both 4 and 8 kN was larger with more flattened peaks and there was evidence of greater taper engagement (Fig. 7). There was evidence of imprinting on tapers impacted with both 4 and 8 kN but this was more pronounced with the tapers impacted with 4 kN. Volumetric assessment indicated no significant difference in volume loss between tapers impacted at 4 and 8 kN.

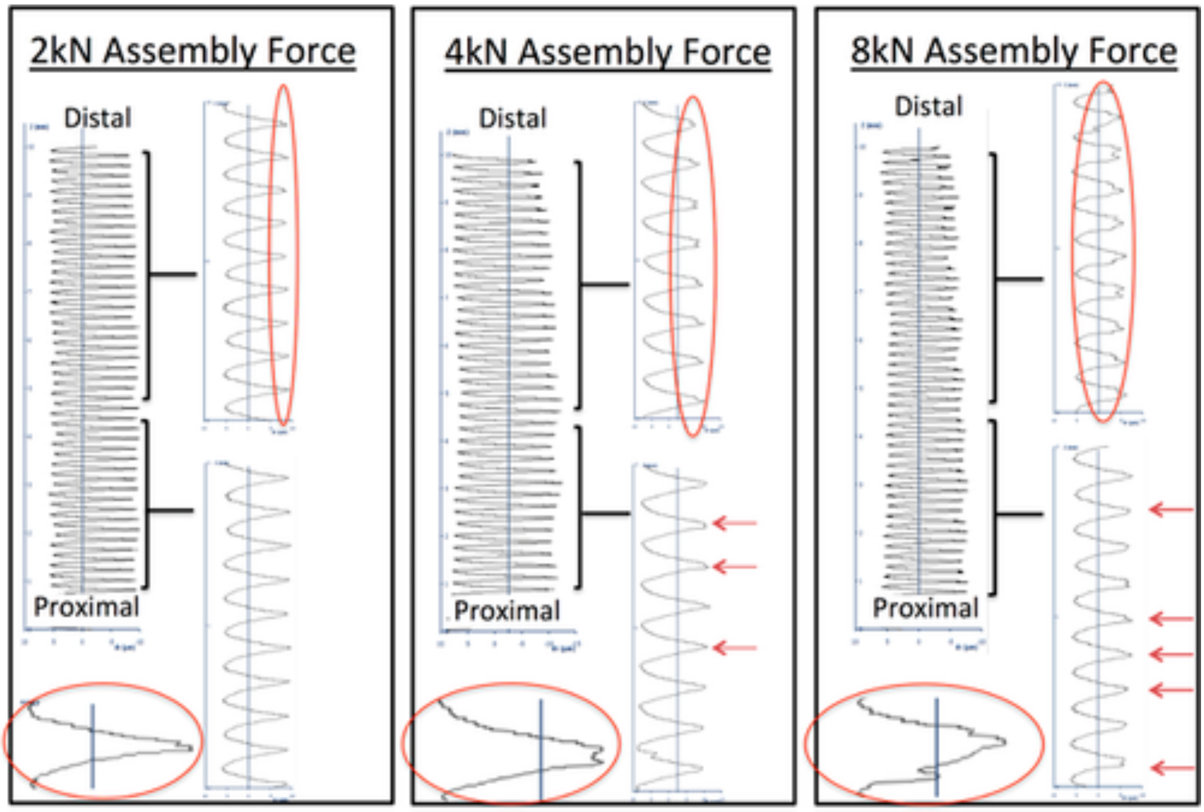

Figure 6
Single line profile measurements during volumetric wear analysis using Talyrond 365 of Ti-6Al-4V neck tapers immediately after impaction at 2, 4 and 8 kN. Showing evidence of progressive increase in the deformation of the peaks with increase in impaction load (flattening of the peaks at the apex, area of maximal engagement). Also the greater the impaction force the greater the surface area of engagement with more of the proximal end of the taper engaging when impacted with 8 kN compared to 4 and 2 kN.

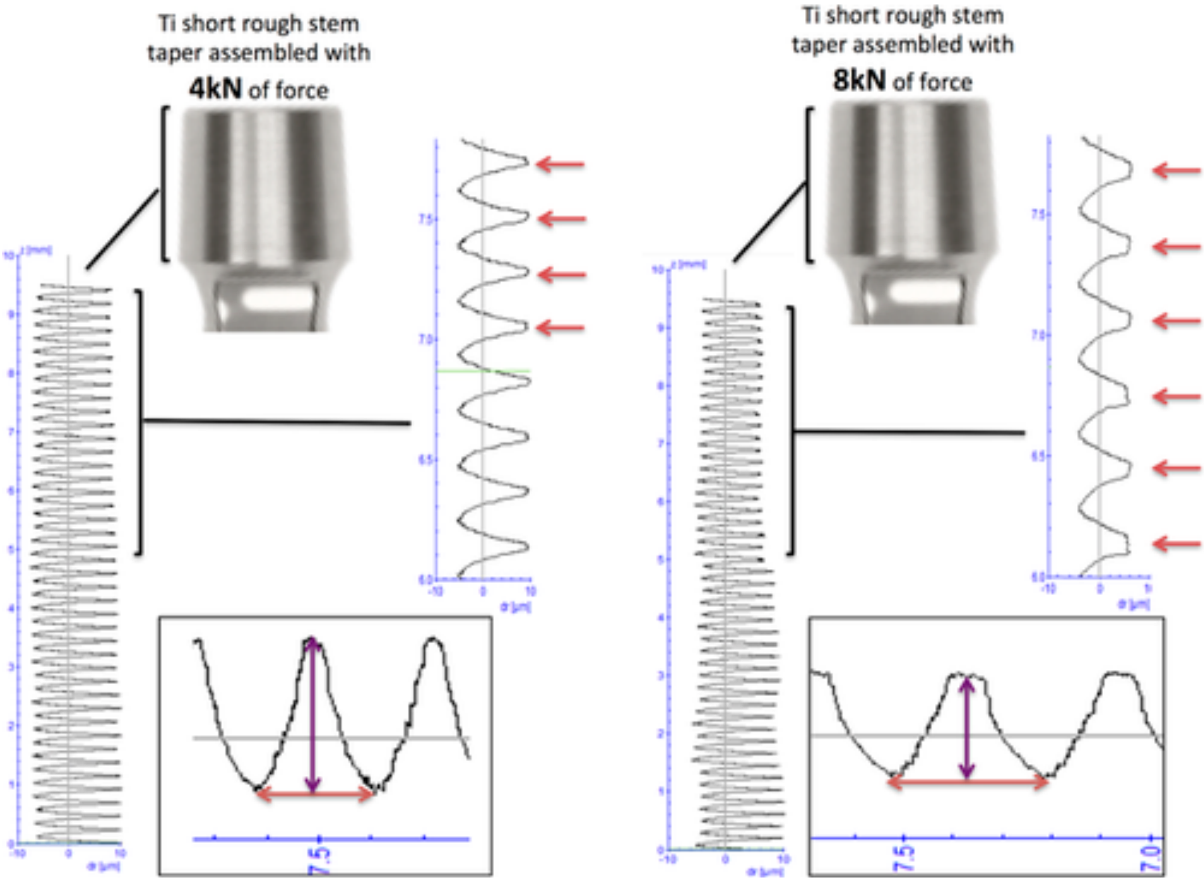

Figure 7

Single line profile measurements during volumetric wear analysis using Talyrond 365 of Ti-6Al-4V neck tapers impacted at 4 and 8 kN following 5 million cycles of loading. Showing evidence of increase in deformation with more flattened peaks and greater taper engagement with increasing number of cycles.

Scanning Electron Microscopy—Test 2 (Long Term)

Fretting scars were seen to a greater extent on the 4 kN than the 8 kN assemblies (Fig. 8). Tapers impacted with both of these loads showed corrosion occurring in areas, which was consistent with the large bending moment (Fig. 9). This pattern was also evident on visual inspection and using optical microscopy (Fig. 10). There was visual evidence corrosion with black deposits, as well as imprinting, on samples both at 4 and 8 kN assembly load (Fig. 10).

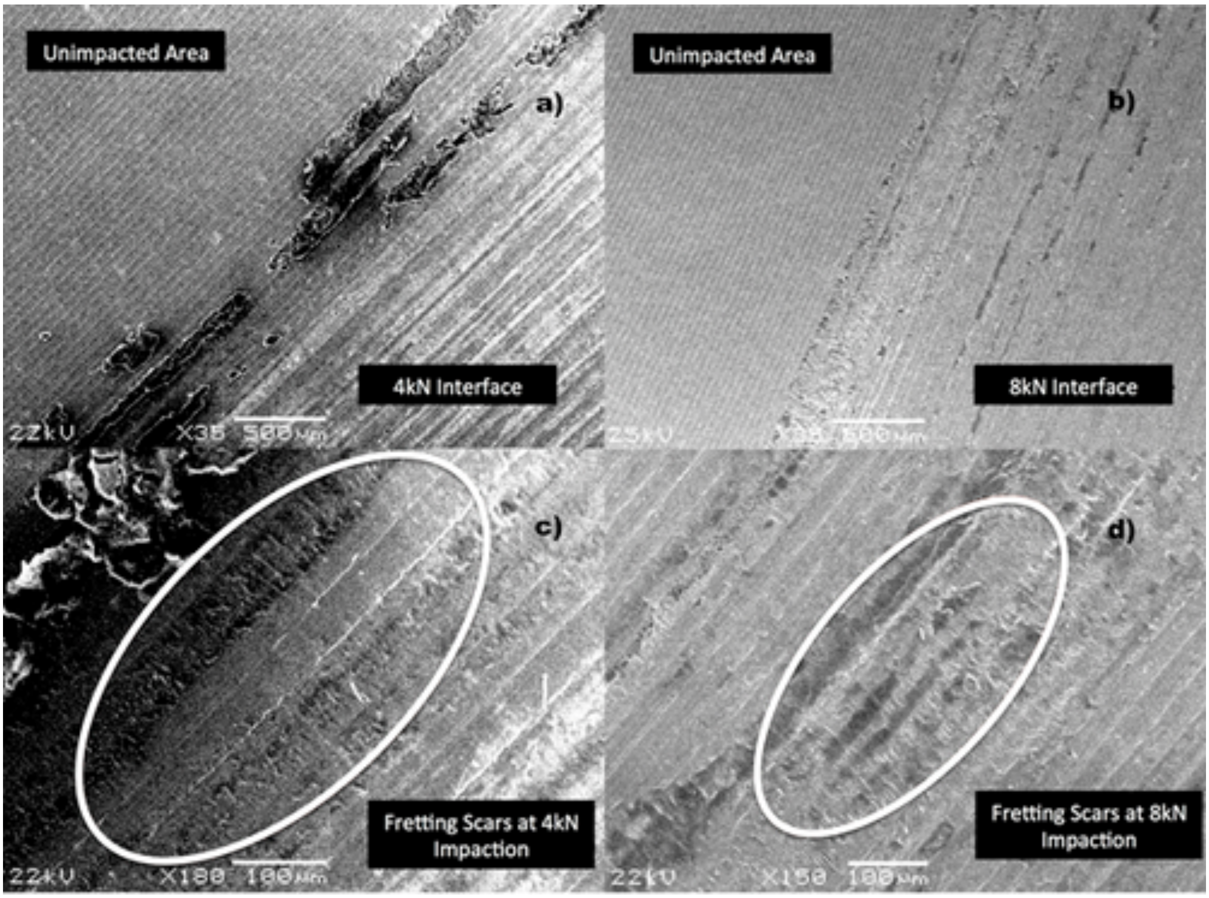

Figure 8

SEM images showing: (a) An overview of the edge of the interface with 4 kN assembly load. (b) An overview of the edge of the interface with 8 kN assembly load. (c) Evidence of fretting scars near the interface edge with 4 kN assembly load. (d) Evidence of fretting scars near the interface edge with 8 kN assembly load.

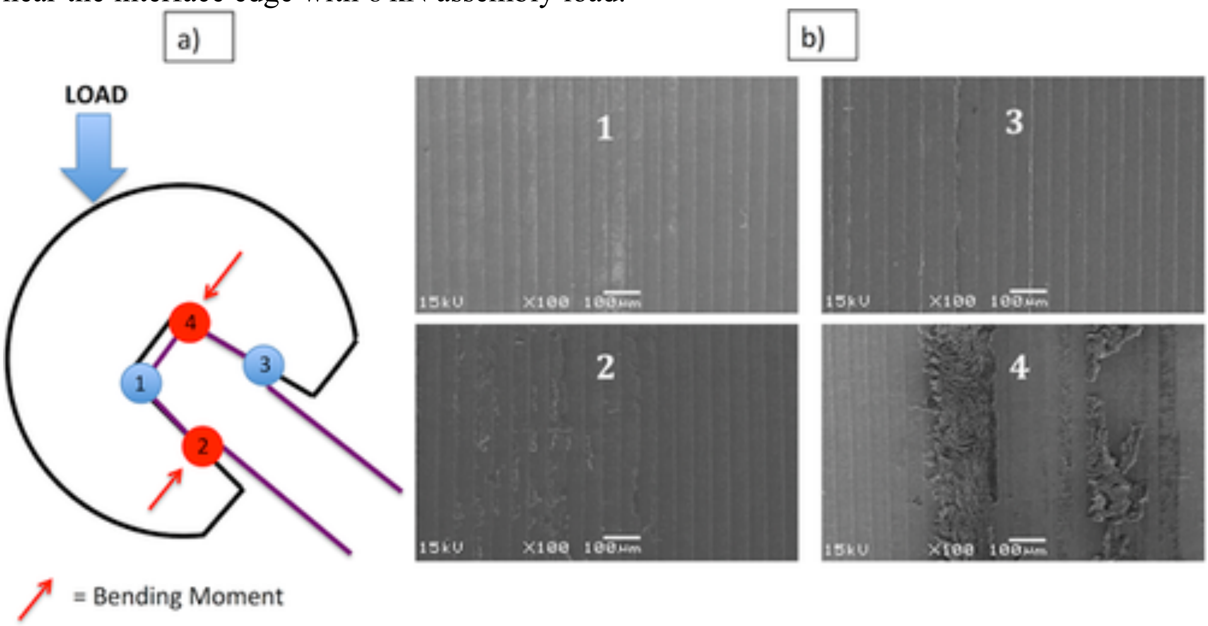

Figure 9

(a) Diagram showing highest bending moment with a +14 mm neck offset head. (b) SEM pictures 1 and 3 show areas of little stress and therefore less corrosion/wear, pictures 2 and 4 show areas of high stress due to bending and evidence of high corrosion/wear.

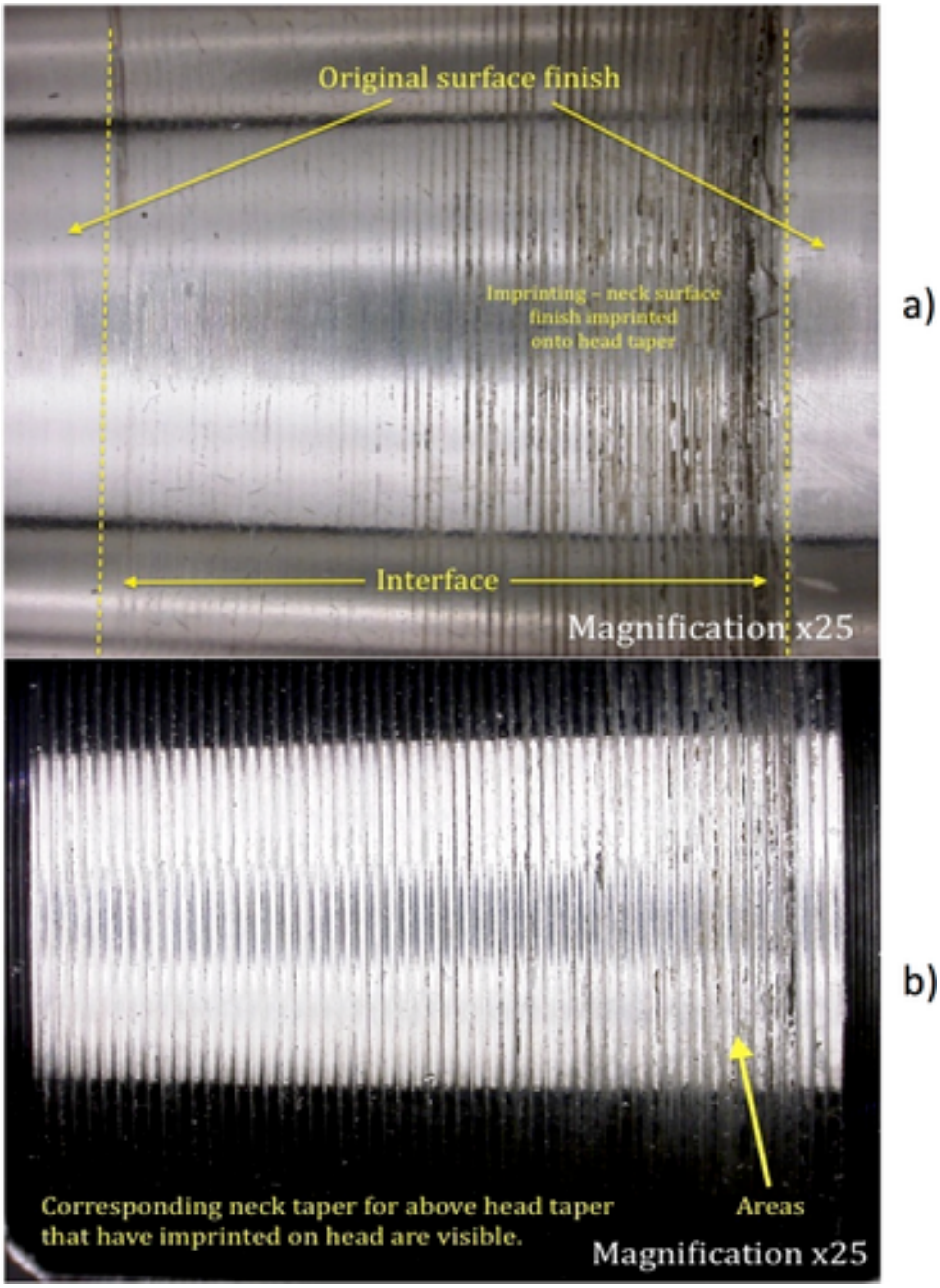

Figure 10
Light microscopy pictures of head taper (a) and neck taper (b) showing evidence of Goldberg Type 2 corrosion following 5 million cycles of sinusoidal loading. The surface finish of the neck taper is imprinted onto the head taper.

DISCUSSION

A number of factors investigated by other studies have been proposed to affect the amount of corrosion and mechanical wear at the taper junction.35-37 These studies indicate that surface finish, neck length, impaction load and manufacturing tolerances may contribute to the quality of interlock of the two tapers,26-28, 33 also that high frictional torque and bending stresses encountered with the use of large head diameters, exacerbated by improper alignment, may increase the amount of mechanical wear at the head–neck interface.35, 36, 38 The degree of deformation of each surface is relevant as it determines the strength of the taper interlock. Rehmer et al.26 demonstrated that the quality of fixation increases with the amount of impaction force used to assemble the implant. Our study aimed to investigate the effect of assembly load on the deformation and fretting corrosion of tapers used in hip replacements. Fretting corrosion was assessed by measurement of the fretting current during cyclic loading. The extent to which this occurs is an indication of micromotion at this junction and, ultimately, determines the rate of MACC. Each head–neck combination was impacted with 2 kN (a light blow), 4 kN (roughly the average force used) or 8 kN (a large blow).

Results from the short-term cyclic loading test (Test 1) showed that for smooth-long neck tapers in both material combinations, 4 kN impaction was preferable to 2 kN with 8 kN faring better than both ($p < 0.05$). Interestingly, however, rough-short neck tapers in both material combinations did not follow this trend, as impaction forces of above 2 kN initially showed increased MACC whilst 8 kN showed a significant reduction ($p < 0.05$). The reason for this increase in MACC between 2 and 4 kN in rough-short tapers is not clear. Although we did not investigate the causality of this unexpected result in this study, we suspect it may be due to the increased contact between the neck and head taper with higher impaction where reduction in motion is not alleviated by the increased force until 8 kN is used. The combination of interlock roughness and impaction force is complex and one of the ways to investigate this further might be to investigate micromotion at the junction with increasing impaction.

Irrespective of material combination and surface finish, the least fretting current is found in samples with the greatest assembly load with the exception of CoCrMo smooth-standard neck tapers that showed a slightly higher fretting current when impacted with 8 kN compared to 4 kN (Table 2). This may be because according to Rehmer et al. CoCrMo heads and necks have a lower fixation capacity when combined together. For both 2 and 4 kN impaction loads, the corrosion current was higher for Ti-6Al-4V necks compared with CoCrMo. However, when assembled with 8 kN, Ti-6Al-4V generated lower corrosion currents than CoCrMo most likely due to greater deformation of this softer material. Previous studies have demonstrated that tapers with a long neck and smooth finish are superior, in terms of fretting, to those with a short neck and rough surface finish.39 Panagiotidou et al.39investigated the fretting current seen with rough-standard versus rough-short tapers, as well as rough-short versus smooth-short, finding that short and rough tapers were subject to a concerning degree of fretting and may be 'unsuitable for neck tapers'. Our current study demonstrates that when impacted with 8 kN of force, this is not the case and a well impacted rough short taper performs equally well. However if a 2 or 4 kN load is used to impact the head then rough short tapers do corrode more than long smooth tapers. We were able to measure the effects of taper geometry on the corrosion current and subsequently how these effects can be reduced given the appropriate level of impaction. The clinical relevance of this finding is that the impaction force at the time of assembly is a factor controlled by the surgeon and therefore they have the potential to effect taper corrosion.

Following the results of the short-term tests, 4 and 8 kN impaction loads were compared through long-term cyclic loading in the rough-short group for both material combinations. In doing so, the average force currently used was compared with the force that appeared to be the best option from the short-term tests. We showed that as time and number of simulated walking cycles progresses, the fretting current decreases. This decrease is larger in those samples impacted with 4 kN. In samples assembled with 4 kN of force, there was a large fall in fretting current between 1 and 2 million cycles ($p < 0.05$). This is probably a direct result of the two tapers bedding into each other. This effect is seen in those impacted with 4 kN, but impaction with 8 kN provides a secure initial fixation with low corrosion currents measured from the start of the test. There is no statistically significant difference between the fretting currents at 1 and 2 million cycles for 8 kN assemblies and these are lower than the first 1 million cycles when compared with tapers impacted with 4 kN ($p < 0.05$). For the remaining 4 million cycles the change in fretting current, particularly amplitude, is far less marked for the 8 kN assemblies. We can, therefore, conclude that for both impaction loads over time the fretting corrosion processes seem to run in and reach equilibrium, with seating loads mainly affecting the immediate post-seating fretting corrosion processes (between 1 and 2 million cycles). This difference is more noticeable in the group impacted at 4 kN.

After long-term testing (Test-2), imprinting was visible on the CoCrMo head taper. This imprinting of regular circumferential grooves on the head taper surface is identical to the circumferential grooves seen on the neck taper only in the contact region indicating that the original smooth surface of the head taper has now changed to a more roughened surface whilst the surface finish of the neck taper has remained the same. Bolland et al.[35] has reported this morphological change with black markings and deposits on the head taper modular interface in his retrievals study. The amount of corrosion is greater in the samples impacted with only 4 kN of force. As corrosion has been identified as a largely time-dependent process[15] it is probable that more pronounced evidence of corrosion and imprinting would have been measured had either the number of cycles been increased or the frequency of loading increased. The localised position of crevice corrosion on the tapers seen in our in vitro study is likely due to the imposed bending forces. MACC has been associated with other modular junctions such as the neck-stem junction as well as with more conventional metal-on-polyethylene bearings. Additionally, high torque and large bending moment at the head–neck junction associated with large diameter metal-on-metal heads can exacerbate MACC and may increase the risk of malfunction.[36]

In this comparative study, we have shown that impaction force has an effect on MACC in vitro and therefore we predict that impaction force will have an effect on MACC clinically. However, the precise amount of force used clinically to alleviate MACC is not known. This paper merely says that impaction force is important and that different taper configurations require different impaction levels in order to reduce MACC. Our in vitro study findings suggest the benefit of impaction at 8 kN. However, it is possible that the bone condition of some patients undergoing THA will not allow for this amount of force to be imparted to an already inserted femoral stem without causing a fracture. It is also very difficult for the surgeon to assess the force required to impact with 8 kN. However, the results of our study demonstrate that greater impaction results in more deformation, that reduces fretting corrosion and surgeons should strive to achieve these.

CONCLUSIONS

The hypothesis of our study was that increasing impact assembly load affects the deformation at the taper junction resulting in a stronger taper interlock that reduces MACC under high torsion and bending moments. In this study, all tapers tested exhibited fretting corrosion, however, we were able to identify that greater impaction force resulted in less fretting corrosion regardless of the engagement length, surface roughness or material combination. Long-term testing over 5 million cycles illustrated a progressive improvement in resistance to fretting corrosion with an increase in the number of cycles for Ti-6Al-4V rough-short neck tapers. Eight kilonewtons impaction force showed a better resistance to fretting corrosion for Ti-6Al-4V rough-short neck tapers compared to 4 kN of impaction force. This may be associated with increasing deformation at the higher impaction loads and a stronger taper interlock. It is advised that high impaction forces be used to assemble a taper as this may reduce MACC.

ACKNOWLEDGMENT

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