Enhancing Osseointegration of Orthopaedic Implants with Titania Nanotube Surfaces

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Introduction/Purpose: Solid biologic fixation at the bone-implant interface provides long-term stability of orthopaedic implants. Historically, coatings and surface treatments on implant surfaces have been used to promote osseointegration of orthopaedic implants. The purpose of this research study is to evaluate two morphologies of titania nanotube (TiNT) surfaces via in vitro experiments as well as an in vivo model of femoral intramedullary fixation, in order to assess the influence of TiNT structure on de novo bone formation and bone-implant stability.

Methods: TiNT structures were grown from Ti-6Al-4V materials via an established electrochemical anodization process. Samples were either sonicated then annealed (Aligned TiNT) or annealed without prior sonication (Trabecular TiNT), to produce different morphologies. As-received titanium alloy was the control. Marrow-derived stem cells were isolated from long bones of Sprague Dawley rats and cultured on samples. Alkaline phosphatase (ALP) and osteocalcin (OC) expression by stem cells were assessed via ELISA. Cells were lysed and subjected to quantitative polymerase chain reaction (qPCR) to assess Col1a1, osteonectin, and IGF-1 expression. An in vivo study evaluated bone formation at 4- and 12-week endpoints. Eight female Sprague Dawley rats per group per endpoint received bilateral Ti-6Al-4V K-wires as femoral implants. Left femur received control, while right femur received Aligned/Trabecular TiNT K-wire. Bone formation was assessed via microCT, backscatter electron imaging (BEI), and non-decalcified histologic analyses.

Results: Aligned and Trabecular TiNT groups demonstrated higher ALP activity than control at 2 and 3 weeks. The in vivo study demonstrated increased bone volume fractions (BV/TV) and total bone volume (TBV) for TiNT surfaces (microCT). The ratio of both BV/TV and TBV in the distal VOI were nearly equivalent for both TiNT surfaces, indicating similar bone formation between both TiNT surfaces and control. In the midshaft VOI, the ratios between TiNT surfaces and control were 1.5 or greater, indicating increased bone formation. At 12 weeks, the bone-implant contact fraction ratio (BEI) showed Aligned TiNT and Trabecular TiNT were 1.3 and 1.4 times greater than control, respectively. Histologic analysis showed both TiNT surfaces had 1.5 times the bone-implant contact as control.

Conclusion: In vitro studies demonstrated improved support for osteogenic functions of cultured marrow-derived stem cells on TiNT surfaces compared to controls. μCT, BEI, and histologic analyses associated with the in vivo study demonstrated increased bone formation in the TiNT femora, at specific timepoints and VOIs.

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