Introduction and Motivation: Healthy cartilage is a complex tissue facilitating lubrication and smooth movement at the interface of long bones in joints. Cartilage stores and secretes synovial fluid to minimize friction during compressive articulation, giving cartilage interfaces a coefficient of friction lower than any engineering material[1]. Natural articular cartilage also experiences shear, compressive, and torsional stresses as a bearing surface, and exhibits highly anisotropic properties in response to complex loading. A particular area of interest is the replacement of articular cartilage that has been compromised through osteoarthritis. 800,000 TJRs occur per year in the United States, with 12% of primary joint replacements requiring revision surgeries within the first decade[2]. Revised devices have a lower success rate than initial implantation. Wear of devices is a primary cause of failure: 24-30% of knee revisions are due to wear and its effects: osteolysis (bone loss), or mechanical loosening of the device[3]. Post-implantation lubrication is crucial to extending the life of implants; poor lubrication increases adhesive wear volume threefold [4]. To imitate cartilage in Total Joint Replacements (TJR), the biomedical community relies on polymers for their relatively low elastic moduli. Since the 1960's, Ultra-High Molecular Weight Polyethlene (UHMWPE) has been the gold standard, with increasing interest in cross-linked UHMWPE (XLPE). However, use of UHMWPE and XLPE in implants necessarily involves tradeoffs amongst fatigue crack propagation resistance, wear resistance, and oxidation resistance[5]. The ongoing need for an ideal cartilage implant motivates my proposed research into the viability of polycarbonate urethane (PCU).

PCU presents two advantages over UHMWPE and XLPE. The low elastic modulus of PCU is on the order of cartilage, and PCU has been shown to have excellent wear resistance[6]. Additionally, unlike polyethylene, the properties of PCU can be controlled at the microstructural level[6]. By varying the distribution of hard and soft phases, optimal viscoelastic properties can be achieved. These in turn dictate the compressive response and the ability to exude fluid for lubrication, and can thus prevent wear and eliminate osteolysis.

I propose conducting a comprehensive fundamental study of the tribological performance of PCU and developing a functional grading scheme that optimizes *in vivo* performance.

Methods: Traditional wear testing, or tribo-testing, is conducted on either pin-on-disk configurations or full joint simulators. A unique ball-on-flat multi-directional tribo-testing system was developed in the Medical Polymers Group (MPG) at UC Berkeley to address the gap in testing capability and resultant gap in understanding of material properties, as shown in **Fig 1**. The system captures *in vivo* wear conditions more accurately than existing systems[3]. Specifically, the system is able to model cross-shear, which has a significant effect on the wear of devices[3].

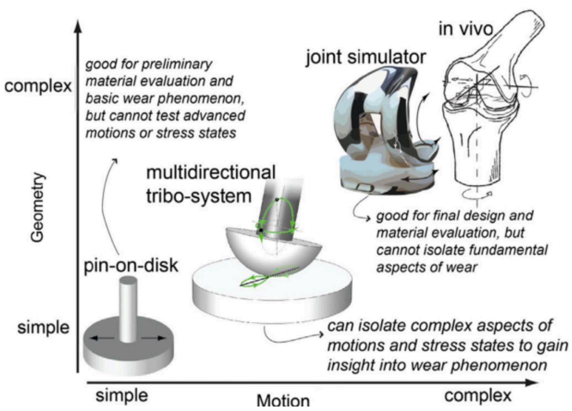

Fig 1. A comparison of wear simulation methods[3].

The wear performance of PCU under the trade name BioNate will be tested against both UHMWPE and XLPE samples. Three formulations of PCU will be tested: B55D, B75D, and B80A. In MPG's tribo-tester, a Cobalt Chromium (CoCr) head will be programmed to cyclically articulate against each BioNate, UHMWPE and XLPE sample in isolated motions from hip and knee kinematic models. Each sample will be tested for 20 million cycles to capture 20 years of use. Tribo-testing will be conducted in a bovine serum bath to mimic synovial fluid at the joint.

During testing, gravimetric analysis will assess the micro-particle generation rate of PCU, indicating total wear.

Macro-scale surface wear will be evaluated using a polymer surface wear scoring system developed by MPG[7], and micro-scale surface wear will be observed using optical microscopy. Microstructural changes, specifically the realignment of lamellae to the principal stress direction, will be analyzed using electron microscopy. The shape of wear marks will determine whether wear has occurred via abrasion, adhesion, delamination, or contact fatigue, which indicates shear, cross-shear, or Hertzian contact stress as the predominant wear instigator. From the wear analysis, a set of stress tensors acting at different points through the polymer bearing will be derived. Stresses at each point will be input to the Kelvin-Voigt model of polymer viscoelastic response and matched to the strain of natural cartilage at the same point, calculated from existing models[8]. This calculation determines the modulus of PCU required at each point to match natural cartilage deformation, as described in **Fig 2**. The model will be validated by testing samples optimized for hip and knee kinematics against XLPE, and observing wear response at 20 years.

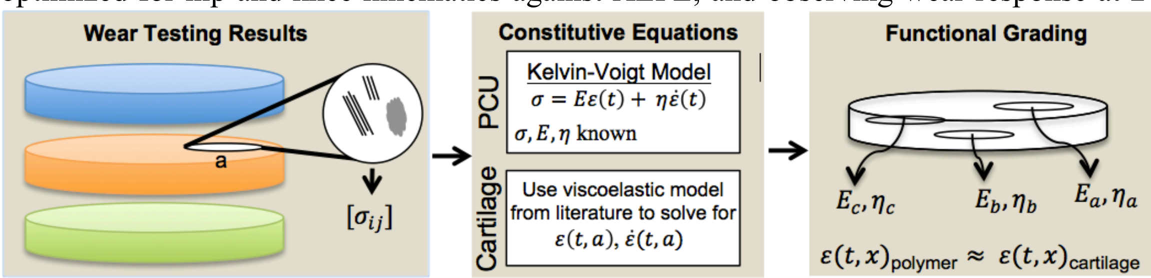

Figure 2. The proposed process to develop a functional grading scheme for PCU.

Academic Significance: Novel bearing surfaces are of considerable interest in the orthopedics community. Few studies have researched PCU in load-bearing situations, and no implemented functional grading schemes have been reported in the literature. This research will be the first to quantitatively characterize the response of PCU to individual motions of a validated kinematic model, and will provide a significantly deeper understanding of PCU performance on the microstructural level. The development of a quantitative functional grading scheme will enable novel performance tailoring and wear prevention in implants.

Broader Impacts: Improving material durability is crucial to increasing the success rate of TJR and minimizing costly revision surgeries. Especially in younger patients who can expect several revision surgeries with current implant lifetimes, improving the wear properties of devices has an inestimable impact on quality of life. New implant bearing surfaces engineered to accommodate high-impact activity will benefit the increasing numbers of younger patients and athletes receiving implants[2], whose joints are subject to strenuous mechanical demands.

Outreach: Investigating structure and function of joints provides a fantastic interactive learning opportunity. I am currently writing a lesson that Berkeley Engineers and Mentors and the Science and Engineering Community Outreach clubs will present each semester to elementary students in Berkeley and Oakland. By educating students about their own bodies and asking them to think critically about the mechanical demands we make of ourselves, the lesson aims to inspire curiosity and healthy practices around everyday movements.

Citations: [1] Pruitt LA, Chakravartula AM. *Mechanics of Biomaterials*. 2011. [2] Kurtz SM et al. *Clin. Orthop. Relat. Res.* 2009. [3] Patten E, Citters D Van, Ries M, Pruitt L. *Wear*. 2013. [4] Komvopoulos K. *Fundamentals of Tribology and Contact Mechanics*. 1998. [5] Atwood S et al. *J. Mech. Behav. Biomed. Mater.* 2011. [6] Cipriani E. Characterization of Bionate: Morphological model. [7] Gunther SB et al. *J. Arthroplasty*. 2002. [8] Ehlers W et al. *IUTAM Symp. Theor. Numer. …*. 2002.