

## Synovial Fluid Electrochemical Properties Are Altered After Total Knee Arthroplasty

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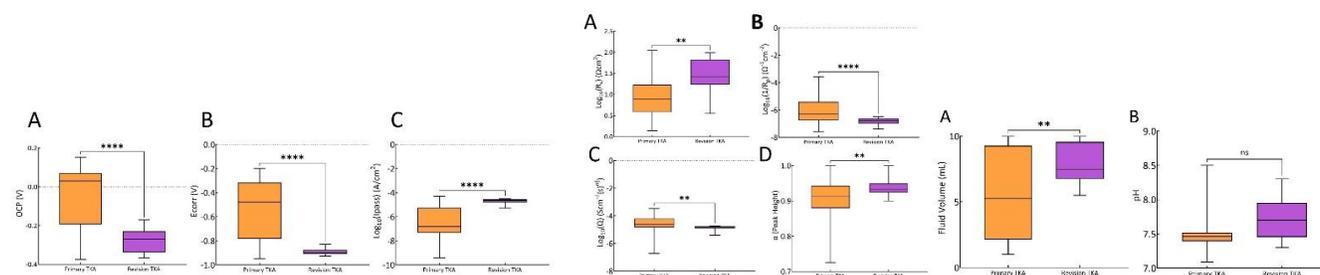
**INTRODUCTION:** Total knee arthroplasty (TKA) is generally a successful procedure, with a 10-year implant survival rate as high as 96%. However, around 20% of TKA patients remain dissatisfied with their surgical outcome. Patients describe symptoms of pain, swelling, instability, and a limited range of motion as some common reasons for dissatisfaction. The role of metal release and synovial fluid physiological properties remains largely unknown after primary TKA. We investigated human osteoarthritic synovial fluid's physical and electrochemical properties in patients undergoing primary TKA and revision TKA (RTKA) procedures to objectively record any of these physical property changes that may influence patient satisfaction.

**METHODS:** Synovial fluid was aspirated from 118 patients (n=54 male, n=64 female) undergoing primary TKA for osteoarthritis (OA) and 9 patients (n=3 male, n=6 female) undergoing RTKA following IRB approval (#16-04802-XP, 21-08403-XP, 22-09069-XP). The fluid volume of synovial fluid was recorded, and the synovial fluid pH was recorded using a LAQUAtwin pH meter. Electrochemical properties were assessed in a three-electrode setup (Palmsense 4 potentiostat) with a wrought cobalt chrome alloy rod (ASTM F1537) as the working electrode, an Ag/AgCl reference electrode, and a platinum counter wire electrode. Three electrochemical tests were performed: open circuit potential (OCP) for 65 minutes, electrochemical impedance spectroscopy (EIS) from a  $10^5$  to  $10^{-2}$  frequency range, and linear polarization testing from -1.0 V to +1.0 V with respect to the OCP. To characterize oxide film properties, the data acquired from EIS testing were fit to a Randles-CPE and coated circuit models. Oxide polarization resistance ( $R_p$ ) values were area-adjusted, and the inverse was taken to calculate the instantaneous corrosion rates ( $1/R_p$ ). Solution resistances ( $R_s$ ), constant phase element parameter (Q), and peak height ( $\alpha$ ) were also observed. Potentiodynamic curves were created by plotting the applied voltage versus the log of the current density. Corrosion potentials ( $E_{corr}$ ) and passive current densities ( $I_{pass}$ ) were calculated from the potentiodynamic curves. Reasons for revisions were recorded. A Welch's t-test ( $\alpha=0.05$ ) was performed using GraphPad Prism to determine differences in the synovial fluid's volume, pH, and electrochemical properties in each group.

**RESULTS:** Synovial fluid volume from OA patients ( $5.8 \pm 3.3$  mL) was significantly lower than in RTKA patients ( $7.8 \pm 1.6$  mL,  $p=0.004$ , Figure 1A). We did not identify significant differences in pH (Figure 1B). The OCP values for OA patients ( $-0.05 \pm 0.16$  V) were significantly higher than in RTKA samples ( $-0.28 \pm 0.06$  V,  $p<0.0001$ , Figure 1C). We found significant differences in the circuit parameters ( $R_s$ ,  $1/R_p$ , Q, and peak height, Figure 2A-D). The instantaneous corrosion rates of CoCrMo were higher in OA synovial fluid ( $9.43 \times 10^{-6} \pm 2.90 \times 10^{-7} \Omega^{-1} \text{cm}^{-2}$ ) than in RTKA samples ( $1.70 \times 10^{-7} \pm 9.18 \times 10^{-8}$ ,  $p<0.0001$ , Figure 2B). The mean  $E_{corr}$  in OA samples ( $-0.54 \pm 0.25$  V) was significantly higher than in RTKA samples ( $-0.89 \pm 0.03$  V,  $p<0.0001$ , Figure 3A). Mean  $I_{pass}$  in OA ( $5.22 \pm 9.85 \text{ Acm}^{-2}$ ) was significantly lower than in RTKA samples ( $20.92 \pm 7.79 \text{ Acm}^{-2}$ ,  $p<0.0001$ , Figure 3C). Reasons for revisions included primarily aseptic loosening (n=7). One case of metal sensitivity and one case of arthrofibrosis were reported.

**DISCUSSION:** This study compared the physical and electrochemical properties of synovial fluid from OA patients and patients undergoing RTKA. Fluid properties varied between the two groups. We found that RTKA samples had higher fluid volumes and  $I_{pass}$  values than OA samples. Additionally, RTKA samples had lower  $1/R_p$  and  $E_{corr}$  values than OA samples. Future work will investigate the metal ion content in the synovial fluid and surrounding tissue and increase the revision TKA sample size. Acknowledgments: This study received funding from the Food and Drug Administration and an AAHKS FARE Grant.

**SIGNIFICANCE/CLINICAL RELEVANCE:** This study compared the physical and electrochemical properties of synovial fluid from OA patients and patients undergoing RTKA to objectively record any property changes that may influence patient satisfaction.



**Figure 1.** (A) Open circuit potential values for osteoarthritic and revision TKA synovial fluid samples. (B) Corrosion potential ( $E_{corr}$ ) values for osteoarthritic and revision TKA synovial fluid samples. (C) Passivation current densities values for osteoarthritic and revision TKA synovial fluid samples. \*\*\*\*indicates a p value  $< 0.0001$ .

**Figure 2.** Solution resistance values for osteoarthritic and revision TKA synovial fluid samples. (B) Instantaneous corrosion rate values for osteoarthritic and revision TKA synovial fluid samples. (C) Constant phase element values for osteoarthritic and revision TKA synovial fluid samples. (D) Peak height values for osteoarthritic and revision TKA synovial fluid samples. \*\*indicates a p value  $< 0.01$  and \*\*\*\*indicates a p value  $< 0.0001$ .

**Figure 3.** (A) Fluid volume values for osteoarthritic and revision TKA synovial fluid samples. (B) pH values for osteoarthritic and revision TKA synovial fluid samples. \*\*indicates a p value  $< 0.01$ .