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Short communication

The effects of bone and pore volume fraction on the mechanical properties of PMMA/bone biopsies extracted from augmented vertebrae

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ABSTRACT

Vertebroplasty forms a porous PMMA/bone composite which was shown to be weaker and less stiff than pure PMMA. It is not known what determines the mechanical properties of such composites in detail. This study investigated the effects of bone volume fraction (BV/TV), cement porosity (PV/(TV-BV), PV…pore volume) and cement stiffness. Nine human vertebral bodies were augmented with either standard or low-modulus PMMA cement and scanned with a HR-pQCT system before and after augmentation. Fourteen cylindrical PMMA/bone biopsies were extracted from the augmented region, scanned with a micro-CT system and tested in compression until failure. Micro-finite element (FE) models of the complete biopsies, of the trabecular bone alone as well as of the porous cement alone were generated from CT images to gain more insight into the role of bone and pores. PV/(TV–BV) and experimental moduli of standard/low-modulus cement (R^2 = 0.91/0.98) as well as PV/(TV–BV) and yield stresses (R^2 = 0.92/0.83) were highly correlated. No correlation between BV/TV (ranging from 0.057 to 0.138) and elastic moduli was observed ($R^2 < 0.05$). Interestingly, the micro-FE models of the porous cement alone reproduced the experimental elastic moduli of the standard/low-modulus cement biopsies (R^2 = 0.75/0.76) more accurately than the models with bone (R^2 = 0.58/0.31). In conclusion, the mechanical properties of the biopsies were mainly determined by the cement porosity and the cement material properties. The study showed that bone tissue inside the biopsies was mechanically "switched off" such that load was carried essentially by the porous PMMA.

1. Introduction

Poly-methyl-methacrylate (PMMA) is the most commonly used augmentation material in vertebroplasty. During the infiltration of vertebral bone a porous PMMA/bone composite is formed, but only one study so far (Race et al., 2007) investigated the material properties of such composites extracted after vertebroplasty. In other studies (Baroud et al., 2003; Boger et al., 2008), PMMA was injected into trabecular bone biopsies, which may lead to different cement porosities compared with vertebral augmentation. The mechanical behaviour of such composites is important for understanding biomechanical changes in the spine after augmentation and, therefore, for the development of new cement materials such as low-modulus cements (Boger et al., 2009).

The mechanical properties of PMMA/bone composites were significantly lower compared to pure cement, but significantly higher than for native bone (Baroud et al., 2003; Boger et al., 2008). Surprisingly, bone volume fraction (BV/TV) had no influence on the material properties of PMMA/bone biopsies (Race et al., 2007). It is not clear why bone tissue, which is 5-times stiffer than PMMA (Kühn, 2000; Zysset et al., 1999), does not reinforce PMMA and what determines the composites's mechanical properties. Possible influences are the cement porosity (PV/(TV–BV)), the PMMA/bone interface or bone damage during augmentation.

The contribution of bone, cement and pores to overall mechanical properties can be investigated by using compression experiments together with micro-CT images. Numerical experiments such as micro-FE models (Van Rietbergen et al., 1995; Guldberg et al., 1998) can give more insight into the load sharing, especially if separate analysis of trabecular bone and porous cement are done. In that sense, our objectives were to investigate the effects of BV/TV, PV/(TV–BV) and cement stiffness on the mechanical properties of PMMA/bone biopsies from augmented vertebrae by comparing experimental and numerical results.

2. Materials

2.1. Specimen preparation

Nine human vertebral bodies (T9-L4) were obtained from three female and four male donors (age 49–82). The cortical endplates were removed using a diamond-coated band saw. The vertebral bodies were augmented with either a

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