A FULLY COUPLED COMPUTATIONAL FRAMEWORK FOR BONE FRACTURE REPAIR IN THE PRESENCE OF BIOABSORBABLE MAGNESIUM FIXATION DEVICES

Conall Quinn, Kerstin Van Gaalen, Peter E. McHugh, Alexander Kopp, Ted J. Vaughan
Biomechanics Research Centre (BioMEC), School of Engineering, University of Galway

Introduction

Magnesium (Mg) alloys have significant potential in orthopaedic applications as they avoid long-term complications associated within permanent metallic implants. Mg-based device reduce the need for implant removal surgeries as they are biodegradable, while also having osteoinductive properties and showing comparable mechanical properties to native bone tissue [1]. However, understanding the biomechanics of implanted Mg-based devices presents distinct challenges as they exhibit a non-uniform pitting corrosion process, which occurs simultaneously alongside the complex tissue repair process of the implanted region.

Materials and Methods

This study presents the coupling of a fracture repair and surface-based Mg corrosion algorithm developed by the author [2, 3] to predict the long-term viability of titanium and biodegradable Mg fixation plates for tibial fracture repair. A pre-processing step was implemented to calculate the random numbers for Mg corrosion, fracture callus generation and the homeostatic bone density. Bone fracture repair consisted of (i) bone fracture healing and (ii) bone remodeling. Bone fracture healing was implemented according to biphasic mechanoregulatory theory [4], whereby cells differentiated into different cell phenotypes based on the local biophysical stimulus. Bone remodeling was determined by local strain energy density (SED) and microdamage. Mg corrosion considered the role of β-phase components throughout the material volume to simulate non-uniform corrosion within the bone plates. All models were implemented through a series of user-defined field subroutines (USDFLD) within Abaqus Standard. The outlined algorithms were fully coupled allowing for bone ingrowth into regions once occupied by Mg components.

Results

Non-plated models underwent indirect fracture healing whereby the fracture gap was stabilised through soft callus formation, generation of a “bony bridge” and hard callus formation. The introduction of an internal plate stabilised the fracture region allowed for direct fracture healing to occur (Figure 1), whereby cells within the interfragmentary gap differentiated directly into mature bone cells, accelerating fracture healing outcomes and the reducing fracture callus volume. The introduction of an overly stiff titanium plate disrupted normal physiological loading, stress shielding cortical regions proximal to the plate. Mg implant strength decreased as Mg corrosion occurred allowing for restoration of normal loading, allowing for the tibia to remodel to pre-fractured morphology.

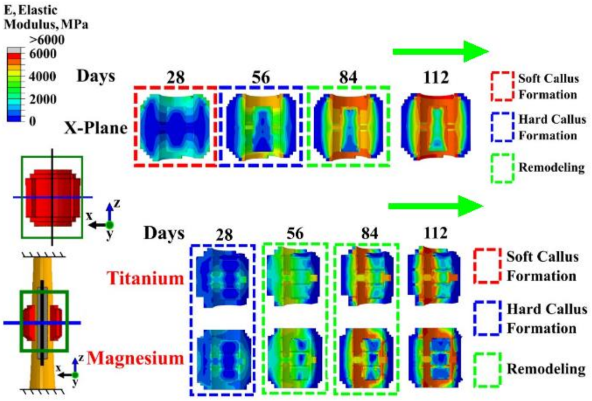

Figure 1: Stages of fracture healing within (A) non-plated and (B) plated tibial fractures.

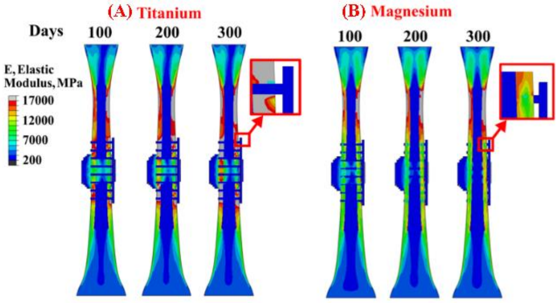

Figure 2: SED and micro-damage-based remodeling within (A) titanium and (B) Mg bone plates.

Discussion

This study presents the first fully coupled computational modelling framework to predict the long-term performance of biodegradable fixation devices. The model captured key aspects of the bone fracture repair process in the presence of plated fixators, showing good qualitative agreement with in vivo performance [5], highlighting the long-term potential of bioresorbable implants.

References

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