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Mechanical versus manual mixing of bone cement

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Conventional mixing of three different bone cements (CMW, Simplex P, and Zimmer LVC) was compared with a mechanical technique with respect to porosity and density. Density was increased in all the mechanically mixed cements, and the percentage porosity was diminished for CMW and Simplex P.

During the mixing of bone cement, inclusions of air are unavoidable; bubbles harm the mechanical properties of cement used for fixation of arthroplastic components (de Wijn et al. 1975). Manually mixed bone cement has a variable and unpredictable degree of porosity (Lindén 1984). In order to solve this problem, Burke et al. (1984) introduced centrifugation and Lidgren et al. (1984) tested vacuum mixing. Both techniques improved the quality of the cement compared with manual mixing. Mechanical mixing, which is commonly used in industrial applications, has not been studied previously. I have investigated whether a mechanical mixing device could improve the quality of the cement as compared with manual mixing.

Material

Three bone cements of different viscosity were studied: high viscosity CMW (CMW Laboratories Ltd, Blackpool, U.K.), medium viscosity Simplex P (Howmedica International Inc., Northill Plastics Division, London, U.K.), and low viscosity Zimmer LVC (Zimmer, Warsaw, Indiana, U.S.A.).

The cement syringe used was Disposable insert (Cat. no. 0 183–0010, Howmedica International, Kiel, West Germany), and the mixing device used was a CAP-vibrator (Ivoclar AG, Fl-9494 Schaan, Liechtenstein), consisting of an electric motor with an eccentric to which is attached a holder with clamps to retain the cement syringe. The mixing device was modified for the purposes of the present work, so that the amplitude of the motion was kept constant while the mixing time and speed varied. The tip of the syringe was sealed with a rubber stall.

Method

The conditions for mechanical mixing were first determined with Simplex P. The powder polymethylmethacrylate (PMMA) and the liquid methylmethacrylate (MMA) were introduced into the syringe. The tip of the syringe was screwed into place and sealed with the rubber stall. The syringe was placed in the machine and mixing was carried out for 30 seconds, 1, 2, or 3 minutes at speeds of 250, 500, 1,000, or 2,000 rpm. No manual mixing took place. For each cement and mixing condition, seven specimens were used.

At 250 rpm, all tested specimens showed gross heterogeneity regardless of mixing time and type of cement (Figure 1). At 500 and 1,000 rpm, there

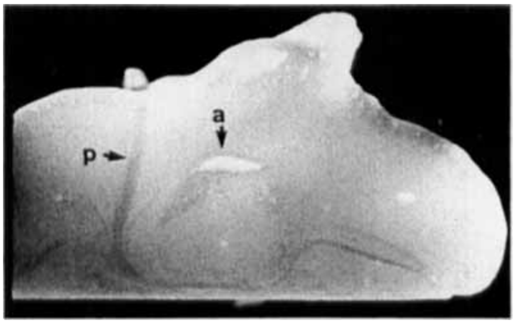

Figure 1. A specimen mixed at 250 rpm with heterogeneities of the cement in form of air inclusions (a) and laminations of the PMMA powder (p).

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was a decrease in porosity after a mixing time of 2 minutes when compared with 1 minute, but no further improvement was noted for longer mixing times (Table 1). At 2,000 rpm, there was an increase in porosity ranging from 19–25 vol% compared with the lower mixing speeds, regardless of mixing time.

Both CMW and Zimmer LVC were tested at the extreme mixing speeds for 2 minutes, and they behaved the same way as Simplex P. Thus, for comparison, all three types of bone cement were tested at 500 rpm and a mixing time of 2 minutes, because this was found to be the best mixing condition. All the cements were mixed at 20 °C and at a relative humidity of 50 percent.

Manual mixing was done as recommended by the manufacturers.

In all the tests the cement was allowed to polymerize in the syringe. After 24–48 hours, the polymerized mass was removed, sawed, ground, and polished. All the specimens were examined radiographically for the distribution of barium sulfate granules. The density was estimated by measuring and weighing each specimen (kg/m^3).

The porosity was measured in a microscope with incident light at a 5x magnification. The percentage porosity was estimated by a spot-counting technique using a 500-point grid placed over the sample. The volume fraction voids (Vp) or its equivalent percentage porosity (P) is the ratio of the number of grid points falling on a void (Pv) to the total number of grid points (Pt), and according to the following formula:

$$V_p = \frac{P_v}{P_t} = P \times 100.$$

The Wilcoxon rank sum test and *F*-test were used.

Results

All three cements increased 5–10 percent in density after mechanical mixing as compared with manual mixing (Table 2). The porosity of Simplex P was reduced by 40 percent after mechanical mixing compared with the manual mixing. The porosity of Zimmer LVC was low with both mixing modes (Table 3).

The variations in porosity expressed as SD percentage of the mean disclosed that there was less scatter with Simplex P in the mechanically mixed than in the manually mixed samples, 26 and 13 percent, respectively ($P < 0.05$). By mechanical mixing, Simplex P and Zimmer LVC showed less scatter when compared with CMW, 13 percent, 12 percent, and 32 percent, respectively ($P < 0.05$). Manually mixed Zimmer LVC showed less scatter than both CMW and Simplex P ($P < 0.05$), but no difference emerged between the latter.

At radiographic examination, all the manually mixed samples and samples mixed mechanically at speeds exceeding 250 rpm appeared homogeneous.

Table 1. The percentage porosity of mechanically mixed Simplex P. The values of the specimens mixed at different speeds and periods of time. N 7 in each group. Mean values with standard deviation within brackets

Speed (rpm)	Mixing time (min)			
	0.5	1.0	2.0	3.0
500	16.9 (3.9)**	13.0 (1.6)*	10.3 (1.3)	10.5 (2.6)
		*		
1,000	17.1 (4.5)	16.8 (2.8)*	12.7 (4.2)	12.3 (3.7)
	*	**	**	*
2,000	24.3 (4.6)	23.5 (2.9)	24.8 (4.2)	19.7 (3.6)

Levels of significance:
no symbol not significant.
* $P < 0.05$
** $P < 0.01$
*** $P < 0.001$

Table 2. The density (kg/m^3) of the different bone cements produced by manual and mechanical mixing technique, respectively. N 8 in each group. Mean values with standard deviation within brackets

	Manual		Mechanical
CMW	1.05 (0.02)	***	1.14 (0.01)
			**
Simplex P	1.08 (0.02)	***	1.19 (0.02)
	**		*
Zimmer LVC	1.14 (0.008)	**	1.18 (0.02)

Levels of significance as in Table 1.

Table 3. The percentage porosity of the different bone cements, mixed manually and mechanically, respectively. N 8 in each group. Mean values with standard deviations within brackets

Porosity (vol %)	Manual		Mechanical
CMW	26 (9)	**	12.6 (4.0)
			*
Simplex P	23 (6)	**	10.3 (1.3)
	*		*
Zimmer LVC	13 (2)		13.0 (1.2)

Levels of significance as in Table 1

Discussion

Studies on the mechanical properties of bone cement have yielded widely differing results, especially with regard to tensile strength and fatigue (Carter et al. 1982). One explanation could be the differences in testing technique. Variations in porosity probably account for the considerable scatter in the results of mechanical tests.

The spot-counting method that we used for evaluation of the porosity means that pores less than 0.1 mm in diameter were not counted. This restriction probably accounts for the discrepancy in the findings of porosity and density for Zimmer LVC; in a low viscosity cement the air inclusions tend to be smaller. However, there was good accord in the results from the determinations of density and porosity for both CMW and Simplex P.

The basic mixing conditions were determined only for Simplex P . Because CMW and Zimmer LVC had the same reduction in porosity as Simplex P at a mixing time of 2 minutes and for the extreme speeds, the same mixing conditions were used for all the cements. A low mixing speed gave gross heterogeneity of the cement mass; samples mixed at 2,000 rpm showed increased porosity. This confirms the findings of Lee et al. (1978).

Centrifugation has been shown to reduce porosity and increase both the tensile strength and the fatigue properties of bone cement (Burke et al. 1984). The same findings were made by Wixson et al. (1987), and they also found an increase in compressive strength.

The vacuum mixing technique introduced by Lidgren et al. (1984) is extremely efficient in evacuating air from the cement. By this technique it is possible to get a more complete reduction in porosity and improvement of the mechanical properties of bone cement as compared with conventional manual mixing or centrifugation (Lidgren et al. 1987, Wixson et al. 1987).

The reduction of porosity achieved by the mechanical mixing technique described was of the same magnitude as obtained by centrifugation as described by Wixson et al. (1987). Skinner and Murray (1985) found a gradient of density in bone cement after centrifugation, which raises some concern about the homogeneity of centrifuged bone cement.

The mechanical mixing described apparently increases the density of the cement, reduces the variation in quality, and may also give greater homogeneity. On the other hand, manual mixing results in a cement of unpredictable quality (Carter et al. 1982, Lindén 1984).

The previously described mixing techniques using centrifugation or a vacuum are manual. In the conventional mixing technique, the surgeon is in direct manual contact with the cement and is thus exposed to the MMA vapors, which have been reported to cause allergic reactions, including dermatitis (Fischer 1979, Fregert 1983). Our mechanical technique minimizes direct manual contact with the cement and reduces exposure time to both the cement and the MMA vapors.

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