Development of a large animal model for the evaluation of screw augmentation materials

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Introduction: Internal stabilization of fractured or otherwise mechanically destabilized bones often occurs in the presence of compromised bone quality. Placement of hardware into bone of reduced mechanical competency can significantly affect the performance of the fixation hardware, and ultimately the clinical outcome. This is of particular importance when dealing with lesions that are a consequence of osteoporosis or neoplastic activity. Therefore, the development of materials that are designed to augment the mechanical performance of fixation hardware in these scenarios is a very important clinical issue. However, the development of such materials is hampered by a paucity of clinically relevant and well-described animal models for evaluating candidate materials. The objective of this study was to develop and implement an ovine model for evaluating potential screw augmentation materials. In brief, a mid-shaft tibial osteotomy was created and repaired using a single stainless steel locking plate (LCP). The most distal screw location was over-drilled and filled with either PMMA or a novel fiber reinforced calcium phosphate cement. The performance of the materials was evaluated using serial radiographs, gross inspection at necropsy, and micro-CT imaging.

Materials and Methods: Thirty-eight skeletal mature sheep were enrolled into the study using an unilateral tibial osteotomy model. A non-reduced mid-diaphyseal transverse tibial osteotomy was subsequently plated with a 4.5mm narrow stainless steel, seven hole locking plate (LCP). Plate holes 1-3 and 5 to 6 were filled with Locking Head Screws. The most distal hole (#7) was the region of interest and was filled with a non-locking cortex screw. A non-locking screw was used at this location to allow for relative plate/screwhead motion and to allow for potential screw migration. Twenty two sheep received either a 4.5mm or an 8mm over-drilled defect respectively which was subsequently filled with a fiber-reinforced calcium phosphate cement and allowed to cure. The resulting cement mantle was then drilled, tapped and filled with a bicortical 4.5mm bone screw. The identical procedure was used for the comparative study cohort using PMMA in the place of CaP. A bi-valve fiberglass splint was applied and animals were allowed to freely exercise immediately following recovery. Serial post-operative digital radiography allowed for in vivo monitoring and at 12 weeks animals were euthanized. Ex vivo analyses consisted of gross pathology and micro-CT imaging.

Results: Thirty-seven out of thirty-eight animals tolerated the procedure well and successfully completed the study. Two animals sustained a proximal incomplete, non-displaced fracture involving screw holes 1&2. Stall confinement allowed for the completion of the study. One animal sustained a severe proximal tibia fracture after a slip and fall on cement floor and was immediately euthanized. Analgesia was administered for three to four days peri-operatively. Animals were seen fully weight bearing within two weeks following surgery and remained comfortable throughout the study. Follow-up radiographs showed radiographic signs of progressive bone remodeling at the osteotomy site and at the CaP cement mantle interface. Necropsies were uneventful and no other pathologies were noted. The distal plate hole showed consistent evidence of dark colored wear debris associated with the surrounding fibrous tissue. There was also considerable evidence of contact wear as well as fretting corrosion at the augmented screw head/plate interface. Micro-CT imaging revealed consistent increases in the intracortical porosity of the bone proximal to the augmented screws, as seen in the images below. In accordance with Wolff’s law, the increases in porosity are evidence of load being transferred through the augmented materials, and the relative stress-shielding of the bone proximal to the augmented screw.

Discussion: The goal of translational research is to transform biologic knowledge into new treatments for human disease. Although preclinical models replicate some of the features of the disease process modeled, they invariably fail to reproduce the complexity of human illness, and by their very experimental nature, they are readily manipulated to maximize evidence of efficacy. The result is that successful translation from preclinical models to clinically effective therapy is uncommon, and that clinical trials are often undertaken without a comprehensive and realistic preclinical portfolio of studies to optimize their design. The current study is an attempt in creating a relevant surgical model that would help determine risks associated when combining biomaterials with modern fracture techniques and armamentaria to augment difficult bone repairs. Our data of clinical progress and ex vivo analyses are strong evidence that this uni-lateral tibial osteotomy model in sheep creates indeed a rigorous mechanical environment in which novel concepts of augmentative fracture techniques can be evaluated.

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