

Mixing does not improve mechanical properties of all bone cements

Manual and centrifugation-vacuum mixing compared for 10 cement brands

Dick Hansen and Jørgen Steen Jensen

Contemporary mixing methods—centrifugation, vacuum mixing with or without precompression—were compared with manual mixing by testing strength characteristics in accordance with a proposed revision of the international standard for bone cements as applied to 10 cement brands.

Simplex® brands and low-viscosity cements were the strongest, and were not improved by any of the vacuum-mixing procedures. Centrifuging was found unsuitable for low-viscosity cements.

Without attaining the strength of the former, the cements best suited for auxiliary mixing methods were CMW-1® and Palacos® brands, which improved 6–11 percent by either of the methods. The Sterivac® system was generally found unacceptable, because about 20 percent of a cement package was retained in the mixing gear, and the application of precompression had no additional effect on compressive and bending strengths.

University of Copenhagen, Department of Orthopedics U-2162, Rigshospitalet, DK-2100 Copenhagen Ø, Denmark
Correspondence: Dr. J. Steen Jensen. Tel +45-35 452369. Fax +45-35 366733
Submitted 90-10-20. Accepted 91-08-17

Manual mixing of polymethyl methacrylate (PMMA) bone cements has been miscredited, because voids and microporosities make the cement more susceptible to mechanical failure. Supplementary mixing methods, such as centrifuging (Burke et al. 1984, Davies et al. 1987a, 1989a), prechilling, and vacuum mixing (Lidgren et al. 1984, 1987, Wixson et al. 1987), or vacuum mixing and precompression after chilling of the cement compounds (Draenert 1986), have been advocated.

We have previously shown that prechilling and vacuum mixing might have adverse effects on the exothermic temperature and handling characteristics (Hansen and Jensen 1990), and we have now compared strength characteristics in relation to different mixing methods.

Materials and methods

Low-viscosity cements, i.e., Cerafix®, CMW-3®, Palacos-E®, Sulfix-6®, and standard viscosity cements, i.e., CMW-1®, Palacos-G®, Palacos-R®, Simplex-P®, Simplex-RO®, Zimmer-Dough®, were tested.

Manual mixing in accordance with the manufacturers' recommendations was performed in a bowl with one beat per second before transferring the mixed

cement to a cement syringe. All the components had been stored at room temperature (20°–21°).

After storage of the cement compounds at 5 °C, vacuum mixing was performed in a closed chamber. By one method, this was done with the cement cartridge contained in a stirring chamber applying 0.2 bars (MITAB, Sweden). By another system, the compounds were admixed in a separate mixing chamber (Sterivac®, SD, Germany) applying 0.15 bars. The cement was stirred quickly for 15 s, slowly by two turns per sec for 15 s, and evacuated for a further 15 s. The cement was retrogradely extruded into a broad-nozzled cement syringe, which was pressed into the mixing chamber. With an air-driven cement gun, precompression at 6–7 bars for 2 min was applied before use.

Centrifuging was performed at 2,300–2,400 rpm for 30 s after manual admixing in a cement cartridge. Low-viscosity cements had been stored at room temperature, and the other cements in a refrigerator at 5 °C.

The cements were injected with the cement gun, being part of the systems, into moulds according to a proposed revision of the international standard (ISO 5833). Specimens with visible air inclusions or moulding errors were discarded. After 24 hours' storage of the specimens ($\varnothing = 6$ mm, $L = 12$ mm) in air at room temperature, testing was performed (M 5 testing

Table 3. Deflection in four-point bending of PMMA bone cements

[illegible]

Table 4. Modulus of elasticity in four-point bending of PMMA bone cements

	Low-viscosity cements			Conventional bone cements						
	Cerafix	CMW-3	Palacos-E	Sulfix-6	CMW-1	Palacos-G	Palacos-R	Simplex-P	Simplex-RO	Zimmer-D
Manual										
Mean	2.5	2.8	2.6	2.6	2.3	2.2	2.3	2.5	2.6	2.2
SD	0.08	0.15	0.02	0.11	0.02	0.07	0.09	0.15	0.09	0.09
Vacuum MIT AB										
Mean	2.4	2.6	2.6	2.4	2.5*	2.5*	2.5	2.5	2.6	2.1
SD	0.04	0.20	0.07	0.08	0.06	0.07	0.09	0.14	0.09	0.12
Sterivac										
Mean	2.7*	2.7	2.9*	2.4	2.7*	2.5*	2.7*	2.6	2.7	2.4*
SD	0.21	0.08	0.06	0.16	0.06	0.19	0.08	0.03	0.06	0.12
Centrifuging										
Mean	—	—	—	—	2.5*	2.5*	2.7*	2.5	2.7	2.4
SD	—	—	—	—	0.16	0.10	0.20	0.10	0.07	0.13
Cerafix	s/v					M				M, V
CMW-3					M	M	M	M		M, V
Palacos-E					M	M	M			M, V
Sulfix-6						M				M
CMW-1					m/v, m/s, m/c					V
Palacos-G						m/v, m/s, m/c				V
Palacos-R							m/s, m/c			V, C
Simplex-P						M				M, V
Simplex-RO						M				M, V, C
Zimmer-D										v/s

machine, Nene Instruments Ltd., U.K.) at a velocity of 20 mm/min with calculation of ultimate compressive strength (UCS). Four-point bending strength (UBS) and bending modulus (E) were determined at a velocity of 5 mm/min after 50 hours' storage of the specimens (L = 75 mm, W = 10 mm, H = 3.3 mm) in 37 °C water in accordance with the proposed standard. At least six specimens from each cement brand were examined by each of the methods. Data are presented as mean values and standard deviations (SDs). Analysis of variance with multiple comparison procedures (Scheffe's test) identified differences at the 5 percent level of significance.

Results

Compression tests

The auxiliary mixing methods did not influence compressive strength of *low-viscosity* cements apart from a marginal gain for Sulfix-6® mixed with the Sterivac® system (Table 1). However, 16.1 (13.2–19.5) grams of cement was lost in the Sterivac® gear. After centrifuging, all the specimens were discarded because of a pool of free MMA monomer on top of the cement, amounting to 3–7 mm. The UCS ranged from 95 to 105 MPa. Palacos-E® was weaker than manually mixed Sulfix-6® or CMW-3® and Sulfix-6® mixed in the Sterivac® system.

Standard viscosity cements (CMW-1®, Palacos-G®, Palacos-R®, Zimmer-D®) had the lowest strengths by hand mixing. For CMW-1® the UCS was about 10 percent lower than with any other mixing method, whereas Palacos® brands improved 10–15 percent by MITAB® vacuum mixing. A decreased strength of 9–12 percent was experienced with Simplex® brands mixed by any of the mechanical methods as compared with manual mixing. Zimmer-D® was by far the weakest cement, but could by centrifuging be improved to the level of the weakest hand-mixed cements. UCS ranged from 77 to 100 MPa, and apart from hand-mixed Simplex® brands, all of them were weaker than *low-viscosity* cements. The strength of hand-mixed Simplex® brands was 13–16 percent higher than the other brands, which could be improved to an equal level using auxiliary methods. In the Sterivac® gear, 11.9 (8.8–16.1) grams of a 60-gram cement portion was retained and was inaccessible for use.

Four-point bending tests

For the *low viscosity* cements, the UBS (Table 2) ranged from 64 to 77 MPa. Palacos-E® was superior to CMW-3® and Sulfix-6® mixed manually or with a vacuum, and vacuum-mixed Cerafix was superior to manually mixed CMW-3®. The differences in relation to *standard viscosity* cements were somewhat more scattered. MITAB® vacuum mixing or centrifuging improved Palacos® brands by 10–11 percent, whereas the other brands were unaffected. Zimmer-D® was the weakest and Simplex® brands generally superior as manually mixed.

The deflection at four-point bending testing (Table 3) of *low-viscosity* cements decreased with the vacuum-mixing methods, apart from CMW-3®. The range was 4.7–9.0 mm, with Cerafix® and Palacos-E® having the largest deflections before failure. For *standard viscosity* cements, the deflection was 4.4–8.9 mm by hand mixing, the Zimmer-D® and Simplex®-brands generally having among the lowest deflections. Decreased deflections were observed with Sterivac® mixing of CMW-1® and with any auxiliary method applied to Palacos-G®, whereas MITAB® vacuum mixing increased deflection for Zimmer-D® cement. A higher deflection was observed for Simplex-P® cement in relation to Sterivac® mixing or centrifugation.

The modulus of elasticity (E-modulus) of *low-viscosity* cements was 2.4–2.9 GPa (Table 4). Cerafix® and Palacos-E® became stiffer from the Sterivac® mixing compared with MITAB vacuum mixing, and Palacos-E® also with respect to manual mixing. No significant differences between the brands were encountered. Manually mixed *standard viscosity* cements had E-modules of 2.2–2.6 GPa. Zimmer-D® generally had the lowest E-modulus, which, however, increased by Sterivac® mixing when compared with MITAB mixing. Simplex®-brands were unaffected by the mixing method. All the auxiliary methods increased the E-modulus for CMW-1® and Palacos-G® as compared with manual mixing; and for Palacos-E®, centrifugation and Sterivac® mixing had a similar effect.

Discussion

Porosity in bone cements can be reduced by mechanical mixing with the theoretic advantage of improving the longevity of the cements (Linden 1989). The clinical relevance of different testing procedures is unknown. It has been claimed (Lee 1983) that the cement mantle acts as a compression wedge between a femoral stem and the bone tube, and Ling (1983)

found the cement seal valuable as a shock absorber and decoupler between the implant and bone. With the background in such considerations, compressive strength has the highest priority, and has also until a recently proposed revision of the ISO standard (1987) been the only requirement for strength testing. The introduction of four-point bending, however, adds information about stiffness (E-modulus) and brittleness (i.e., deflection). An E-modulus in the lower end and a larger deflection should be aimed at to counteract cracking in the cement mantle during loading. The bending strength is probably of less clinical relevance, because the principal forces acting on the cement mantle are compressive and shear.

The low-viscosity cements and Simplex® brands behaved as the strongest, but also as the stiffest, cements (Burke et al. 1984, Davies et al. 1987b, Davies et al. 1989b). CMW-3® and Sulfix-6® were more brittle than the other group members. Contemporary mixing methods applied to low-viscosity cements did not improve strength properties, and might even have a negative effect. Prechilling followed by vacuum mixing inevitably leads to a highly increased exothermic temperature (Hansen and Jensen 1990). Further, about 20 percent of the standard package of cement was retained in the Sterivac® mixing gear; and by centrifuging low-viscosity cements, a layer of free monomer separated out. Consequently, low-viscosity cements should be mixed manually. The higher E-modulus can be explained by better packing and more complete polymerization (Brandrup and Immergut 1975), which are most likely due to the styrene copolymer in Simplex® cement, and in the low-viscosity cements through an improved escape of oxygen, which inhibits polymerization.

The standard viscosity cements all fulfilled the new ISO requirements for compressive strength (i.e., > 70 MPa), and were well above (CMW-1®, Palacos® brands) or at the limit (Zimmer-D®) of the 50 MPa required for bending strength. Prechilling and vacuum mixing improved compressive strength of Palacos® brands and of CMW-1®, and Palacos® brands were also stronger in bending with MITAB® vacuum mixing. However, these cements became stiffer, and the deflection before fracture was reduced, which might possibly increase the risk of crack initiation and crack propagation because of increased stress in the cement mantle. The Sterivac® system cannot be recommended because of a loss of about 20 percent of the cement in the vacuum mixing gear.

Centrifuging has been claimed to improve the tensile fatigue strength of bone cement (Davies et al. 1987a, b), but not for all the brands (Davies et al. 1989a, b). The procedure has no effect on crack propagation (Rimnac et al. 1986), perhaps because of

uneven distribution of cement additives (Dingeldein and Wahlig 1987, Schreurs et al. 1988). We found improvements of UCS for CMW-1®, Palacos® brands, and Zimmer-D® cements, and of UCS for Palacos® brands, but again the stiffness increased and the deflection abilities dropped.

By application of any of the contemporary mixing methods to CMW-1® and Palacos® brands, the compressive strength and the bending strength could almost be brought up to the strength level of low-viscosity and Simplex® cements. The increased brittleness (i.e., lower deflection) is considered moderate, and the deflections were at level with hand-mixed radiopaque Simplex-RO®. Consequently, the contemporary methods seems well suited for these particular cement brands.

With respect to Zimmer-D® cement, only centrifugation had a beneficial effect, although limited to the UCS. In spite of a lower E-modulus, Zimmer-D® cement was the most brittle compound and the weakest cement brand overall.

Acknowledgements

Financial support was received from Industri- og Handelsstyrelsen, Danish Ministry of Industry. The bone cements and mixing equipments were kindly supplied by the distributors and manufacturers.

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