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Development of a bovine collagen–apatitic calcium phosphate cement for potential fracture treatment through vertebroplasty

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ABSTRACT

The aim of this study was to examine the potential of incorporating bovine fibres as a means of reinforcing a typically brittle apatite calcium phosphate cement for vertebroplasty. Type I collagen derived from bovine Achilles tendon was ground cryogenically to produce an average fibre length of 0.96 ± 0.55 mm and manually mixed into the powder phase of an apatite-based cement at 1, 3 or 5 wt.%. Fibre addition of up to 5 wt.% had a significant effect ($P \leqslant 0.001$) on the fracture toughness, which was increased by 172%. Adding ⩽1 wt.% bovine collagen fibres did not compromise the compressive properties significantly, however, a decrease of 39–53% was demonstrated at ⩾3 wt.% fibre loading. Adding bovine collagen to the calcium phosphate cement reduced the initial and final setting times to satisfy the clinical requirements stated for vertebroplasty. The cement viscosity increased in a linear manner ($R^2 = 0.975$) with increased loading of collagen fibres, such that the injectability was found to be reduced by 83% at 5 wt.% collagen loading. This study suggests for the first time the potential application of a collagen-reinforced calcium phosphate cement as a viable option in the treatment of vertebral fractures, however, issues surrounding efficacious cement delivery need to be addressed.

1. Introduction

Fractures of the neck and spine account for over 35,000 emergency admissions to hospital and approximately 450,000 bed-days per year in England alone [1]. The most common types of fractures are compression and traumatic burst fractures of the vertebrae, which constitute approximately 51% [2] and 15% [2,3] of all spinal fractures, respectively. Three approaches are typically available for the treatment of vertebral fractures: (1) non-surgical, conservative treatments (e.g. bed rest and back bracing) [4,5]; (2) surgical intervention for the placement of internal fixation devices [6,7]; (3) minimally invasive procedures such as percutaneous vertebroplasty (PVP) [8]. However, for a variety of reasons conservative treatments and standard surgical interventions are being superseded by minimally invasive procedures such as PVP [6].

Commercial biomaterials utilized for PVP include polymethyl methacrylate (PMMA), calcium phosphate and composite-based cements. The current material of choice for PVP applications is PMMA bone cement. However, the scientific and clinical literature have identified major deficiencies with PMMA bone cement, including an inability to chemically bond with bone [9], a mismatch in biomechanical properties [10] and thermal and chemical necrosis of tissue due to a highly exothermic setting reaction [11]. Many opportunities remain to enhance the biocompatibility, suboptimal fatigue performance and limited bone regeneration capabilities of composite-based cements. Consequently, there has been an increase in the use of calcium phosphate cement (CPC) systems for PVP applications, as they demonstrate significant advantages over PMMA and composite-based cements, including excellent biocompatibility and resorbability, thereby encouraging the growth of new bone [12]. The latter advantage represents an attractive proposition for patients suffering from traumatic vertebral burst fractures as such patients are typically younger and are more likely to have the capacity for bone remodelling at the fracture site, therefore bioactive or resorbable CPC systems may be of benefit [13–15].

For a CPC to be wholly successful as a bone substitute material in PVP applications a number of properties are essential. The cement must demonstrate a compressive strength of 10–30 MPa and compressive modulus of 50–800 MPa for this load-bearing application [16,17]. The setting times must allow both an acceptable working period for injection yet permit the surgeon to close the wound within a reasonable period. Clinical requirements for setting times have been defined whereby the initial setting time (t_i) must be between 3 and 8 min and the final setting time (t_f)

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