Microtomographic assessment of bone cement

INTRODUCTION

Aseptic loosening of cemented hip components is the most common reason for revision surgery and may be due to failure of the cement mantle. Pores in the mantle are thought to be detrimental to the construct and much research has been directed at assessing and reducing porosity. In vitro measurement of porosity is difficult and imprecise and volumetric quantification of porosity relies on extrapolation of two dimensional data rather than direct measurement. Our aim was to investigate the relationship between cement viscosity, density and porosity, using a novel microtomographic (micro-CT) technique that allows quantification of pore volume in bone cement.

METHODS

Bone cements of differing viscosities (CMW 1, high viscosity, De Puy International, Blackpool, England and Simplex P, medium viscosity, Stryker Howmedica, Limerick, Ireland) were mechanically mixed in a standardised fashion, with and without the addition of vacuum during the mix, and fashioned into 25 pegs per group according to ASTM F451-99a. The densities for each peg were calculated using Archimedes principle and three random samples from each group were obtained at a magnification of 20× with a slice thickness of 13.67 μm and in-house written software (Matlab, Mathworks Inc., MA) was used to individually identify each pore and calculate pore volume and number in the reconstructed images. Results were analysed and compared with the two sample t test assuming unequal variances. Significance was set at P<0.05.

RESULTS

Mean total pore volume (MTPV) for Simplex P with vacuum (Simplex vac) was 12.35 mm³ (3.64% of total peg volume) and 13.88 mm³ (4.09% of total peg volume) for Simplex without vacuum (Simplex no vac). This difference was not statistically significant but suggested a trend towards lower MTPV with vacuum. MTPV for CMW 1 with vacuum (CMW vac) was 7.91 mm³ (2.33% of total peg volume). The difference between CMW vac and Simplex vac was statistically significant (P=0.005).

Mean pore volume (mean volume per individual pore) was 0.15 mm³, 0.13 mm³, and 0.06 mm³ for Simplex vac, Simplex no vac and CMW vac respectively. These differences did not reach statistical significance due to the large range in pore size (0.04 – 0.22 mm³). There was a trend towards higher density in Simplex vac (1.19 g/cm³) vs. no vac (1.18 g/cm³) which did not reach statistical significance in the scanned samples. However, analysis of the entire Simplex group (25 samples each) revealed a significantly higher density in the batch with vacuum (mean 1.189 g/cm³ vs. 1.185 g/cm³, P=0.00002) than without vacuum. There was a significant difference between Simplex vac (1.189 g/cm³) and CMW vac (1.207 g/cm³, P=0.008). Qualitative and quantitative assessment demonstrated a very wide range of pore numbers, size (volume), distribution and shape.

DISCUSSION

The trend for reduction in MTPV for Simplex vac is in keeping with published data that vacuum applied during mixing reduces porosity and this is supported by the increase in density of this group. Given that we attempted to control for variability in batch, manufacture, temperature, mixing technique, application and constraint during the curing process, it seems likely that the lower MTPV observed for CMW 1 is related to its viscosity and therefore, indirectly, to its constituents. Different constituents to Simplex P could also explain the higher density of CMW 1, which was shown in a separate analysis of 25 samples per group to be denser than Simplex without as well as with vacuum, indicating that the reduction in porosity was not the sole determinant of measured density. Although Simplex was qualitatively less viscous during mixing than CMW, monomer content is likely to be a greater contributor to overall porosity than entrained air. The contribution of porosity towards ultimate failure of the cement mantle in vivo is controversial, although the balance of opinion suggests that reducing porosity is a favourable objective. Another possibility is that distribution of pores may affect the cement mantle. Although we did not quantify pore distribution, the use of Micro-CT makes this theoretically possible as well as providing a method to qualitatively assess pore architecture in three dimensions.

CONCLUSIONS

Viscosity is likely to be a determining factor of porosity in the cured cement. The use of Micro-CT in vitro allows accurate three dimensional qualitative and quantitative assessment of pore distribution and architecture. In combination with other techniques, this may shed light on the clinical significance of porosity in cemented hip replacement.