

Fracture behavior of a composite of bone and calcium sulfate/hydroxyapatite

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Summary

The mechanical and structural properties of bone augmented with a calcium sulfate/hydroxyapatite (CaS/HA) biomaterial were evaluated. Plugs of human trabecular bone with and without addition of CaS/HA were imaged using synchrotron X-ray tomography. Loading was applied *in situ* during tomography. Mechanical and structural parameters were compared, and the crack propagation was followed. Adding CaS/HA increased the peak force and absorbed energy due to formation of microcracks in CaS/HA.

Introduction

New tools for reinforcing bone or fixation of orthopaedic implants are being investigated [1]. Calcium sulfate/hydroxyapatite (CaS/HA) based biomaterials are an attractive alternative owing to their injectability, osteoconductivity and mechanical properties. Despite the wide variety of applications the biomaterial is used in, the mechanical behavior of the composite of CaS/HA and bone on a microscale is still largely unknown. Current developments in imaging techniques allow for better investigation of the mechanics of bone-biomaterial interactions at the microscale. The aim of this study was to determine if and how bone augmentation with CaS/HA alters the fracture behavior of bone.

Methods

Eleven cylindrical plugs (\varnothing 6 mm, H 7.5 mm) were drilled from two human femoral heads (one male, one female). Bone marrow was removed from all plugs and CaS/HA was introduced into the 5 plugs by manual tapping. 1 plug of only CaS/HA was prepared. The plugs were imaged with synchrotron X-ray tomography (TOMCAT, PSI, Switzerland) (energy: 30 keV; scanning speed: \sim 2 min/scan; isotropic voxel size: 2.75 μ m). Loading was performed *in situ* (displacement rate: 0.9 mm/min) and tomographs were taken at increments of 0.15 mm. Images of unloaded samples were used to obtain bone volume/total volume (BV/TV), CaS/HA volume/total volume (CV/TV), and trabecular thickness (Tb.Th). From the load curves, peak force (Fmax), stiffness (k) and work (W) were determined. One sample from each group was used for further image analysis, by selecting a region of interest where damage occurred. At each loadstep, cracks in this region were segmented. For the composite sample, a distinction was made between cracking in CaS/HA, cracking in bone and separation of the bone-CaS/HA interface.

Results and Discussion

The CaS/HA-only sample had the highest peak force, stiffness and work (Table 1). The resulting fracture for this sample was

brittle (Figure 1). The composite sample showed the most plastic behavior (Figure 1). During early loading, the CaS/HA matrix developed small cracks and started to separate from the bone at the interface. However, the force kept increasing and at the last loadstep the bone was still mostly intact. The bone-only sample showed large deformations before failing at a relatively low peak force.

Reinforcing bone with CaS/HA results in an increased peak force, stiffness, and work. Most interesting is the fracture behavior leading to the increase in absorbed energy, which is caused by the large amounts of micro-cracks that are formed in the CaS/HA before global failure.

Table 1: Median mechanical and structural properties.

	Bone	Composite	CaS/HA
Fmax [N]	56	265	479
k [N/mm]	122	497	792
W [Nmm]	34	91	131
BV/TV	0.21	0.21	-
CV/TV	-	0.44	0.99
Tb.Th [μ m]	165	175	-

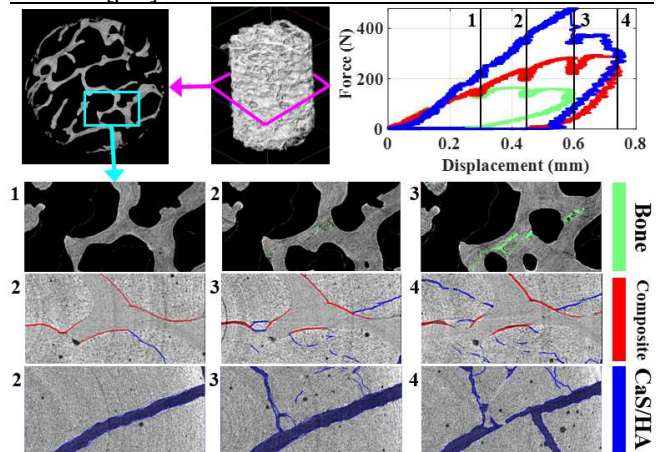


Figure 1: Force-displacement curves of the three samples and the crack evolution over the last three load steps (numbered). Cracks' localizations are colored blue (CaS/HA), green (bone), and red (bone-CaS/HA separation).

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References

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