

# MECHANICAL PROPERTIES AND OSSEOINTEGRATION OF A LOAD BEARING BIOACTIVE BONE GRAFT

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## Introduction

Successful repair of bone defects remains a major concern to reconstructive surgeons, especially in the elderly patient population in whom the osteogenic repair and regeneration potential is compromised.<sup>1</sup> Such defects arise from trauma as well as pathologies associated with osteopenia, avascular necrosis, or tumor excision caused loss of osteochondral tissues. Present synthetic bone void fillers, made of porous hydroxyapatite (HAP)/  $\beta$ -tricalcium phosphate (TCP) composites, are not indicated for load bearing applications without supplemental fixation.<sup>2</sup> In this paper, we report on the mechanical properties and bone ingrowth characteristics of a new class of porous cortico-cancellous structured ceramics (CSC), made from high strength biocompatible ceramics, with osteoconductive properties stemming from a high surface area biomimetic cancellous scaffold with a bioactive coating. We hypothesize that 1) the mechanical properties of the cancellous ceramic and the CSC will match that of the human cancellous and cortico-cancellous bone, respectively, and 2) the bioactive coated CSC grafts will have greater ingrowth and bone penetrations compared to noncoated CSC grafts.

## Materials and Methods

### Mechanical Properties

The static (compression strength) and dynamic (fatigue) mechanical properties were determined per ASTM 2077-01 protocol on 20 x 20 x 18 mm high blocks of CSC grafts.

### Osseointegration

Six porous CSC grafts were fabricated into plugs of 11 mm dia x 20 mm long, 70% porous with 500 – 750  $\mu$ m pore size. Three of the porous grafts were coated with a bioactive coating of a composition similar to bone apatite in the Ca-P phase diagram. The implants were sterilized and used for implantation into skeletally mature sheep (average weight 150 lb) in a load bearing condyle defect model per an approved IACUC protocol. Both coated and uncoated plugs were moistened with saline solution and impacted with sheep bone marrow aspirate immediately prior to implantation. The coated CSC grafts were implanted in the left condyle and the uncoated plugs in the contralateral condyle into a precision hole defect drilled to the dimensions of the plugs. The sheep were allowed to ambulate freely and monitored carefully. Two weeks and four weeks before sacrifice, the sheep were injected with tetracycline for fluorochrome label analysis. The implants were left in-vivo for 12 weeks. The implant/knee distal medial condyles were removed, dehydrated and mounted in PMMA. Sections of the mounted implant were cut using a low speed bone saw and ground to 2 mm thick sections for SEM and microradiography, and 60-100  $\mu$ m thick sections for fluorochrome label analysis and 30  $\mu$ m thick sections for histomorphometry. Bone apposition and formation indices were measured using previously published methods<sup>3,4,5</sup>. Bone formation and apposition index (ABI) was determined along the implant/host bone interface as well as through the cross-section. Regional analysis was conducted to compare and contrast ingrowth between the medial and lateral aspects of the graft materials.

## Results and Discussion

### Mechanical Properties

Static compressive load to failure of the CSC graft structures was found to vary as a function of porosity and pore size, and ranged from 3500 N (~8.5 MPa) for 70% porous bodies to 66,000 N (~160 MPa) for <10 % porous bodies. Dynamic testing on graded porosity CSC structures showed that cyclic loads of 3200 N could be held for up to 2 million cycles. Modulus of Elasticity for the cancellous structured CSC graft varied from 300 – 650 MPa depending on porosity. For the graded porosity CSC grafts (10% porosity, 10  $\mu$ m size, 1 - 4 mm thick cortical shell with 70% open porosity cancellous core) the modulus varied from 11 to 115 GPa depending on the thickness of the cortical shell. Note that the modulus of human cancellous bone is 250 MPa and cortical bone is 17 GPa. The close material property match between the CSC structures and natural bone should aid in minimizing stress shielding.

### Osseointegration

Histologic evaluation of coated ceramic graft revealed bone formation both at the ceramic (C)/host bone (H) interface and within the

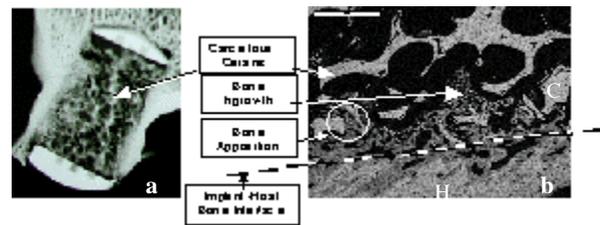


Figure 1: a) Contact radiograph and b) BSE

pores of the scaffold (Figure 1). Figure 1a demonstrates excellent bone apposition and penetration. Figure 1b demonstrates new bone formation (dark contrast) and penetration at the host bone/graft interface. Complete interconnection of the pores allowed osteoblastic presence to be observed within the graft. A high degree of vascular penetration was also observed, consistent with bone formation. After 12 weeks in-vivo, new bone growth was noted penetrating to 4 mm radial depth of the graft (Figure 1b). Coated grafts had higher bone ingrowth (Total amount = 25% in coated vs 20% in uncoated) and a higher ABI (86% for coated vs 72% for uncoated). Medial aspect showed twice the bone ingrowth than the lateral aspect in both type of grafts (Figure 2). Tetracycline double label trabeculae were observed with the coated grafts indicating viability of the ingrown bone. As compared to the uncoated grafts, significantly less fibrous encapsulation was noted in coated grafts. Macrophage and giant cell response was limited to the uncoated grafts only.

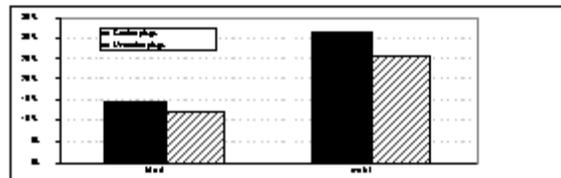


Figure 2: Bone formation in Coated and Uncoated CSC grafts

Bone formation typically occurs near, but not on the surface of biocompatible / inert implants such as Ti or alumina ceramics. In contrast, the coated CSC graft showed bone formation typical of bioactive HAP/TCP ceramics<sup>6</sup>. This bioactivity, complemented by the high strength structure, can provide good osseointegration with host bone while allowing immediate load bearing. The CSC grafts retain the bioactivity of HAP/TCP materials while providing for load bearing and stability. Additionally, the CSCs have a hybrid graded porosity architecture similar to natural bone with a peripheral cortical shell for load bearing, and a high surface area bioactive core for vascularization and rapid bone remodeling and implant integration.

The data supported the hypothesis that the coated grafts would have more ingrowth than uncoated grafts in both the medial and lateral aspects of the grafts. These results are encouraging and point the way to design of load bearing bioactive bone graft materials. The data support continued investigation of these bioactive load bearing grafts. The measured osseointegration, high bone formation and bioactivity suggest that these grafts may have the potential to repair large bone defects. The material property match to bone permits design of immediate load bearing grafts with similar mechanical properties which may encourage skeletal incorporation while preventing stress shielding.

## References

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