CHARACTERIZATION OF A NEW BIOACTIVE BONE CEMENT - A COMPARISON WITH PMMA.

Introduction: Polymethylmethacrylate (PMMA) bone cements present various problems with respect to their biocompatibility and stability. Recently, interest has been shown in the use of Glass-ionomer cement (GIC) as a bone cement in orthopaedic surgery due to reported bioactive behavior and low exotherm in the field of dentistry. In this study the mechanical properties of compressive strength, flexural strength, and fracture toughness for two traditional GICs, one resin-modified GIC (experimental bone cement) and two Polymethylmethacrylate (PMMA) cement systems have been evaluated. To determine the suitability of a GIC system for use in the clinical orthopaedic setting, the additional characteristics of setting exotherm and setting time have also been evaluated. The characterization of these two vastly different cement systems has raised some concern as to the applicability of using the current orthopaedic standards for the testing of GIC systems. In particular, issues relating to the strain rate dependence of PMMA cement and the exothermic basis for determining setting time are not applicable, as these factors are not characteristic of GIC systems. The bioactive benefits of GICs are well established but the evaluation of their mechanical properties has received limited attention. If these materials are to present themselves as a bone cement replacement in orthopaedic surgery, then as a preliminary stage, their material properties must be determined.

Materials and Methods: Simplex bone cement (Howmedica) and CMW3 bone cement (DePuy) have been assessed in this study. These two materials are representative of current PMMA bone cements used in orthopaedic surgery. The 'traditional' GICs that have been investigated are Fuji IX and Fuji II (GC Corporation, Tokyo, Japan). Both are current dental cements. One resin-modified (experimental GIC bone cement), incorporating a 10% (by weight) hydroxyethyl-methacrylate (HEMA) component has been included in this study. This formulation has been included in the study with the expectation that its mechanical behavior will be characteristic of both the brittle GIC systems and the elastic/plastic PMMA system. The flexural strength of cements were measured using beam shaped specimens 20mm x 5mm x 1.6mm. The cured cement was removed from the mould and stored in distilled water at 37°C for 24 hours before testing. Compressive strength bone cement specimens were prepared in accordance with International Standard 5833 and International Standard 9917. International Standard 9917 was specifically drafted for the dental use of GICs whereas International Standard 9917 was specifically drafted for the orthopaedic use of PMMA cements. The fundamental differences between the two standards are the required specimen dimension and the rate of mechanical testing. Specimens prepared for ISO5833 and ISO9917 were tested at crosshead speeds of 20mm/min and 1mm/min respectively i.e. four (4) strain rates because of different specimen dimensions. The fracture toughnesses for GIC and acrylic cements have been determined according to ASTM E399-83. The standard specimen is a single edge notched beam (SENB) loaded in three-point bending.

Results: The tests results indicate that traditional GICs (Fuji II and Fuji IX) display on average higher compressive strength, lower bending strengths, lower fracture toughness and higher modulus when compared to the PMMA bone cements tested. Results for the resin-modified GIC (experimental bone cement) show that the addition of the resin component to the traditional GIC will increase the flexural strength, reduce the compressive strength and increase the fracture toughness compared to the traditional GICs tested. The average compressive strength for the traditional GICs tested (Fuji II and Fuji IX) was 168.7 MPa compared to 72.1 MPa for PMMA cements at a strain rate of 0.167/min. The compressive strength of resin-modified GIC was 106.1 MPa (0.167/min). The traditional GIC flexural strength was on average less than half the average PMMA cement strength, being 33.6 MPa and 68.6 MPa respectively. The addition of the resin component led to an increase in the flexural strength to a value of 59.3 MPa - approaching the strength of the acrylic cements tested (68.6 MPa). The fracture toughness of PMMA is 1.65 MPa.m^{1/2} compared to traditional GIC at 0.63 MPa.m^{1/2}, however this is still much higher than most phosphate cement/bone replacement materials. The addition of the HEMA component has resulted in an increase in fracture toughness to a level of 0.91 MPa.m^{1/2}. This study has determined that GICs, in larger volumes than specified, can generate substantial exotherm reaction temperatures. The average exothermic temperature measured for the traditional GICs was 43.4°C. Whilst the recorded temperatures may be considerably lower than those for the PMMAs tested (average 62°C) it may indicate that GICs, in larger volumes, could possibly damage bone tissue.

Discussion: Static mechanical testing is widely used to initially characterize and screen potential bone cements. This study has highlighted some of the problems of testing to a standard designed for a particular material composition. The problem lies in trying to characterize the properties of two very different cement systems for the same clinical application. The chemical composition of both systems make them ultimately suited to the application but the various methods to assess them are distinctly separate. It has been determined that setting and working time should be determined in a manner that relates to handling characteristics. In addition, it has been shown that GICs are unique materials that show potential to be successful bone cement. In contrast to acrylic cements, the setting reaction of traditional GICs does not generate considerable heat, so the thermal damage to tissues at the implant site will be minimal. However, as resin is added to the system to improve mechanical properties this exotherm is increased substantially. The aim, therefore, is to improve the toughness and strength of traditional GICs without a trade-off in the intrinsic properties of bioactivity and low-exotherm. Current results demonstrate that the addition of a resin component to a purely traditional acid-base glass can improve the flexural strength and toughness for a small reduction in compressive strength. The introduction of the resin has the ability to modify a purely brittle GIC with a measurable degree of ductility.

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