Anti-infective and osteointegration properties of silicon nitride, poly(ether ether ketone), and titanium implants

T.J. Webster, A.A. Patel, M.N. Rahaman, B. Sonny Bal

1. Introduction

Silicon nitride (Si₃N₄) is a synthetic non-oxide ceramic used in spinal fusion and maxillofacial reconstruction. Maximizing bone formation and minimizing bacterial infection are desirable attributes in orthopedic implants designed to adhere to living bone. This study has compared these attributes of Si₃N₄ implants with implants made from two other orthopedic biomaterials, i.e., poly(ether ether ketone) (PEEK) and titanium (Ti). Dense implants made of Si₃N₄, PEEK, or Ti were surgically implanted into matching rat calvarial defects. Bacterial infection was induced with an injection of 1 × 10⁷ Staphylococcus epidermidis. Control animals received saline only. On 3, 7, and 14 days, and 3 months post-surgery four rats per time period and material were killed, and calvariae were examined to quantify new bone formation and the presence or absence of bacteria. Quantitative evaluation of osteointegration to adjacent bone was done by measuring the resistance to implant push-out (n = 8 rats each for Ti and PEEK, and n = 16 rats for Si₃N₄). Three months after surgery in the absence of bacterial injection new bone formation around Si₃N₄ was ~69%, compared with 24% and 36% for PEEK and Ti, respectively. In the presence of bacteria new bone formation for Si₃N₄, Ti, and PEEK was 41%, 26%, and 21%, respectively. Live bacteria were identified around PEEK (88%) and Ti (21%) implants, whereas none were present adjacent to Si₃N₄. Push-out strength testing demonstrated statistically superior bone growth on Si₃N₄ compared with Ti and PEEK. Si₃N₄ bioceramic implants demonstrated superior new bone formation and resistance to bacterial infection compared with Ti and PEEK.

Long-term, stable fixation of orthopedic implants to skeletal bone relies on direct in-growth of host bone into the textured implant surface. Implant failure and clinical symptoms of pain can follow if such bone in-growth does not occur. A serious problem that can complicate an otherwise well-fixed and properly functioning implant is bacterial infection, which can manifest itself immediately after surgery or even years later. Implant-related infections usually require extensive surgical debridement, implant extraction, and prolonged antibiotic treatment [21,22]. Adherent bacteria such as Staphylococcus epidermidis are known to synthesize a complex surrounding biofilm layer that is impervious to host immune surveillance and systemic antibiotic therapy [23–25]. Therefore, resistance to bacterial infection would be a very desirable material property in orthopedic implants. To date, however, all implant materials are susceptible to bacterial seeding in vivo.

The purpose of this investigation was to test the potential antimicrobial properties and osteointegration capability of dense Si₃N₄ implants in an animal model. For comparison we used two common