A brief review of current orthopedic implant device issues: biomechanics and biocompatibility

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The improvement of bone fixation and joint replacement hardware has been an evolutionary process involving a team approach with biomechanists, physicians, and mechanical/materials engineers. Biomaterials in orthopedics or dentistry require that the implant material be very resistant to repeated stresses and metals, ceramics, and some composites meet this requirement. Improvements in joint replacement polyethylene components have also become more durable with reduced penetration by incorporating highly cross-linked polyethylene into the articulating surfaces [1]. The complexity of the development of these hardware devices lies in factors and problems relating to: 1) biocompatibility 2) the use of modular components in joint replacements for an improved custom fit and 3) the failure of the bone fixation due to stress shielding of the underlying bone.

Biocompatibility

Biocompatibility is an increased concern in joint replacements where fretting may potentially contribute to an increase of the migration of metal ions as well as fatigue failure of the implanted device over time. However, biocompatibility is still a concern in bone fracture/defect fixation due to the possible toxicity of metal implant components. Metal implants exhibiting a degree of biological tissue toxicity such as cobalt-chromium alloys are still used in joint implants because of their resistance to shear stresses and reduced surface fretting in joint replacements. Yet, cobalt-chromium alloys have been found to be toxic to surrounding biological tissues at high levels in a small number of patients (i.e., cobalt mean of 0.6 ng/ml and chromium mean of 0.6 ng/ml) when used in a cobalt-chromium alloy femoral neck stem joined to the modular femoral head of the implant at the acetabulum (i.e., hip socket) [2]. Metal alloys containing nickel or aluminum although corrosion resistant and low in mass relative to volume have been found to be toxic and may result in inflammation of laminar bone and surrounding soft tissues. For example, an accumulation of aluminum but not titanium was found in soft tissues and newly formed bone lamella surrounding titanium plates affixed to human maxillae of the face with the use of Ti6Al4V titanium alloy bone screws (a titanium alloy with 6% aluminum and 4% vanadium) [3]. Furthermore, the titanium alloy Ti6Al4V (i.e., Ti-64) is in widespread use in orthopedic joint and bone fixation plate/rod implants and is very corrosion resistant, exhibits a high tensile strength (860 MPa) in addition to exhibiting high stiffness with a Young’s Modulus of cortical bone (i.e., approximately 20 GPa). Titanium alloy implants incorporating such metals are less stiff with a Young’s Modulus of 50-70 GPa and therefore more closely approximate the

Reducing stress shielding in bone

Ti-64 alloy exhibits high stiffness which due to stress shielding can result in bone atrophy/degradation resulting in a failed implant interface with time. New titanium alloys which may include iron (FE), niobium (Nb), molybdenum (Mo) or tin (Sn) act to reduce the stiffness of an orthopedic implant to more closely approximate the Young’s Modulus of cortical bone (i.e., approximately 20 GPa). Titanium alloy implants incorporating such metals are less stiff with a Young’s Modulus of 50-70 GPa and therefore more closely approximate the

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1 Galvanic corrosion has long been known to occur when dissimilar metals of screws, plates or rods come together in the presence of body tissue fluids (electrolytes) to form an electrical (galvanic) couple.
stiffness of the underlying cortical bone enabling the implant to better transfer the loads of daily human activity to the bone. In accord with Wolff’s law, this transfer of repeated significant loads to bone tissue results in maintaining the structural and functional integrity of both spongy and cortical (laminar) bone and therefore better maintains the implant interface over the longer term extending or eliminating the need for a surgical implant revision. Other factors such as the length of the long bone stem in TKA/THA joint replacements (i.e., affect upon stress shielding) or using cemented v. non-cemented components in joint replacements may affect the long-term outcome in specific patients. Biological individuality including factors such as gender, regional bone density/muscle density, age and general health can all affect the surgeon’s choice of orthopedic hardware and method of fixation [1,8-10].

Joint replacements are increasingly being developed for new body regions and fracture fixation plating, intramedullary rod fixation (long bones) has improved with changes in geometry and implant material to reduce stress shielding. Plates and cages sometimes remain in the body over the human life span, some are removed later and some implants are now biodegradable (over a predictable time) eliminating the necessity of future removal [11].

References