Fatigue properties of bone cement

Comparison of mixing techniques

Ulf Lindén

A four-point bending test was made on 54 specimens of CMW, Simplex P, and Zimmer LVC bone cements. The samples were cyclically loaded at a stress level of 20 MPa at a frequency of 4 Hz. The different cements were mixed either by hand or mechanically with or without a 0.15-bar vacuum. Mechanical mixing in a vacuum improved all three cements, and was the best of all the tested mixing techniques. Simplex P showed the best fatigue properties regardless of mixing technique.

Centrifugation and vacuum mixing reduce porosity in bone cement (Burke et al. 1984, Lidgren et al. 1987). Mechanical mixing reduces the porosity compared with the conventional manual technique, which results in cement of an unpredictable quality (Lindén 1988 a, b).

The centrifugation and vacuum techniques are applied to manual mixing. I have examined the fatigue properties of three different cements mixed manually or mechanically with or without a vacuum.

Materials and methods

Bone cements of three different viscosities were used. CMW (CMW Laboratories Ltd, Blackpool, UK) was regarded as a high viscosity cement, Simplex P (Howmedica International Inc., Northill Plastics Division, London, UK) as a medium viscosity cement, and Zimmer LVC (Zimmer, Warsaw, Indiana, USA) as a low viscosity cement.

Mixing technique. Manual mixing was done according to the manufacturers' instructions.

Mechanical mixing was done by a device consisting of a motor coupled to an eccentric to provide vibration/shaking. A holder for the cement syringe was fixed to the eccentric (Lindén 1988 a). The mixing time was 2 min and the speed 500 rpm as determined in earlier work from this laboratory and previously described.

Mechanical mixing in a vacuum was done with the same device as described above. During the mixing, the air was evacuated by a vacuum pump (Piab M-32, PIAB, Åkersberga, Sweden) and a vacuum of 0.15 bars was applied. The cement was mixed in a cement syringe (Disposable Insert Cat. no. 0-183-0010, Howmedica Internat. Inc., Kiel, West Germany).

Preparation of specimens. After mixing, the cement mass was injected from the syringe into an aluminum mould to form 10 x 15 x 100-mm beams. These specimens were allowed to cure for 1 week. Before testing, they were polished and inspected. One specimen each of CMW and Zimmer LVC were rejected because they showed surface defects; a notch in the surface of the tested specimen may act as a stress raiser (Freitag and Cannon 1977). Six specimens for each mixing condition were used.

Fatigue testing. A four-point bending test with a sinusoidal cyclic loading program from zero to maximum was performed. To find the apparent endurance level (endurance limit), which was the level at which further cycling did not cause failure (10^5 cycles), three different stress levels (15, 20, 25 MPa) were used. Thereafter, the final fatigue testing was made at a stress level of 20 MPa, the apparent endurance level, and at a frequency of 4 Hz. This rate of loading did not increase the internal temperature of the specimen. The support spans were 80 and 40 mm, respectively. The testing took place in a room with constant + 20 °C and 60 percent relative humidity (Figure 1).

The Mann-Whitney *U*-test was used.

Department of Orthopedics, University Hospital, S-581 85 Linköping, Sweden

Results

CMW was improved by mechanical mixing in a vacuum compared with manual ($P < 0.01$) and mechanical mixing ($P < 0.01$). No difference emerged between the latter.

Simplex P. Mechanical mixing of Simplex P did not improve its fatigue properties when compared with the manual technique, but mechanical mixing in a vacuum improved the cement ($P < 0.05$).

Zimmer LVC. Manual and mechanical mixing of Zimmer LVC resulted in a cement of inferior fatigue properties compared with mechanical mixing in a vacuum ($P < 0.01$).

Simplex P showed the best fatigue properties of the examined cements regardless of mixing technique (Table 1).

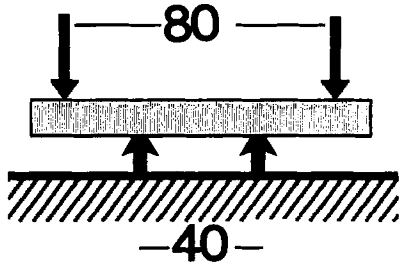

Figure 1. The set-up in the 4-point bending test. The spans (mm) for load and support are marked.

Discussion

A reduction of the porosity improves the mechanical quality of bone cement. Centrifugation and vacuum mixing techniques reduce the porosity (Burke et al. 1984, Lidgren et al. 1987, Wixson et al. 1987, Davies et al. 1987.

The results in the present study accord with those of Wixson et al. (1987) and Lidgren et al. (1987) when comparing vacuum mixing with a manual technique.

Rimnac et al. (1986) found no difference between centrifuged and uncentrifuged specimens of different bone cements, but found that cement of a higher molecular weight was more resistant to crack propagation than low molecular weight cement.

Centrifugation as a mixing technique has been questioned as regards the homogenous distribution of the pores and particles (Skinner and Murray 1985). A heterogeneous distribution of particles and pores may contribute to uneven polymerization with mechanical properties varying from one part of the cement mass to the other.

In the present tests, polished specimens without surface irregularities were used. However, in the clinical situation the cancellous bone makes intrusions in the cement and causes notching. Hamati et al. (1987) showed that notching definitely reduces the fatigue life of bone cement compared with smooth specimens, and they also showed that the fatigue properties of Simplex P, regardless of surface characteristics, were better when it was mixed in a vacuum as compared with conventional manual mixing. This fact is explained by the reduction of porosity in vacuum-mixed cement, which gives it a larger cross section, which can absorb the load. In sum, my study shows that mechanical mixing in a vacuum is an effective means of improving fatigue properties. This can reduce the risk of early cement failure and increase the survival of cemented total joint replacements.

Table 1. The number of cycles x 10^3 to failure. Mean (range) *SD*

	CMW			Simplex P			Zimmer LVC		
Manual	10.3 (5–16)	*5.0***		580 (287–1,400)	*409***		113 (24–267)	*84*	
Mechanical	23.0 (5–43)	*17***	**	526 (87–1,570)	*604*	*	120 (34–256)	*99*	**
Mechanical in a vacuum	350 (216–431)	*93***		1,540 (432–2,200)	*730***		351 (253–528)	*106*	

Levels of significance: * $P < 0.05$, ** $P < 0.01$.

References

Burke D W, Gates E I, Harris W H. Centrifugation as a method of improving tensile and fatigue properties of acrylic bone cement. J Bone Joint Surg (Am) 1984; 66(8):1265–73.

Davies J P, Burke D W, O Connor D O, Harris W H. Comparison of the fatigue characteristics of centrifuged and uncentrifuged Simplex P bone cement. J Orthop Res 1987;5(3):366–71.

Freitag T A, Cannon S L. Fracture characteristics of acrylic bone cements. II. Fatigue. J Biomed Mater Res 1977; 11(4):609–24.

Hamati F I, Wixson R L, Novak M A, Lautenschlager E P. The effect of notching of Simplex P bone cement on the fatigue lives of regular vs. vacuum mixed specimens. 33rd Annual ORS 1987:226.

Lidgren L, Bodelind B, Möller J. Bone cement improved by vacuum mixing and chilling. Acta Orthop Scand 1987; 58(1):27–32.

Lindén U. Mechanical versus manual mixing of bone cement. Acta Orthop Scand 1988;59(4):400–2.

Lindén U. Porosity in manually mixed bone cement. Clin Orthop 1988;(231):110–12.

Rimnac C M, Wright T M, McGill D L. The effect of centrifugation on the fracture properties of acrylic bone cements. J Bone Joint Surg (Am) 1986;68(2):281–7.

Skinner H B, Murray W R. Density gradients in bone cement after centrifugation. 31st Annual ORS 1985:243.

Wixson R L, Lautenschlager E P, Novak M A. Vacuum mixing of acrylic bone cement. J Arthroplasty 1987; 2(2):141–9.

Acknowledgements

I would like to thank Mr. Rune Thyselius and Mr. Sven Falander, SAAB-Scania Aerospace Division, Linköping, for mechanical and engineering guidance and assistance.