BRYAN JAY MCENTIRE

Thesis Abstract

Silicon Nitride: A Unique Bioceramic for Total Joint Arthroplasty

Advanced bioceramics currently play important curative roles for various orthopaedic morbidities, including their use as bearing surfaces in total hip arthroplasty (THA). Introduced during the latter half of the 20th century, these materials rapidly evolved from monolithic alumina (Al2O3) and yttria-stabilized zirconia (Y-TZP) to alumina-zirconia composites (ZTA). While their use in THA has proliferated because of their perceived bioinertness, they have yet to deliver the promised objective of being "lifetime" devices; which, in fact, brings into question the very definition of bioinertness. However, only recently have investigative tools been developed which allow examination of the surface chemistry and mechanical properties of these materials at the molecular level. In this thesis, Raman and cathodoluminescence spectroscopy coupled with traditional micromechanical methods were employed to evaluate the surface chemistry and fracture toughness of three bioceramics: Al_2O_3, ZTA, and a promising alternative non-oxide material, silicon nitride (Si_3N_4). Contrary to conventional wisdom, oxide-based ceramics were not *bioinert*. Indeed, bio-tribological interactions resulted in the release of oxygen from Al_2O_3, and mechanical instability in ZTA, which in turn, may accelerate oxidative degradation in polyethylene and increased wear of self-mated bearings, respectively. On the other hand, Si_3N_4 was also not *bioinert*; but uniquely, it possesses positive *non-bioinertness*. It scavenges oxygen from the tribolayer instead of releasing it, thereby providing a protective benefit to polyethylene; and its surface toughness is immune to even severe hydrothermal conditions. Nevertheless, wear studies using self-mated Si_3N_4 bearings exhibited fluctuating friction (*i.e.*, slip-stick behavior), which was also attributable to chemical interactions with the biologic environment. Overcoming this limitation represents a key challenge and recommendation for this novel biomaterial. Lastly, it was also discovered that Si_3N_4's tribochemical wear products (*i.e.*, predominately silicic acid, $Si(OH)_4$, and ammonia, NH_3) are soluble, resorbable, and can potentially buffer the local pH within the joint capsule. As such, Si_3N_4 may yet prove to be beneficial for arthritic patients whose diseased joints have degeneratively low pH values. While additional research is required, particularly to overcome the unfavorable frictional behavior for self-mated bearings, Si_3N_4's performance as an articulation device appears particularly promising.