Metallic biomaterials currently in use for load-bearing orthopedic applications are mostly bioinert and therefore lack sufficient osseointegration. Although bioactive ceramics such as hydroxyapatite (HA) can spontaneously bond to living bone tissue, low fracture toughness of HA limits their use as a bone substitute for load-bearing applications. Surface modification techniques such as HA coating on metals are current options to improve osseointegration in load-bearing metal implants. Over the last few decades, researchers have attempted to find a bioactive metal with high mechanical strength and excellent fatigue resistance that can bond chemically with surrounding bone for orthopedic applications. Recent in vitro, in vivo, and clinical studies demonstrated that tantalum is a promising metal that is bioactive. However, tantalum applications in biomedical devices have been limited by processing challenges rather than biological performances. In this article, we provide an overview of processing aspects and biological properties of tantalum for load-bearing orthopedic applications.

INTRODUCTION

Musculoskeletal disorders are serious health conditions that severely affect quality of life. In most cases, restoration of lost structures and functions of diseased bones, particularly load-bearing structures, requires an artificial bone substitute material that does not damage the healthy tissue or pose any viral or bacterial risk to patients. However, artificial materials, in particular metals that are bioinert, implanted into bone defects are generally encapsulated by a fibrous tissue and become isolated from the surrounding bone. This has been a critical challenge for metallic implants in bone repair. Over the last few decades, researchers have attempted to find a bioactive metal with high mechanical strength and excellent fatigue resistance that can bond chemically with surrounding bone for orthopedic applications. Some bioactive ceramics such as Bioglass®, hydroxyapatite (HA), and glass-ceramic A-W, spontaneously bond to living bone tissue. However, compared with human cortical bone, they have lower fracture toughness and cannot be used as bone substitute for high load-bearing joints. Therefore, several surface modification techniques have been developed to enhance biological fixation and the healing process of load-bearing metal implants. Application of HA coating on titanium implants is the most common form of surface modification process, where the HA layer provides an osteoinductive surface for tissue fixation with the surrounding bone. Unfortunately, cracking, delamination, decomposition of HA, with amorphous calcium phosphate (ACP) formation, are some of the challenges for long-term in vivo stability of HA-coated implants.

Another popular approach is the use of porous metal coatings on dense metal implants to enhance biological fixation. Clinical and histological evidence from retrieved implants clearly demonstrates that porous coated implants enhance bone tissue ingrowth and are effective in supplementing the stability of the implant by biological fixation. Apart from low mechanical strength, the porous coated titanium alloy implants show 50 to 75% lower fatigue strength in comparison to their equivalent fully dense materials. A bioactive metal will not require any additional coating and therefore can alleviate most of these problems for load-bearing implants.
purally pure tantalum is then deposited onto this interconnected carbon scaffold using chemical vapor deposition/infiltration. The pore size and mechanical properties of Trabecular Metal can be tailored by adjusting the tantalum coating thickness (40–60 μm). Current Trabecular Metal implants for orthopedic applications have 75–85% porosity with pore size ranging from 400 to 600 μm. These open-cell porous tantalum materials are best suited for use as coatings or non-load-bearing implants because of low mechanical properties. The relatively high cost of manufacture and inability to produce a modular all-tantalum implant are other concerns of the present processing route. In addition, tantalum’s high affinity for oxygen and extremely high melting temperature at 3,017°C make it difficult to process tantalum-based coatings or implant structures via conventional processing routes. Therefore, fabrication technologies which can ensure a tailorable porosity maintaining near-net shape with high mechanical strength and purity assume significant importance for tantalum-based biomedical devices.

The development of porous tantalum structures and dense tantalum coatings is in its early stages of evolution. Recently we have demonstrated fabrication of bulk porous tantalum structures, with total porosities between 27% and 55%, and dense tantalum coatings on titanium using high-power lasers in Laser Engineered Net Shaping (LENS™)—a solid freeform fabrication technology. Figure 1 shows typical microstructural features of laser-processed bulk porous tantalum structures and dense tantalum coatings on titanium. The experimental results show that this process has the potential to create modular all-tantalum implants with tailored porosity. The Young’s modulus and 0.2% proof strength of tantalum have been tailored between 2–20 GPa and 100–746 MPa, respectively. Mechanical properties of laser-processed porous tantalum are similar to those of human cortical bone. Also, the dense tantalum coatings do not suffer from a low fatigue resistance due to the absence of porosity and sharp interface between the coating and the substrate, which is a major concern for porous coatings used for enhanced biological fixation. In addition, the specific advantages of using laser processing in conjunction with LENS are: the ability to control the melting of high melting point tantalum, thus creating fully dense or tailored porosity implants; the net-shape fabrication of complex shaped implants; the retention of the high purity.