Simultaneous Hip Head-Stem Taper Junction Measurements of Electrochemical Corrosion and Micromotion: A Comparison of Taper Geometry and Stem Material

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Introduction: Fretting and/or corrosion of modern taper connections have been reported; micromotion at these connections may be an important factor that influences fretting corrosion [1-2]. In this study, a test method was developed to concurrently measure the electrochemical response and micromotion at the head-stem taper junction subjected to physiologically relevant loading conditions. This model was used to investigate the effect of taper material combination: Ti6Al4V/CoCr [Accolade II] vs. TMZF/CoCr [Accolade TMZF] and design: V40TM taper [Accolade II & Accolade TMZF] vs. C taper [Secur-Fit Max] (all Stryker Orthopaedics, Mahwah, NJ).

Methods: Specimen Groups:
Testing was performed on three specimen groups (n=4-6). Each group included CoCr femoral heads (Stryker Orthopaedics, Mahwah, NJ) with a 36mm diameter and +5mm offset were tested and stems that had either a larger (C-taper) or small (V40) taper geometry. The larger taper geometry has about 8% greater surface area than the small taper geometry. Group 1 included a Ti6Al4V/CoCr [Accolade II] V40 stem, Group 2 included a TMZF/CoCr [Accolade TMZF] V40 stem, and Group 3 included a Ti6Al4V/CoCr [Secur-Fit Max] C-taper stem.

Specimen setup and Electrochemical testing:
For electrochemical testing, stems from each sample group were embedded in epoxy (10° valgus /9° flexion orientation), and the heads and necks were pre-wetted with saline (PBS, pH 7.4) before assembling with a single ramp load of 2 KN (line of force nominally 35º to neck axis). Testing involved an initial 2000N controlled load followed by short-term loading scheme where cyclic load magnitude (R=0.1) was incremented in from 100N to 2000N in 100N load steps and from 2000N to 3200N in 200N load steps. This equaled a total of 26 loading steps. Cyclic loading was performed at 3Hz and data was collected for 3 minutes at each load. steps (from 100 N up to 3200 N, 3 min at each load at 3 Hz, R=0.1). All tests were performed at room temperature in phosphate buffered saline environment and electrochemical measurements (potential and current) were made using a three electrode arrangement consisting of a taper working electrode, Ag/AgCl reference electrode and an auxiliary electrode made of the same material as that of the stem taper.

Micromotion Measurement: Eddy current sensors (Micro-Epsilon, Ortenburg, Germany) were used to collect relative micromotion between the femoral head and stem. Delrin fixtures were secured to the femoral head and the stem (Figure 1) using the same setup as previously described in literature [3].
Three sensors were offset from each other by 120 degrees with one located in the stem’s medial region. Aluminum target plates were mounted opposite the sensors. Micromotion data was collected periodically at each load and the output data consisted of both elastic and rigid displacements. Elastic displacement of the specimen was isolated by performing a final static calibration where the specimen was loaded up to 3kN [4].

Data Analysis: Average current and current amplitude values were reported for each test load from the periodic electrochemical measurements taken throughout the duration of the test. Rotational and translational motions at each sensor were used to transform raw sensor data into pistoning (displacement along the z-axis) and rocking (rotation displacement about the x- and the y- axes) displacements which were determined at the center of the femoral head (Figure 1). A static load test was conducted to determine the effect of component elasticity on sensor displacements. Rigid motion was calculated by subtracting this elastic motion from the total motion. Subsidence was calculated as the permanent rigid linear displacement (displacement along the z-axis) between cycles where as pistoning represented the total linear displacement during a single load cycle. Specimen groups were statistically compared with a single-factor ANOVA test and Tukey post hoc test at 95% confidence level.

Results: For different taper groups tested, the results showed that both pistoning and rocking type of motion were present at the tapers and that the average currents, current amplitude, and pistoning magnitude varied with the applied load. Figure 2 is a sample data showing the correlation between the subsidence and fretting current. At loads greater than 1500 N, the head suddenly subsided (seated) with a subsequent drop in the average corrosion currents. Pistoning had a positive linear correlation (R^2≥0.97) to the peak cyclic load while rotation increased until reaching a peak load of 2000 N and then decreased slightly. The effect of loading on mechanical parameters is shown in Figure 3. Rotation in the x-axis reached a peak rotation of 0.07°. A rotation of 0.01° is approximately equal to 1μm of circumferential displacement around the taper surface. Due to the 10° valgus /9° flexion sample alignment, rotation about the x-axis was approximately two orders of magnitude greater than rotation about the y-axis. Analysis of a single-factor ANOVA test indicated there were no significant statistical difference in the micromotion or the fretting currents as a result of differences in either the taper geometry (V40 vs. C taper) or stem-head material combination (Ti6Al4V/CoCr vs. TMZF/CoCr).

Discussion: The test methodology was able to identify and measure different types of motions and secondary seating that may occur at head-neck taper junction and related these motions to electrochemical measurements such as fretting currents. The results from this in vitro bench top testing showed that the variation produced by material combination and taper design within the range of test groups tested were less than the variation that existed in each test group. Further studies will include exploration of the effects of taper surface finish, taper assembly conditions, and more complex loading mechanisms, on the corrosion and micromotion performance of different tapers.

Significance: This test provides a comprehensive method to correlate mechanical (pistoning, rocking, and subsidence) micromotion and electrochemical fretting corrosion results in order to compare head-stem taper geometry and material composition in an in vitro analysis.
Figure 3. Subsidence and pistoning increased with loading while rotation increased until reaching a peak load of 2000 N, after which it decreased. Error bars represent standard deviation.
Figure 1. The electrochemical and micromotion tests were performed in a PBS bath (A). Micromotion tests were used to define pistoning (about z-axis), rocking (about x- and y-axis), and subsidence values (B).

Figure 2. A SecurFit Max sample was used to represent typical specimen behavior and show that both mechanical subsidence and fretting current results had an abrupt change in output at approximately 1500N.