Variation of Knee Osteoarthritis Synovial Fluid Electrochemical Properties Against Orthopaedic Alloys

Alayna Robinson[1], Madison Brown[1], Lisa Phan[1], Marc J. Mihalko[2], Marcus C. Ford[2], John Crockarell Jr.[2], James Harkess[2], James Guyton[2]
William M. Mihalko[1,2]
[1]University of Tennessee Health Science Center, Memphis, TN; [2]Campbell Clinic Orthopedics, Germantown, TN

Disclosures: AR: No Disclosures; MB: No Disclosures; LP: No Disclosures; MCF:3B DePuy,Osteoremedies,7B Elsevier Inc; MJM: 7B Elsevier Inc; JC:7B Elsevier inc; JH: 3B Smith & Nephew, 7B Elsevier inc; JG:3B Smith & Nephew, 7B Elsevier Inc ; WMM:1-Aesculap Inc; 3B-Aesculap Inc, Pacira biosciences Inc, Zimmer/Biomet; 7A-Aesculap Inc; 7B-Elsevier Inc; 8-J Orthop Res, J Arthroplasty, J Long Term Eff Med Implants, Orthop Clinics NA; 9-Campbell Foundation, AAOS, ASTM International, AAHKS, Knee Society, Hip Society, ORS

ABSTRACT INTRODUCTION: Total knee arthroplasty (TKA) is a very common orthopedic procedure used in the treatment of end-stage osteoarthritis. Despite the commonality of this procedure, 20% of patients continue to report unsatisfactory outcomes. As the number of individuals receiving total knee arthroplasties is only expected to increase, it is important to decipher the causal factor of patients' dissatisfaction. Cobalt-Chromium (CoCrMo) and Titanium-Aluminum (TiAlV) are the replacement metal alloys commonly utilized in TKAs due to their high biocompatibility. Despite their proven track record, as in the case with all metal alloys, they are susceptible to corrosion. In addition, a previous study illustrated that lower pH solutions increase the corrosion rate of CoCrMo[1]. This finding underlines the importance of understanding the microenvironment surrounding the implant as it could be contributing to the corrosion rate as well as patients' reported outcomes. We hypothesize that a subset of patients will have a high variability in the electrochemical properties of their synovial fluid.

METHODS: IRB approval was first obtained for our study and patient consent was received prior to any surgical procedures performed. A 10cc syringe with an 18-gauge needle was utilized to aspirate the synovial fluid by a board-certified orthopedic surgeon. The synovial fluid was then transferred into a three-electrode low volume electrochemical cell within 30 minutes of the sample being obtained (Figure 1). Three parameters were then assessed through a series of electrochemical tests: Ecorr, Icorr, and corrosion rate. The corrosion potential of the metal, denoted as Ecorr (V), was first determined with a metal alloy working electrode (ASTM F1537 CoCrMo rod or ASTM F136 TiAlV rod), an Ag/AgCl reference electrode, and patients' synovial fluid as the electrolyte. Once the corrosion potential, Ecorr, was determined, electrical impedance spectroscopy (EIS) and a linear polarization (LP) scan were run to determine the corrosion current of the system- represented as Icorr (µA). A platinum wire was also utilized as the counter electrode. The corrosion current (Icorr) was then used to assess the corrosion rate of the metal alloy (mm/year). Statistical outliers for Ecorr, Icorr, and corrosion rate were determined by being 2 standard deviations above the mean. A one-tailed t-test was performed between outliers and non-outliers to determine if data was statistically significant.

RESULTS SECTION: Upon analysis of Ecorr for CoCrMo, 2 statistical outliers were found out of the 86-person sample size. The average Ecorr for non-outliers and outliers were 0.05 V and -2.21 V, respectively. In reference to Icorr for CoCrMo, there were 4 statistical outliers found (patient 2, patient 4, patient 50, patient 73). The average Icorr with outliers excluded was 1.82 µA while the outlier group had an average of 49.2 µA. A statistically significant difference was observed between the two groups ($p<0.05$). In reference to the corrosion rate for CoCrMo, there were 4 statistical outliers found (patient 2, patient 4, patient 50, and patient 73). The average corrosion rate with outliers excluded was 0.012 mm/year while the average corrosion rate for the outliers was 0.332 mm/year. A statistically significant difference for CoCrMo corrosion rates was found between the outlier and non-outlier group with a p-value of 0.01.
In reference to TiAlV Ecorr, there were 5 statistical outliers found out of the 65-person sample size. The average Ecorr for non-outliers and outliers were -0.37 V and -0.57 V, respectively. Furthermore, statistical significance was found with a p value of 0.001. For TiAlV Icorr, there was one statistical outlier found with an Icorr of 1.571 µA (patient 2). The average Icorr with patient 2 excluded was 0.306 µA. There were 2 outliers found for TiAlV corrosion rate with an average of 0.032 mm/year. The average corrosion rate with outliers excluded was 0.007 mm/year.

DISCUSSION: Two outliers were determined for CoCrMo Ecorr (patient 2 and patient 73); however, a t-test was not performed due to the limited number of outliers present. There was a subset of patients found to be outliers for both CoCrMo Icorr and CoCrMo corrosion rate: patient 2, patient 4, patient 50, and patient 73. The average CoCrMo Icorr for outliers and non-outliers was significantly different; specifically, patient 50 had an Icorr value of 78.55 µA which is substantially higher than the average Icorr of the non-outlier group (1.82 µA). Regarding corrosion rate for CoCrMo, the same subset of patients had a significantly higher corrosion rate than the non-outlier group. The highest two corrosion rates were 0.511 mm/year (patient 50) and 0.332 mm/year (patient 2); these values were also notably higher than the non-outlier group average corrosion rate of 0.012 mm/year.
Only 65 samples were included in the analysis of TiAlV as there was limited synovial fluid volume remaining after the CoCrMo test. Of note, the outliers whose corrosion rates were significantly higher than the non-outlier group (0.007 mm/year) were patient 2 (0.036 mm/year) and patient 53 (0.028 mm/year). A t-test was not performed for TiAlV Icorr or TiAlV corrosion rates due to the limited outliers found. As the data obtained is promising thus far, we will continue to obtain samples and plan to correlate these findings with patient satisfaction outcomes in the future.

SIGNIFICANCE/CLINICAL RELEVANCE: As previous studies have illustrated the effect of the local environment on CoCrMo corrosion rates, it is important to further analyze the electrochemical interactions between patients' synovial fluid and the implant metal alloys. These electrochemical interactions may point to a causal factor of patient dissatisfaction with TKAs.

REFERENCES:

1. Gilbert JL, Sivan S, Liu Y, Kocagöz SB, Arnholt CM, Kurtz SM. Direct in vivo inflammatory cell-induced corrosion of CoCrMo alloy orthopedic implant surfaces. J Biomed Mater Res A. 2015 Jan;103(1):211-23. doi: 10.1002/jbm.a.35165. Epub 2014 Mar 26. PMID: 24619511; PMCID: PMC4162871.

ACKNOWLEDGEMENTS: This work was supported in part by a FARE grant from the American Association of Hip and Knee Surgeons.

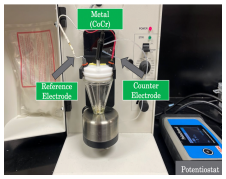

Figure 1. Three-Electrode Electrochemical Cell.