QUANTIFICATION OF THE VARIABILITY IN FATIGUE LIFE OF PMMA BONE CEMENT IN RELATION TO MIXING TECHNIQUE

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INTRODUCTION Polymethylmethacrylate (PMMA) bone cement is used to fixate many orthopedic implants. However, it is a brittle material, prone to damage accumulation leading to cement cracking and prosthesis loosening [1]. Experimental testing has shown that its fatigue strength is quite variable, as evidenced in SN (stress vs. number of cycles to failure) data. In this study, the variability of fatigue strength is quantified as a function of stress level and mixing technique.

MATERIALS AND METHODS Vacuum-mixed and hand-mixed bone cement specimens were prepared using Cemex© Rx (Tecres, Verona, Italy) low viscosity acrylic bone cement. The vacuum mixed set was prepared using the Optivac system (Scandimed A.B., Sjöbo, Sweden), while a control set of specimens were prepared using conventional hand mixing. All specimens were prepared at 22°C (±1°C). The specimens were allowed to cure in a polyethylene mould for 24hrs. The specimens produced had rectangular cross-sections (3.5mm in thickness) and gently tapering lengths. The specimens were stored in a water bath at 37ºC for a minimum of 2 weeks prior to testing. Uniaxial fatigue tests were performed in pure tension at an R-ratio of zero. During the tests the specimens were submerged in a water bath and maintained at 37ºC. Fatigue tests were conducted at four stress levels and 8 tests were conducted at each stress level for each mixing technique. The four stress levels were 13 MPa, 17 MPa, 21 MPa, and 25 MPa. The fatigue data was analyzed at each stress level using a Weibull model.

Fracture surface analysis was conducted using a Scanning Electron Microscope (Hitachi Ltd. Model S-3500N). The specimens were sectioned one centimeter from the fracture surface and were cleaned in an ultrasonic bath using a non-ferrous ultrasonic cleaner (Metprep, Coventry, UK).

RESULTS The stress vs. number of cycles to failure data for both mixing techniques are presented in Fig 1. The correlation coefficients are 0.76 for the vacuum-mixed and 0.89 for the hand-mixed.

DISCUSSION The cumulative distributions (Fig. 2) allow the two data sets to be compared. Vacuum mixed cement has a greater mean fatigue strength than the hand-mixed cement; however there is a greater variability in the fatigue life of the vacuum-mixed cement. It could be argued that high reliability is required for bone cement rather than high strength per se – if so then hand-mixing would have advantages in high stress situations as it is more likely to survive a greater number of cycles; e.g. at 25 MPa, if a 95% probability of survival is required, it would be best to use hand-mixed cement, see Fig. 2. The hand mixed cement produces fracture surfaces in which the fatigue crack initiation site is located around a number of pores. This accounts for the lower strength of the hand-mixed cement since pore interaction causes stress concentrations. On the other hand, the vacuum-mixed cement has much fewer pores and no pore interaction occurs. The result is a higher mean strength for vacuum-mixed cement. Occasionally, however, pores do appear in the vacuum-mixed cement, and when they do they are large – these occasional large pores are directly responsible for the variability of strength in vacuum-mixed cement.

Many vacuum-mixing systems seem prone to pore formation of this kind [1]. This work has shown that pores cause vacuum-mixed cement to be less reliable at high stress.


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