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The influence of assembly on stem taper texture and measurement uncertainty

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Abstract

Characterisation of revised orthopaedic surfaces is recognised as an essential requirement for understanding long-term implant performance. Pre-wear data (from which to define material loss) is not often available, so this must be reconstructed by mathematically modelling a small amount of as-manufactured surface. This paper examines the influence of the surgical assembly process and taper design on the contact deformation of CoCrMo head tapers and threaded Ti-6Al-4V stem tapers, and hence how reliable these surfaces are when used for the reconstruction of a pre-implantation surface. Three implant cohorts (n=5) of differing design were measured in an as-manufactured condition, then assembled, dis-assembled, and re-measured. Measurements were aligned using a validated procedure and deformation quantified in terms of amplitude and volume. No damage or imprinting was evident on the head taper bore, but surface texture compression could be more prevalent in stem taper designs with larger surface texture height. Based on the reviewed cohort of implants, the maximum error contribution to volume of material loss was <0.4mm^3.

Hip Arthroplasty, Stem Taper, Taper Measurement, Morse Taper

1. Introduction

Taper corrosion in hip arthroplasty has been recognised as a clinical concern, as the release of metallic debris and corrosion products from the junction has been implicated in premature implant failure. Material loss measurement of revised implants is a vital tool for quantifying damage and assessing implant performance. Contemporary stem tapers (figure 1) are manufactured with a texture (microgrooves), which plastically deforms during assembly and increases contact area.

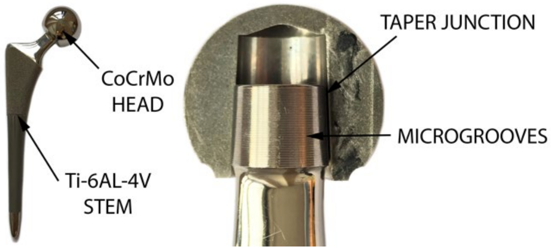

Figure 1. Key features of modern total hip arthroplasty

The limited number of publications detailing stem taper measurement rely upon reprocessing ostensibly pristine surface segments to reconstruct pre-wear geometry [1, 2]. The success of using such methods is largely dictated by the integrity of the input data, so understanding the confines of deformation is important when considering the limitations of material loss measurement. Previous work has so far recognised a relationship between increasing surgical assembly force and flattening of microgrooves by examination of 2D profiles [3, 4]. Higher impact loads have been associated with improved taper interlock, however 4kN is regarded as a clinically representative load [3, 5]. Manufacturing tolerances and dimensions of femoral tapers are poorly standardised, varying both between product lines and manufacturers [3, 6, 7]. Design has been suggested to influence taper performance, with one study documenting a two-fold variation in pull-off strength between designs [7].

Despite this, no results have yet been presented outlining volumetric changes between designs following assembly. This paper applies a validated methodology for the linear and volumetric assessment of assembly induced taper contact deformation to three total hip replacement designs.

2. Materials and Methods

The surgical assembly of three modular hip designs was replicated by delivery of axial impact. Tapers were measured pre and post assembly to study material displacement.

2.1. Measurement

Taper surfaces were digitised using a Talyrond 365 (Ametek, Inc., Berwyn, PA) roundness measurement machine equipped with a 5µm diamond stylus. An angular datum (laser etchings) was established for each implant design to allow concurrent taper maps to be constructed from 180 equally spaced profiles.

2.2. Assembly

Assembly load was delivered by a drop tower assembly rig, calibrated to 4kN. To ensure the intended assembly conditions were met, impact load was measured by a force sensor (Kistler 9031A; Kistler Instruments, Winterthur, Switzerland), integrated into the impactor tip. Assembled samples were subjected to an axial tensile load using an Instron (Instron Corporation, Norwood, MA, USA) 3369 tensile testing machine and the disassembly forces recorded.

2.3. Surface Processing

Surfaces underwent a form removal routine representative of that used for characterisation of wear [8]. Conicity and eccentricity of the taper were simultaneously removed by defining a second order polynomial with the best least-squares fit to each profile trace, and evaluating the resulting error.

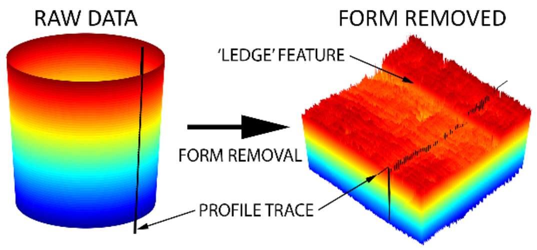

Figure 2. Stem taper surface before and after form removal

Although trunnions are considered to be axisymmetric, microgrooves are machined helically. Measurement start points were defined manually, so some samples showed slight axial misalignment. This was corrected (figure 3) by searching for the axial offset which returned the highest inter-surface Pearson Correlation Coefficient. The collective accuracy of the developed method was quantified by repeat measurement of a single stem.

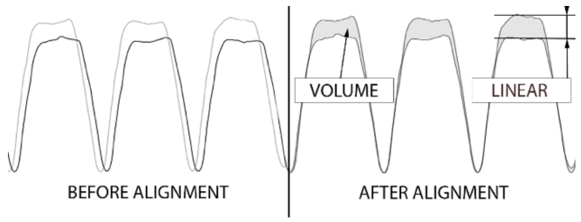

Figure 3. Profile traces showing axial alignment and enclosed volume

Surface subtraction and integration between the aligned pre and post assembly surfaces was executed to establish values for the average linear and volumetric material displacement sustained by each sample following assembly.

3. Results

Assembly process repeatability was quantified by delivering multiple impactions (n=10) to a seated femoral head from a constant drop height and measuring the force. The method showed high repeatability (σ=0.05), however deviation from the intended impact load was observed when assembling head-stem pairs (2.57 – 5.66kN). Pull-off forces ranged from 1.61 to 2.80kN and correlated with measured assembly force (r=0.725). No statistically significant difference was observed in assembly-corrected pull-off forces between the three groups (ANOVA, p=0.5). Measurements were found to have an accuracy limit of 0.2µm and 0.1mm^3 for linear and volumetric distortion respectively. Error levels are indicated on figure 4.

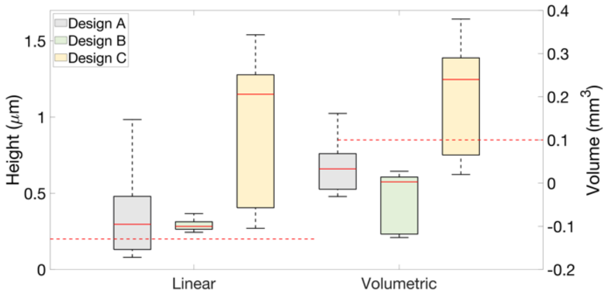

Figure 4. Plots of assembly induced amplitude and volume reduction

Although there was no statistically significant difference in pull-off force between the three groups, the average observed surface texture deformation was found to be larger in group C than groups A and B, both in terms of volume and linear amplitude change. Neither design A nor B sustained volume loss above the threshold of measurement accuracy.

4. Discussion

A strip of un-engaged surface remained at the distal end of stems from designs A and B. Following assembly, a ledge feature was observed at the root of engagement, indicated in figure 2. It is possible that this was formed as a result of the stem conicity conforming to the harder CoCrMo head in the area of contact. Imprinting of the stem texture onto the head taper has been reported with higher assembly loads [3], however no observable change in topography was noted on the head taper.

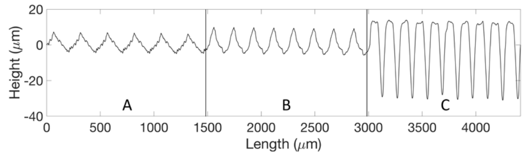

Figure 5. Profile segments of designs A, B and C from left to right

Topographical differences were observed between designs (figure 5), notably the peak to peak height and width of microgrooves. Design C demonstrated the tallest and narrowest groove morphology of the three cohorts and underwent the most deformation. It is not clear from this isolated case whether these observations are linked. A limitation of the testing method is that any additional material deformation caused by disassembly cannot be distinguished.

5. Conclusion

This study utilised a bespoke surface alignment protocol to quantify areal deformation of stem tapers following assembly. Differences in plastic microgroove deformation between designs was observed. Based on the samples reviewed, assembly damage could cause an uncertainty of up to 0.4mm^3 for material loss estimation of microgrooved taper designs. This finding is significant, as uncertainty could exceed material loss volume.

Acknowledgements

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