Employing a Pendulum Wear-Testing Model to Evaluate the Feasibility of a 3D-Printed Polymer for Small Joint Arthroplasty

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Introduction

- Thumb carpometacarpal osteoarthritis (CMCOA) is a degenerative bone condition that affects 20-25% of those over the age of 50, resulting in pain, weakness, and limited thumb mobility.[1]
- Conventional surgical repair by metal joint reconstruction (arthroplasty) has been associated with complaints of aches and poor outcomes.
- 3D-printed Polyetherketoneketone (PEKK) has been FDA-cleared as an implantable, load bearing polymer for use in bone replacement.
- PEKK compounds have not been tested in the setting of arthroplasty, but are candidates for better long term outcomes than metal implants.
- A previously established pendulum model has been applied as a method of measuring cartilage wear with an intact animal joint.[2]
- We postulate that this pendulum model can be applied to wear test PEKK against a native joint to simulate PEKK arthroplasty, and that this model can be applied to study PEKK joint replacements compared with metal joints.

Aims

- Employ an established pendulum model to demonstrate the feasibility of wear-testing 3D-printed PEKK in articulation with cartilage.
- Utilize intact rabbit femurs to test *in vitro* cartilage wear against an articulating joint constructed with PEKK, simulating *in vivo* arthroplasty.
- Explore the varying effects of different PEKK surface textures on femur surface wear.
- Quantify the degree of wear on cartilage by comparing coefficient of friction (COF) and Damping Time (DampT) to native joint values.

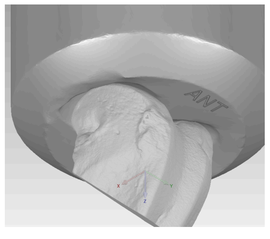

Figure 1. A 3D render of femur articulation with a PEKK part.

Methods

- **Pendulum Setup:** A pendulum model was retrofitted to accommodate passive swinging and cyclic motion. The rabbit femur was potted, mounted, and immersed in bovine serum. A Micro CT of the femur specimen was obtained, and a corresponding PEKK model was printed, polished, and mounted to articulate with the femur (figure 1).
- **Wear test protocol:** Weighted (2.5kg) cyclic loading on the femur was performed for 26 hours. Coefficient of friction was measured by passively swinging the pendulum 14 times at varying intervals, according to previously established protocol. A polished PEKK part (pPEKK), unpolished PEKK part (uPEKK), and native joint were tested.
- **Measurements and Analysis:** DampT and swing measurements were gathered with Qualysis motion sensing cameras. Qualysis motion data was imported to Visual3D, fit to a constructed model, and exported to MATLAB. MATLAB code was used calculate COF, which was compared to that of the native joint. India ink stain was applied to demonstrate wear.

Results

- **COF**, a measure of resistance that directly relates to surface wear, was highest in the pPEKK trial, and lowest in the uPEKK trial. Native joint COF fell between the two values (figure 2).
- **DampT**, a measure of pendulum swing time that inversely correlates with resistance, showed that the passively-swinging pendulum took more time to rest with pPEKK than with uPEKK.
- **India ink** staining showed significantly more wear with uPEKK than with pPEKK (figure 3).

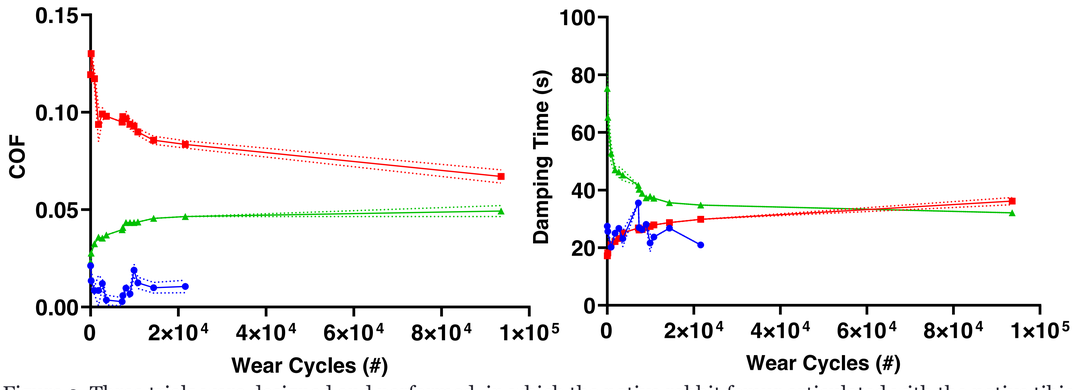

Figure 2. Three trials were designed and performed, in which the native rabbit femur articulated with the native tibia (green), an unpolished PEKK part (blue), and a polished PEKK part (red) respectively.

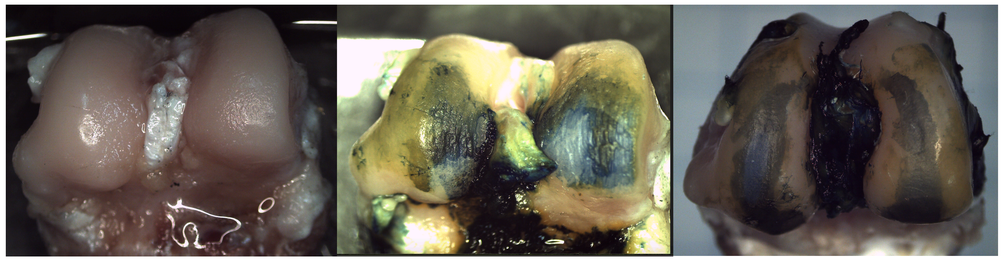

Figure 3. Femur pre-testing (left), and India Ink staining of the rabbit femurs after wear testing with unpolished (middle) and polished (right) PEKK parts. Unpolished wear testing was discontinued after 2E4 cycles due to cartilage destruction.

Conclusions

- The pendulum model is a useful tool for quantifying degree of wear in joint articulation.
- *In vitro* femur testing showed that PEKK wear on cartilage improved with surface polishing.
- India Ink showed significantly less visible cartilage wear from pPEKK than from uPEKK..
- pPEKK trial showed COF, DampT, and wear results more consistent with native cartilage, which indicated improved results with polishing.

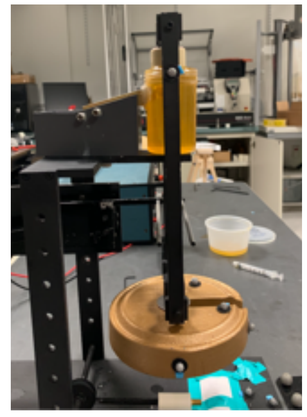

Figure 4. Pendulum apparatus used for cyclic wear testing,

Future Directions

- Having shown the feasibility of the pendulum model in the setting of *in vitro* PEKK testing, it can be applied to test further polishings of PEKK to obtain results more compatible with bone.
- Pendulum testing can be applied to *in vitro* testing of other materials that might be candidates for arthroplasty.

References

[1]Wilder FV, Barrett JP, Farina EJ. Joint-specific prevalence of osteoarthritis of the hand. Osteoarthr Cartil. 2006 Sep;14(9):953–957. PMID: 16759885

[2]Drewniak EI, Jay GD, Fleming BC, Crisco JJ. Comparison of two methods for calculating the frictional properties of articular cartilage using a simple pendulum and intact mouse knee joints. J Biomech. 2009 Aug 25;42(12):1996–1999. PMCID: PMC2734508

Acknowledgements

I'd like to thank Dr. Crisco, the Brown Biomechanics Lab, and Lifespan for their support and funding.