THE EFFECT OF CENTRIFUGING BONE CEMENT

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We have tested the porosity and fatigue life of five commonly used bone cements: Simplex P, LVC, Zimmer regular, CMW and Palacos R. Tests were conducted with and without centrifugation and with the monomer at room temperature and, except for LVC, at 0°C.

We found that the fatigue life of different specimens varied by a factor of nearly 100. It did not depend on porosity alone, but was more influenced by the basic composition of the cement. Simplex P when mixed with monomer at 0°C and centrifuged for 60 seconds had the highest fatigue life and was still sufficiently liquid to use easily.

Nonseptic loosening of cemented joint replacements can, in the vast majority of cases, be attributed to disruption of the integrity of the cement mantle or its two interfaces (Stauffer 1982; Sutherland et al. 1982). Clearly it is important to know the causes of cement weakness and to improve its fatigue life.

Several different formulations of methylmethacrylate bone cements are in use for joint replacement. They have varying amounts of porosity and varying fatigue lives when prepared according to the manufacturer's specifications (Kusy 1978; Davies et al. 1987). Recent advances in modifying the preparation methods have led to decreased porosity and increased fatigue life of some cements. In one study, centrifuging Simplex P for 30 seconds after mixing resulted in a 132% increase in its fatigue life, which was attributed to decreased porosity (Burke, Gates and Harris 1984).

While fatigue life may be improved by decreasing porosity, the effect of porosity on the fatigue life of different bone cements has not been compared quantitatively. Some cements may have a shorter fatigue life and yet a low degree of porosity; moreover reduction in porosity may not necessarily lead to increase in fatigue life.

Many of the commercially available bone cements possess different chemical and physical characteristics in addition to different porosities (Kusy 1978). Zimmer regular, LVC and CMW contain powdered polymethylmethylacrylate polymer; Palacos R powder is a methylmethacrylate-methacrylate copolymer; and Simplex P consists of a mixture of polymethylmethacrylate and methyl methacrylate-styrene copolymer. Zimmer regular, LVC, CMW and Simplex P use barium sulphate to make them radiopaque while Palacos R uses zirconium oxide. Palacos R also contains chlorophyll to provide a green tint.

Manufacturers also powder the polymer into different bead sizes which, for the most part, accounts for their differing viscosities (Lautenschlager, Stupp and Keller 1984). LVC has the lowest viscosity of the cements tested in this study, followed by Zimmer regular and Simplex P; Palacos R and CMW have the highest (de Wijn, Slooff and Driessens 1975; Krause, Miller and Ng 1982).

To investigate the relationship between fatigue life and porosity and to determine if other factors were important, we first quantified the porosity of five widely used acrylic cements prepared (1) as recommended by the manufacturers, and then (2) as recommended by manufacturers except that the monomer was chilled, and (3) after centrifugation for varying times. Each cement preparation was then tested and its fatigue life correlated with its porosity.

MATERIALS AND METHODS

Specimens of Simplex P, LVC, Zimmer regular, CMW and Palacos R bone cements were prepared according to the manufacturer's instructions. The Simplex P, Palacos R, Zimmer regular and CMW were mixed with the monomer at room temperature until the cement no longer adhered to a surgical glove. This, the dough stage, was reached at 2.5 to 3.5 minutes for Zimmer regular and Simplex P, and at 1 to 1.5 minutes for Palacos R and CMW. The cement was then introduced into the Harris cement syringe by hand. The LVC cement was mixed with the monomer at room temperature for 90 seconds

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Table I. Porosity and fatigue life of common bone cements, prepared according to the manufacturer's recommendations, but not centrifuged

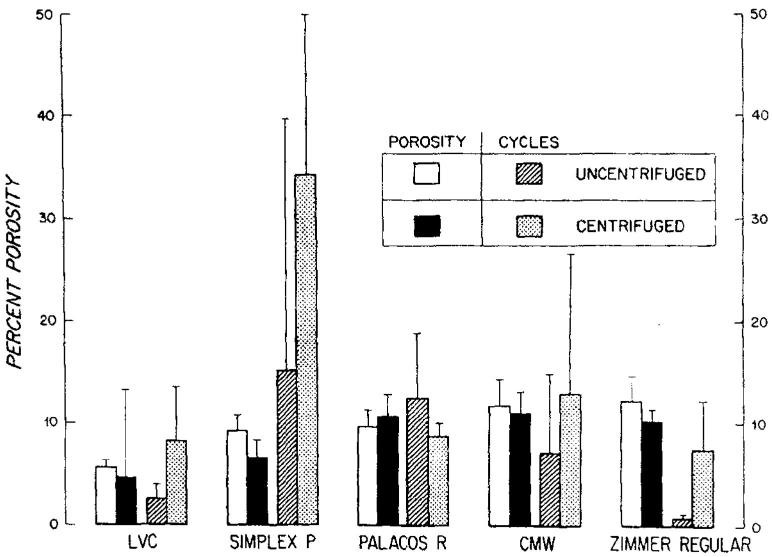
Cements*		Porosity (*per cent*) mean (s.d.)			Cycles to failure mean (s.d.)	
LVC		*5.06 (0.52)*			2,575 (1,375)	
Simplex P	S	*9.39 (1.53)*	S	S	15,147 (24,690)	S
		S			NS	
Palacos R	S	*9.70 (1.83)*	S	S	11,504 (6,387)	S
		S			S	
CMW		*11.99 (2.18)*	S S	S	7,043 (7,806)	S NS
		NS				
Zimmer regular		*12.38 (2.51)*	S		879 (493)	S

* listed in order of increasing porosity
S significant difference ($p < 0.05$)
NS no significant difference

Table II. Effects of centrifugation on porosity and fatigue life. The monomer was chilled to 0°C (except LVC). One pack of cement was centrifuged

Cements*	Centrifugation time (*seconds*)		Porosity (*per cent*) mean (s.d.)			Cycles to failure mean (s.d.)	
LVC	30		*4.47 (0.85)*			8,233 (5,185)	
Simplex P	30	S	*6.62 (1.88)*	S	S	34,239 (15,889)	S
			S			S	
Zimmer regular	30	NS	*10.35 (1.34)*	S	NS	7,941 (4,662)	NS
			NS			NS	
Palacos R	60	NS	*10.76 (1.27)*	S S	NS	8,687 (1,258)	NS S
CMW	30		*11.11 (2.01)*	S		12,127 (14,051)	NS

* listed in order of increasing porosity
S significant difference ($p < 0.05$)
NS no significant difference



Bar graph showing the porosity (black and white) and cycles to failure (shaded) for commercial bone cements. The uncentrifuged cements were mixed with monomer at room temperature. The centrifuged cements were mixed with chilled monomer (except LVC) and spun for 30 seconds (except Palacos R which was spun for 60 seconds).

Fig. 1

and was then poured into the syringe while still in a liquid state. Each cement was then injected in a retrograde manner into cylindrical Teflon moulds which were 72 mm long with a 10.7 mm inner diameter. The moulds were capped at one end, but no external pressure was applied during injection. The specimens were allowed to cure in the moulds for 20 minutes in a water bath at 37°C.

Another set of specimens of Simplex P was prepared by mixing the powder with monomer which was chilled to 0°C, a common clinical practice used to prolong the period of low viscosity and improve the intrusion properties; this was done to assess the effect of chilling on fatigue strength. After mixing for 75 seconds, the cement was poured into cement syringes, injected into cylindrical moulds and allowed to cure at 37°C.

A set of specimens of all the cements except LVC was also prepared by centrifuging after mixing with chilled monomer; LVC has such a low viscosity when mixed with monomer at 21°C, that there was no point in mixing it with chilled monomer. These cements were mixed for 75 seconds and then, while still in a liquid state, poured into Harris cement syringes. The cement-filled syringes were then introduced into the IEC clinical centrifuge and spun for 30 seconds, reaching a maximum speed of 3,000 rpm.

The Palacos R cement was spun for 60 seconds because preliminary investigation had shown that 30 seconds did not markedly reduce its porosity. The centrifuged cement was then injected into the cylindrical moulds and allowed to cure at 37°C. An additional set of Simplex P specimens was also prepared by centrifugation for 120 seconds to assess the effects of further porosity reduction on fatigue life.

In order to measure porosity the cement preparations were allowed to polymerise in the syringes, and the cured cylindrical specimens (which were 26 mm in diameter) were serially sectioned transversely into discs which were 2 mm thick. The surface of the discs were polished with alumina powder and the pores were stained black by spraying the surface with black paint and wiping the paint off the polished surface. The porosity was measured using a computer-assisted image analysis system based on grey scale thresholds.

For the fatigue tests the cylindrical specimens (10.7 mm in diameter) were machined into waisted specimens with a central gauge length of 10 mm and a diameter of 5 mm, using a computer-driven lathe equipped with a hydraulic tracer arm which followed a template. Fully reversed tension-compression fatigue testing was carried out on these waisted specimens at a stress of 15 mpa and a frequency of 2 hertz using an MTS hydraulic testing machine as previously described (Davies et al. 1987). All the tests were conducted at 37°C and 100% humidity. The number of cycles to failure was recorded.

The results of the fatigue studies were correlated with the results of the porosity measurements. The changes in porosity obtained with centrifugation were correlated with the changes in fatigue life for all cements, and specifically the effect of different centrifugation times on both the reduction of porosity and the increase in fatigue life were evaluated for Simplex P bone cement. The data were analysed using Student's *t*-test. The data which did not follow a normal distribution were also analysed by the Wilcoxon signed rank test.

RESULTS

The porosity measurements and fatigue test results for the uncentrifuged cements are shown in Table I. Different commercial cements, when prepared according to the manufacturer's specifications, exhibited markedly different fatigue lives and porosities ranging from 879 cycles (Zimmer regular), to 15,147 cycles (Simplex P). The variations in mean porosity ranged from 5.06% (LVC) to 12.38% (Zimmer regular).

However, the porosity alone did not determine the fatigue life. Thus, LVC had the lowest porosity of all the uncentrifuged cements (5.1%), yet had a very low fatigue life (2,575 cycles); and Simplex P had an intermediate porosity (9.4%) but the highest fatigue life (15,147 ± 24,690 cycles). Clearly other physical or chemical factors may be more important than porosity in determining fatigue life.

The fatigue lives and porosity measurements of all five bone cements prepared by centrifugation after mixing with chilled monomer (except for LVC which was mixed with the monomer at room temperature) are shown in Table II. Centrifugation for 30 seconds after mixing resulted in a significant increase of the fatigue life of Simplex P, Zimmer regular and LVC, but not that of CMW; centrifuging for 60 seconds did not improve the fatigue life of Palacos R. Centrifugation led to corresponding decreases in porosity of Simplex P and Zimmer regular, but did not significantly lower the total porosity of Palacos R, LVC, or CMW bone cements. However, even after centrifugation, striking disparities between porosity and fatigue life of the different cements were apparent. Thus, major differences in fatigue life must depend on factors other than porosity. However, changes in porosity correlated well with the changes in fatigue life for each of the individual bone cements (Fig. 1). The one exception was LVC, which exhibited a slight but insignificant decrease in porosity and a slight but significant increase in fatigue life after centrifuging for 30 seconds. Centrifugation of Simplex P for 120 seconds resulted in a substantially increased fatigue life when compared to the same cement centrifuged for 30 seconds (Table III); this corresponded to its further reduction in porosity when centrifuged for 120 seconds. However, the viscosity of Simplex P after centrifugation for 120 seconds, even when mixed with chilled monomer, was so high that it was not usable.

Table III. Simplex P spun in the IEC clinical centrifuge

	Monomer temperature	Porosity mean (s.d.)		Fatigue life mean (s.d.)	
Uncentrifuged	Room	9.39 (1.53)		15,143 (24,690)	
Centrifuged for 30 sec.	Chilled	6.62 (1.88)	S	34,239 (15,889)	S
Centrifuged for 60 sec.	Chilled	4.26 (0.81)	S S	54,986 (25,668)	S S

S significant difference (p< 0.05)

Table IV. Effects of chilling the monomer on the fatigue life of Simplex P

Monomer temperature	Centrifugation time	Porosity mean (s.d.)		Cycles to failure mean (s.d.)	
Chilled	Uncentrifuged	12.63 (1.53)	S	5,434 (5,043)	S
Room	Uncentrifuged	9.39 (1.53)		15,143 (24,690)	
Chilled	30 sec.	6.62 (1.88)	S	34,239 (15,889)	S
Room	30 sec.	4.25 (1.21)		69,581 (19,742)	
Chilled	120 sec.	4.26 (0.81)	S	54,986 (25,688)	S
Room	120 sec.	2.89 (0.61)		94,479 (24,651)	

S significant difference (p< 0.05)

Mixing with chilled monomer significantly lowered the fatigue life of Simplex P (Table IV); this decrease was accompanied by a significant increase in porosity. Centrifugation of Simplex P after mixing with monomer at room temperature significantly improved its fatigue life to above that when prepared chilled in the conventional manner (Table IV). The changes in porosity corresponded well to the changes in fatigue life of Simplex P prepared by chilling the monomer and by centrifuging.

DISCUSSION

Our data reveal two important observations. First the dominant determinant of the fatigue life of different commercially available bone cements is their basic composition not their porosity. Secondly, in every instance in which porosity was reduced, the fatigue life of a given cement was significantly improved.

Of the five cements prepared according to the manufacturer's specifications Simplex P had the highest fatigue life, although it was intermediate in porosity. It also showed both the greatest reduction in porosity with centrifugation and the greatest increase in fatigue life. Centrifuged Simplex P had the highest fatigue life of all the centrifuged bone cements tested.

LVC bone cement had a low fatigue life despite having the lowest porosity. Centrifugation led to only a slight and insignificant decrease in its porosity and a slight but significant increase in its fatigue life. Although centrifuged LVC had the lowest porosity, its mean fatigue life was four times lower than that of Simplex.

We believe that the failure of centrifugation to improve the fatigue lives of CMW and Palacos is largely a reflection of their high viscosity. Centrifugation did not result in a significant decrease in their porosity.

To obtain the acrylic bone cement with the optimum fatigue life among these five cements it is necessary to choose the strongest cement and also the best preparation method. Under the conditions studied by us, the best results were obtained with Simplex P prepared by centrifugation for 30 seconds after mixing with monomer at room temperature. This resulted in a cement with excellent fatigue strength which was easy to use; if centrifuged for 120 seconds it had higher fatigue strength but became too viscous and was difficult to inject from the syringe. When mixed with monomer at 0°C and centrifuged for 60 seconds, Simplex P provided an excellent low viscosity state with high fatigue life.

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