CEMENT PRESSURISATION DURING HIP REPLACEMENT

A. W. McCASKIE, M. R. BARNES, E. LIN, W. M. HARPER, P. J. GREGG

From The Glenfield Hospital NHS Trust, Leicester, England

The newer techniques of cementing aim to improve interlock between cement and bone around a femoral stem by combining high pressure and reduced viscosity. This may produce increased embolisation of fat and marrow leading to hypotension, impaired pulmonary gas exchange and death. For this reason the use of high pressures has been questioned.

We compared finger-packing with the use of a cement gun by measuring intramedullary pressures during the cementing of 31 total hip replacements and measuring physiological changes in 19 patients. We also measured pressure in more detail in a laboratory model.

In the clinical series the higher pressures were produced by using a gun, but this caused less physiological disturbance than finger-packing. The laboratory studies showed more consistent results with the gun technique, but for both methods of cementing the highest pressures were generated during the insertion of the stem of the prosthesis.

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Modern techniques of cementing are designed to reduce the incidence of aseptic loosening: many different methods are used.¹⁻³ Low rates of loosening have been reported after both modern⁴⁻⁶ and earlier techniques.^{7,8} The terms 'modern' and 'early' are somewhat misleading; Sir John Charnley emphasised the importance of careful surface preparation, the removal of loose debris and the control of bleeding.⁹ Although there is little agreement about the type

of cement or the method of introduction the use of a cement restrictor has been adopted almost universally.^{1,3}

The retrograde insertion of cement of reduced viscosity with sustained pressurisation will improve penetration of bone and increase the microinterlock. An important consideration is that cementing techniques should maintain a pressure above the bleeding pressure without leading to embolisation and cardiovascular instability.

The introduction of the cement and prosthesis during hip replacement is associated with hypotension and, more rarely, with cardiovascular collapse.^{10,11} The pathophysiology is unclear, but may involve the pulmonary embolisation of fat and bone marrow.¹²⁻¹⁷ Embolic cascades are visible on echocardiographs, and are associated with a reduction in oxygen tension and saturation.¹⁸

Intramedullary pressure increases during finger-packing, and various methods of limiting this pressure have been recommended.¹⁹⁻²¹ Pulsed lavage before insertion reduces pulmonary fat embolism and cardiovascular disturbance by the removal of potential embolic material.^{22,23}

Song et al²⁴ found that the insertion of the prosthetic stem produced the highest pressures and suggested that prior impaction of the cement is probably unnecessary, but it is accepted that sustained pressurisation helps to control cement of low or reduced viscosity and encourages penetration against any opposing blood pressure. The timing of the insertion of the prosthesis, with delay until the viscosity has risen, is necessary to prevent the cement being squeezed back out of the medullary canal.

We have measured the pressure generated at the cement-bone interface during total hip replacement and have produced pressure profiles for each technique. In addition, we have studied the physiological effect of cementation and have devised and validated a laboratory model to simulate arthroplasty.

PATIENTS AND METHODS

Clinical study. We performed a randomised, prospective study on 31 patients having a primary Charnley total hip replacement after informed consent. The operative technique was the same in all cases, using a modified direct lateral approach, femoral preparation with standard Charnley reamers, power brushing, lavage, manual brushing and a Hardinge cement restrictor. The prepared femoral canal was packed with gauze before cementing. Of the 31

A. W. McCaskie, MD, FRCS, Lecturer in Orthopaedic Surgery
M. R. Barnes, BSc, Senior Medical Physicist
E. Lin, MSc, MD, MRCP, FRCA, Consultant Anaesthetist
W. M. Harper, MD, FRCS, Senior Lecturer in Orthopaedic Surgery
P. J. Gregg, MD, FRCS, Professor of Orthopaedic Surgery
Department of Orthopaedic Surgery, Leicester University, The Glenfield Hospital NHS Trust, Groby Road, Leicester LE3 9QP, UK.

Correspondence should be sent to Mr A. W. McCaskie.

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Fig. 1

Diagram of a femur to show the location of pressure monitors. The transducer numbering system should be noted.

patients, 15 were randomised using a counter system to finger-packing and 16 to a cement-gun technique.

Cementing. For the finger-packing group, CMW1 cement (CMW, DePuy International Ltd, Leeds, UK) was mixed according to the manufacturer's instructions in a partial vacuum. When the cement was no longer adherent to the glove it was impacted into the medullary canal. Sustained digital pressure was applied before the insertion of the prosthesis.

The retrograde cement-gun technique used CMW3 cement mixed in a partial vacuum. After 75 seconds the cement was poured into the barrel of a cement gun and allowed to stand for 60 seconds before being introduced into the medullary canal in a retrograde fashion. Sustained digital pressure was applied until the prosthetic stem was inserted at three-and-a-half to four minutes after mixing had begun.

Pressure measurement. Pressures were recorded continuously during cementing using a sterile, disposable measuring system. A sterile 8-gauge manometer line was filled with sterile normal saline. One end was left open to the atmosphere and the other was connected to a sterile pressure transducer linked to a calibrated chart recorder. The tip of the manometer line was placed 10 cm into the medullary canal and the pressure recorder was zeroed. The cement was then inserted with continuous recording of the pressure. The catheter was removed before the stem of the prosthesis was inserted.

Physiological effect. In 19 patients, ten with finger-packing and nine with the retrograde gun, the physiological effect of cementing was measured by recording heart rate, systolic blood pressure, O_2 saturation and end-tidal CO_2 concentration. Readings were made at one-minute intervals for 15 minutes, or until there was a return to baseline values.

Experimental study. We recorded pressures during simu-

lated arthroplasties, eight for each technique, using four cadaver femora and 12 made of plastic. These were prepared in a similar manner to the clinical series to simulate a Charnley total hip replacement.

In each specimen a 3.5 mm hole was drilled at the centre of each Gruen zone except zone 4. The tapered end of a saline-filled pressure monitoring line was fixed into each of the six holes (Fig. 1). Pressure transducers for each line were connected to a chart recorder which provided continuous pressure measurement until the prosthesis had been seated. The methods of cement mixing and insertion were as described for the clinical series with the same timings. The pressure transducers could not reliably measure pressures of more than 667 kPa (5000 mmHg).

Statistical analysis. We used an unpaired *t*-test when data were normally distributed and the Mann-Whitney test when they were not normally distributed. A *p* value <0.05 was considered significant.

RESULTS

Clinical study. The use of a cement gun produced a higher pressure sustained over a longer period. There were pressure waves which corresponded to the action of the trigger of the cement gun (Fig. 2). Finger-packing produced multiple short-duration peaks (Fig. 3).

The results are summarised in Table I which gives the peak pressure achieved during a trace and the mean values derived for each technique. Cement-gun insertion produced a significantly greater mean peak value than finger-packing (157 v 81 kPa; *p* = 0.008). The mean pressure throughout the period of recording was also significantly greater for the gun technique (42.9 v 16.9 kPa; *p* = 0.004). We found no significant differences in the total length of the recorded

Fig. 2

Output of pressure transducer during gun cementation, showing pressure against time.

Fig. 3

Output of pressure transducer during finger packing, showing pressure against time.

pressure curve or the proportion of the curve with a recorded pressure above the bleeding pressure of 27 mmHg (gun 82.2%; finger-packing 77.22%; $p = 0.39$). For the 19 patients who had physiological measurements the maximum pressure reached was found and the mean calculated. As above, the retrograde technique (185.9 kPa) was significantly greater than finger-packing (73.99 kPa) ($p = 0.0042$).

The physiological data produced complex curves for each parameter against time (Fig. 4), and analysis of these serial measurements was accomplished by the use of a summary measure.²⁵ By this means a single number was generated for each trace from the baseline value and either extreme reached during data collection (Fig. 5). For heart rate the summary measure was determined by subtracting the lowest value from the baseline. The summary measures for all patients were calculated, with statistical analysis

Table I. Summary of data and descriptive statistics for the in vivo experiment

	Technique	Number	Mean	Standard deviation
Peak pressure (kPa)	Finger	15	81.1	52.4
	Gun	16	156.9	82.6
Total time(s)	Finger	15	38.47	14.85
	Gun	16	47.08	25.2
Time with pressure recordable (s)	Finger	15	34.17	15.57
	Gun	16	42.85	24.94
Time with pressure higher than bleeding (s)	Finger	15	30.56	15.7
	Gun	16	40.08	24.84
Area under curve (kPa x s)	Finger	15	668	449
	Gun	16	1635	1038
Mean pressure (kPa)	Finger	15	16.91	8.91
	Gun	16	42.88	29.67

Fig. 4

Example of the serial data collected for four patients, in this case for expired CO₂ concentration.

Fig. 5

Example of the calculation of a summary measure from a single patient's results.

based on the mean value for each group (Table II). For heart rate and systolic blood pressure we found no statistical difference in the physiological effect. There was a significant difference for O₂ saturation ($p < 0.01$) and end-tidal CO₂ concentration ($p < 0.05$), with finger-packing causing the largest changes in both variables.

Experimental study. The in vitro pressure curves were similar to those observed clinically. Cement introduction by gun produced a sustained plateau of pressure especially at positions 3 and 5. Pressure was also more uniformly distributed. Finger-packing produced shorter peaks of pressure, predominantly at the proximal levels 1 and 7. The most dramatic feature for both methods of cementing was the extremely large and sustained rise in pressure during the insertion of the stem of the prosthesis.

Analysis by summary measures produced numerical data for statistical analysis²⁵ of two separate periods; before and after insertion of the stem. The duration of each period was measured, from a start time at the first pressure recorded. For each time period we recorded the maximum pressure and also measured the area under the curve to derive the mean pressure in that period. The results are shown in Table III.

During cement insertion, the gun technique produced

consistently greater maximum pressures than finger-packing (significant differences at transducers 3, 5 and 6). Finger-packing generated more pressure at proximal than at distal levels, a pattern reversed by the gun technique. Similar trends were shown for mean pressures, but differ-

Table III. Descriptive statistics showing the mean and standard deviation (SD) for each technique, time period, and pressure parameter in vitro

Transducer	Finger		Gun	
	Mean	SD	Mean	SD
Maximum pressure in cement insertion				
1	96.4	15.9	118.3	48.7
2	56.6	37.2	124.6	73
3	23.4	36.2	190.1	124.4
5	75.8	41.6	260	141.1
6	60.1	46.6	273.4	168.6
7	117.5	54	184.9	109
Maximum pressure in prosthesis insertion				
1	171.7	71.8	154.4	56.2
2	430.3	210.7	402.5	130.2
3	642	70.7	644.5	63.6
5	657.4	25.3	667	0
6	456	209.4	629.4	64
7	179.1	89.4	170.1	94.5
Mean pressure in cement insertion				
1	21.9	12.4	24.9	15.9
2	9	7.7	22.4	15.6
3	2.5	4.4	13.1	9.4
5	12.3	7.8	37.1	19.6
6	19.3	16.1	49.9	42.9
7	30.5	15.3	31.1	23.8
Mean pressure in prosthesis insertion				
1	120.9	60.2	79.8	19.8
2	266	133.6	202.7	69.2
3	393.6	90.5	351.9	71.1
5	418.6	88.6	365.1	71.1
6	310.5	131.8	401.1	120.1
7	130.2	72.1	72.4	30.8

Table II. Mean (SD in parentheses) value for summary measures for each technique and the level of significance of any differences between technique

Parameter	Finger-packing	Retrograde gun	
		Mean	p value
Heart rate (beats per minute)	5.4 (5.3)	3.2 (5.3)	0.39
Blood pressure (mmHg)	19.9 (14.2)	23.7 (22.4)	1.00
Oxygen saturation (%)	4.50 (4.88)	0.78 (0.97)	0.0058
Carbon dioxide (kPa)	0.74 (0.54)	0.29 (0.18)	0.042

ences were significant only at levels 3 and 5. There were no significant differences between cementing methods during insertion of the stem, at any level for maximum or mean pressures. Both techniques recorded much greater pressure distally than proximally.

DISCUSSION

The clinical study showed that the gun technique produced both the highest peaks of pressure and the highest mean pressure. This supports the argument that this method promotes better interlock. Both methods produced pressures in excess of the bleeding pressure at the endosteal surface.

Laboratory studies have shown improved cement penetration and cement-bone interface shear strength with pressures of 300 kPa,²⁶ 700 kPa²⁷ and 1230 kPa.²⁸ The maximum pressure in our study was well below these levels, suggesting that the laboratory models are not representative of the clinical situation and that, with the methods tested, such pressures are unattainable during cement introduction. Another important factor is that such high pressures may cause increased embolisation and cardiopulmonary instability. Laboratory-based conclusions on pressurisation have a doubtful value in clinical practice.

Our study has shown that the cement-gun method was associated with the greatest interface pressure and caused less physiological disturbance than the lower-pressure finger-packing technique. Lavage and brushing will reduce the amount of material available for embolisation and give a proximal 'clean' surface for cementing. The insertion of a cement restrictor helps to compartmentalise marrow, fat and blood, but finger-packing will tend to pressurise residual debris against the restrictor. This effect appears to be more important than the pressure generated at the cement-bone interface. In the absence of a cement restrictor, pressure would be applied directly to distal bone marrow and a high pressure would be expected to result in greater physiological disturbance. The restrictor may well be an important factor in reducing the physiological effects of cementing, when this is combined with retrograde cement-gun insertion. Most surgeons use cement restrictors,¹⁻³ except sometimes in elderly patients having a hemiarthroplasty for fracture. In such patients, however, the use of modern cementing methods, with a gun, appears to reduce cardiopulmonary instability. The use of cement guns, with restriction of the canal, should be encouraged in hemiarthroplasty operations.

An aim of our laboratory study was to show that the model which we used was a reasonable simulation of the clinical situation. The results in Tables I and III, allowing for different operating surgeons, show that there was a satisfactory level of agreement.

The maximum pressure during the insertion of the stem of the prosthesis was up to three times greater than that during the use of a cement gun and 30 times greater than

the maximum for finger-packing. The mean pressures during this period were up to 27 times greater and 35 times greater, respectively. This level of pressure, however, is applied to relatively high viscosity cement; it may not result in useful cement flow. For both maximum and mean pressure the cement-gun method achieved significantly higher values, but only at the distal transducers. During cement insertion, the reduced viscosity of the cement may allow greater cement penetration despite lower overall pressure.

We have confirmed that high pressures are generated during the insertion of the stem, but do not agree that this is the most significant part of cementing. The situation is very complex: only evaluation of cement penetration and interface strength will make this clear. This is the subject of our ongoing research.

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