A comparison of the shrinkage of commercial bone cements when mixed under vacuum

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The outcome of a cemented hip arthroplasty is partly dependent on the type of cement which is used. The production of an interface gap between the stem and the cement mantle as a result of shrinkage of the cement, may be a factor involved. Palacos R, Palacos LV (both with gentamicin), CMW 1, CMW 2, CMW Endurance (CMWE) and Simplex were prepared under vacuum and allowed to cure overnight in similar cylinders. The next day this volume was determined by the displacement of water. Shrinkage varied between 3.82% and 7.08% with CMWE having the lowest and Palacos LV the highest. This could be a factor to consider when choosing a cement for a shape-closed stem.

The variation in outcome of cemented hip arthroplasties is dependent on several factors such as the design of the stem, the material, the cementing technique and the choice of cement used. Recently, greater emphasis has been placed on the importance of the cement-stem interface in aseptic loosening.¹ There is a greater understanding of the relationship between cementing technique and design of the stem, as described by Huiskes, Verdonchot and Nivbrant.² The latter authors borrowed concepts from engineering to categorise cemented stems according to the method by which they derive their stability. A shape-closed stem achieves this by its matching of shape with the femur but a force-closed stem is designed to subside within the cement mantle.²

With shape-closed stems, gaps at the cement-stem interface are thought to be a factor in the initiation of early loosening. When present at insertion such gaps may initiate debonding and it is thought that some debonded regions will expand until the whole interface is debonded.^{1,3} Debonding with a non-polished stem also leads to abrasion and the formation of debris at the cement-stem interface.^{1,3} In a

model of a total hip arthroplasty, Wang, Franzen and Lidgren⁴ quantified the interface gap as being 10% to 15% of the whole interface area 12 hours after insertion of the stem.

Most of the interface gaps appear as a result of linear shrinkage of the cement around a stem.^{4,6} Cement shrinkage can also initiate damage within the cement mantle as a result of the residual stress occurring during curing.^{7,8}

Although shrinkage of cement has been quantified in a few isolated commercial brands and its dynamic volume changes investigated,^{6,9} there is to date, to our knowledge, no published study of a direct comparison of cements. Our aim therefore was to investigate any difference in shrinkage, under the same standardised conditions of a range of polymethylmethacrylate cements in common use.

Materials and Methods

The cements studied are shown in Table I. All the experiments were done in the same laboratory under standardised conditions of temperature (mean 20.8°C; SD 0.4; 20.0°C to 21.0°C) and humidity (mean 35.2%; SD 1.1; 34% to 36%). The cements were stored for at least 12

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Table I. Details of the cements studied

Cement	Manufacturer	Comments
Palacos R (with gentamicin)	Schering-Plough Ltd (Welwyn Garden City, UK)	
Palacos LV (with gentamicin)	Schering-Plough Ltd	
CMW 1 Radio-opaque	Depuy International Ltd (Leeds, UK)	
CMW Endurance	Depuy International Ltd	Low viscosity, also known as Smartset MV
CMW 2	Depuy International Ltd	
Simplex	Stryker-Howmedica Osteonics (Cork, Ireland)	Normally reserved for hand mixing

Table II. Details of shrinkage (% initial volume; SD) in all the cements studied

Cement	Shrinkage
CMW Endurance	3.82 (0.70)
CMW 1	5.05 (0.50)
CMW 2	6.05 (0.56)
Simplex	5.93 (0.36)
Palacos R	6.20 (0.36)
Palacos LV	7.08 (0.47)

hours in the laboratory before being used. For each mixing, one portion (40 g) of cement was used. Mixing was performed according to the manufacturers' recommendations, except for CMW 2 which is recommended for hand mixing only. However, since vacuum suction has an influence on shrinkage,^{6,10} CMW 2 was prepared in the same manner as the other cements for the purpose of our comparative study. For every cement, a minimum of six separate mixes was done. The mixing device used was a Summit Medical HiVac Syringe (Summit Medical, Bourton on the Water, Gloucestershire, UK) at a vacuum pressure of 550 mm Hg. The cement was injected into translucent polypropylene cylinders (Fisher Scientific, Loughborough, Leicestershire, UK) which had a volume of 35 ml.

The cement was then allowed to cure overnight at a temperature of 37°C. Although the initial temperature of the femur just before injection of cement is lower than body temperature as a result of washing,¹⁰ the temperature inside the femur increases thereafter. In our study the temperature chosen for cement curing was body temperature. The next day, the plastic cylinders were sawn off at their lower portions and the cement blocks were gently punched out of the mould. This was a relatively easy task as a result of the overall volumetric shrinkage.

The volume of cement was determined by measuring the volume it occupied in water. The mass of water displaced, and hence the volume, was determined by weighing.

Statistical analysis. The means and SDs were calculated. A one-way analysis of variance (ANOVA) was used to assess whether there was any difference between the cements. This was followed by the *post-hoc* Gabriel's test for multiple comparisons. Analysis of data was performed using SPSS for Windows version 12.01 (SPSS Inc, Chicago, Illinois).

Results

Table II shows the results of shrinkage of the different brands of cement which were tested. Shrinkage varied between 3.82% and 7.08%. CMWE had the lowest while Palacos LV had the highest shrinkage. Both are low-viscosity cements. There was a statistically significant difference in shrinkage between the different cements tested. A one-way ANOVA test showed the F ratio to be 15.7 ($p = 0.001$). Gabriel's test was used to compare the shrinkage between all the groups and the results are shown in Table III.

Discussion

Our study has shown that, under standardised conditions, the shrinkage of polymethylmethacrylate cement is different in the different commercial preparations in current use. The figures for shrinkage in our study are in the range reported by previous studies.^{6,9} Theoretical calculations predicted that the molecular rearrangement occurring during polymerisation would produce a volumetric shrinkage of 7.6%.¹¹

Espehaug et al¹² reported the differences in the long-term outcome of a shape-closed stem, the Charnley stem, with different types of bone cement. It is possible that this difference in outcome was partly due to the difference in shrinkage reported in this study since those with high shrinkage may have poorer outcomes. However, it is difficult to correlate this material property with the long-term outcome because of the changes in formation of the cement over time and the relatively recent introduction of vacuum mixing⁹ which is known to increase shrinkage.^{6,10,13} Vacuum mixing also affects other biomechanical properties of bone cement in a dose-dependent fashion. The porosity of bone cement when mixed is inversely proportional to the vacuum pressure.^{13,14} However, at a given vacuum pressure, any further decrease in porosity is likely to be offset by the production of cracks in the cement mantle.¹³

Polymer manufacturing techniques are available to eliminate polymerisation-induced shrinkage by controlled void formation or by including low-shrinkage polymer additives. However, attempts to change cement formulation, can be fraught with problems, as exemplified by the Bone-loc cement.^{15,16}

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Table III. Gabriel's test of comparison of shrinkage when the difference between the groups was statistically significant, the p value is given; $p < 0.05$

Cement	CMW E	CMW 1	CMW 2	Palacos R	Simplex	Palacos LV
CMW E			0.002	0.001	0.005	0.001
CMW 1				0.034		0.001
CMW 2	0.002					
Palacos R	0.001	0.034				
Simplex	0.005					0.029
Palacos LV	0.001	0.001			0.029	

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