AIR EMBOLISM DURING TOTAL HIP REPLACEMENT: COMPARISON OF TWO SURGICAL TECHNIQUES

R. D. EVANS, M. G. A. PALAZZO AND J. W. L. ACKERS

Cardiovascular collapse is an occasional but well documented complication of the use of acrylic bone cement (polymethylmethacrylate) during hip surgery [1,2]. Although the aetiology is still uncertain, fat [3-5] or air emboli [4] and hypersensitivity to the methylmethacrylate monomer (MMM) [6-9] have been implicated.

Doppler ultrasonography is a sensitive detector of venous air embolism [10-13] and has revealed that the presence of air in the right heart is common during hip surgery [13-16]. Although small air emboli may be benign, the possible serious sequelae of right heart air lock and left sided paradoxical embolism have led to the recommendation of various manoeuvres to reduce the incidence; these include femoral shaft venting [4,17], and carbon dioxide insufflation of the shaft before insertion of cement [6].

Surgeons wish to reduce the volume of air trapped between cement and femoral shaft, so that prosthesis fixation may be improved. Many surgeons now use a long nozzled gun for the introduction of acrylic cement for this purpose. Since the introduction of this device, we have had the clinical impression that the incidence of untoward events during hip replacement surgery has decreased.

We have examined the incidence of air embolism in a double-blind prospective clinical study, comparing manual insertion of cement with insertion using a gun.

PATIENTS AND METHODS

Twenty-one ASA I or II male and female patients scheduled to undergo total hip replacement surgery gave informed consent to take part in the study, which was approved by the local Research Ethics Committee. All patients had a normal preoperative ECG and arterial pressure. They were allocated randomly to two groups: group I (n = 9) had cement placed into the femoral shaft manually; group II (n = 12) had cement placed with a gun (table I).

All patients were premedicated with diazepam by mouth 1 h before operation. Anaesthesia was induced with thiopentone 5 mg kg⁻¹ and fentanyl 1 μg kg⁻¹. Tracheal intubation was facilitated with pancuronium 0.1 mg kg⁻¹, the lungs were venti-

<table>
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<th>Table I. Demographic details (mean (SD))</th>
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<td>Cement insertion</td>
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<td>Manual</td>
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<td>By gun</td>
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lated mechanically, and anaesthesia was maintained with 66% nitrous oxide and 1% enflurane in oxygen (plus fentanyl supplements as required). All patients were monitored continuously using ECG, transduced central venous pressure (CVP) (13-gauge Abbott Drum-Cartridge catheter) via the antecubital fossa, radial arterial pressure (AP) (20-gauge Teflon catheter), end-tidal $PCO_2$ ($P_{E, CO_2}$) (Datex Normocap) and precordial Doppler ultrasound (Sonicaid). The Doppler transducer was positioned to give an optimal signal, which was usually about the 3rd right intercostal space. All monitoring except ultrasound was displayed continuously on a calibrated four-channel Lectromed chart recorder.

The patients were positioned for surgery in a lateral tilt on a horizontal table. In accordance with our normal practice, a small test dose of carbon dioxide (0.3 ml) was injected before surgery, through the central venous catheter in order to determine the best position for Doppler auscultation. In every patient the listening anaesthetist recorded noises, unequivocally characteristic of air emboli, but no cardiovascular changes were noted in any patient.

Throughout the surgical procedure, Doppler sounds were monitored with headphones by an anaesthetist (R.D.E. or J.W.L.A.) who was unaware of the patient group and could not see the operation, which was performed in a Charnley tent. Characteristic sounds (loss of heart sounds, tinkling or "millwheel" type murmurs) heard through the headphones were indicated on the chart recorder using an event marker button. Another anaesthetist (M.G.A.P.) administered the anaesthetic and recorded the stages of the operation. For later analysis, the stages of the operation were defined as: (i) acetabular reaming, placement of acetabular cement and prosthesis and femoral reaming, (ii) insertion of femoral shaft cement and (iii) insertion of femoral prosthesis.

Fluid replacement consisted of crystalloid, in a volume appropriate to the calculated starvation deficit; blood loss was replaced as it occurred. Care was taken to avoid any air trapped in the i.v. infusion catheter reaching the patient.

In group I patients, acrylic cement (Simplex) was introduced into the femoral shaft by hand. The femoral shaft was vented using a 12-French gauge suction catheter. In group II patients, the same cement was introduced into the femoral shaft using an Exeter cement gun (with Howmedica disposable syringe insert) without venting. In all other details the surgical techniques were similar (anterolateral approach and Charnley prosthesis).

Following completion of the operation, the chart was analysed for recorded changes which may have been attributable to air emboli. A change of more than 10% in any of the continuously recorded variables (AP, CVP, $P_{E, CO_2}$, ECG) coincidental with Doppler evidence of air embolism was considered an acute physiological event, and is referred to as such in this paper. Data were analysed using Fisher's exact probability or the Mann-Whitney $U$ test as appropriate. $P < 0.05$ was considered statistically significant.

**RESULTS**

For the purposes of statistical analysis the surgical procedure was divided into three periods. The procedure during the first period was the same in both groups. Table II shows the number of patients in both groups that had one or more acute physiological events during this first stage. Among the 21 patients, six had an increase in systolic arterial pressure, and three of the six had a concomitant increase in central venous pressure; two of them also had ventricular extrasystoles. However, none of the 21 patients had episodes of hypotension, decreases in $P_{E, CO_2}$, or altered heart rate. No statistical difference was found between

<table>
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<th>ECG</th>
<th>Altered AP</th>
<th>Positive Doppler ultrasound</th>
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<tr>
<td>Altered HR</td>
<td>Decreased</td>
<td>Increased          DOP</td>
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<tr>
<td>Arrhythmia</td>
<td></td>
<td>Decreased CVP  $P_{E, CO_2}$</td>
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<td></td>
<td>0</td>
<td>3</td>
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**Table II. Acute physiological events consistent with air embolism during hip surgery before insertion of femoral cement (acetabular reaming, cement and prosthesis insertion; femoral reaming). Number of patients demonstrating acute changes in the recorded physiological variable (multiple changes in the same variable were counted once) in the combined groups (total $n = 21$)
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Table III. Number of patients with evidence of air embolism (acute changes in individual physiological variables: heart rate and rhythm, AP, CVP, PFCO₂, Doppler ultrasonography) during insertion of femoral cement. Each patient was scored according to the number of such physiological variables noted to change during the surgical stage (to a maximum of six variables examined†). No statistically significant difference between groups during this period (data not shown). Before insertion of the femoral cement, by either method, no patient required clinical intervention because of air embolism.

The two study groups during this period (data not shown). Before insertion of the femoral cement, by either method, no patient required clinical intervention because of air embolism.

Table III shows the acute physiological events noted to occur during the second period (insertion of femoral cement by each method). For each patient, the number of recorded variables which changed concomitantly with Doppler evidence of air embolism were summated (to a maximum of 6, as six variables were examined; multiple changes in a single variable were counted only once). There was an increased frequency of acute physiological changes in those patients having cement inserted by hand, but this was not statistically significant.

During the third period (positioning of the femoral head), the frequency of acute physiological events was significantly higher in those patients in whom the cement was inserted manually than in the other group (P < 0.01) (tables IV, V). Furthermore, positioning of the femoral prosthesis in that group was associated with a significantly greater incidence of acute physiological changes than occurred during the earlier period of cement insertion (tables III, V) (P < 0.05). However, this was not the case for those patients in whom the cement was inserted by gun. Following insertion of the femoral cement, no patient having cement insertion by gun required clinical intervention for air embolism.

Three patients in whom the cement was inserted manually had clinically significant emboli requiring intervention (rapid fluid infusion, increased FiO₂ and reduced enflurane): one during insertion of cement and two during subsequent positioning of the prosthesis. In both groups, there was no correlation between the frequency of Doppler-detected air emboli and the side of the operation.

DISCUSSION

Air embolism during total hip replacement surgery is potentially hazardous and may occasionally be fatal [1,2,13,14,16,18]. The manoeuvres that have been suggested to reduce the incidence of air embolism, such as venting the femoral shaft [5,14,16,17], have met with limited success — a soft suction catheter may collapse from pressure exerted by the inserted prosthesis, rendering it ineffectual. Vent holes drilled in the distal femoral shaft have also been described [17].

In our study there was no episode of hypotension in either group up to the time of insertion of femoral cement. However, we recorded six acute episodes of hypertension among the 21

Table IV. Acute physiological events consistent with air embolism during insertion of femoral head prosthesis. Values represent number of patients demonstrating acute changes in the recorded variable. **Significantly different from gun insertion (P < 0.01)

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<tr>
<th>Cement insertion</th>
<th>n</th>
<th>Altered HR</th>
<th>Arrhythmia</th>
<th>Decreased CVP</th>
<th>Increased PFCO₂</th>
<th>Positive Doppler ultrasonography</th>
</tr>
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<tbody>
<tr>
<td>Manual</td>
<td>9</td>
<td>2</td>
<td>2</td>
<td>6**</td>
<td>3</td>
<td>9**</td>
</tr>
<tr>
<td>By gun</td>
<td>12</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

Table V. Number of patients with evidence of air embolism (acute changes in individual physiological variables: heart rate and rhythm, AP, CVP, PFCO₂, Doppler ultrasonography) during insertion of femoral head prosthesis.** Changes more frequent (P < 0.01) than in the other group

<table>
<thead>
<tr>
<th>Cement insertion</th>
<th>Number of acute events</th>
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<tbody>
<tr>
<td>Manual</td>
<td>9 1 0 1 3 4 0 0 2 1 2 8</td>
</tr>
<tr>
<td>By gun</td>
<td>12 0 0 0 1 1 2 0 4</td>
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</table>
patients, during the period before cement insertion, and these coincided with characteristic Doppler sounds of air embolus. This sudden hypertensive response has been recorded previously [2,6,9], and has been suggested to be neurogenic in origin [2].

Air emboli were common throughout the surgical procedure. There was a significantly increased frequency of acute physiological changes during prosthesis insertion in the patients in whom the cement was inserted manually. Abnormalities during placement of femoral cement alone, without prosthesis, were seen by Phillips, Cole and Lettin [2], who found that prosthesis insertion was not essential for the production of cardiovascular abnormalities. They suggested that femoral cement was more potent at inducing such changes than acetabular cement; they suggested further that this was caused by a side effect of the methylmethacrylate monomer, and not by air embolus. We detected cardiovascular abnormalities following insertion of cement, but before prosthesis insertion in both groups, but only in the presence of Doppler evidence of air embolism. Therefore we cannot support or refute their contention with our present data.

The most significant difference between the two groups in the number of air emboli was during positioning, and forcible hammering, of the femoral prosthesis, suggesting that more air is trapped with the manual placement of cement. Presumably, air is forced into the circulation through vascular openings in the bony medulla as a result of the high pressures generated within the distal femoral shaft during hammering. Interestingly, the three patients who became clinically compromised during the femoral cement–prosthesis procedure were all in the group in whom insertion of cement was manual, two of whom were the only subjects to show reductions in $P_{\text{E}_2\text{CO}}$. One of these patients required intervention before insertion of the prosthesis. It would appear that venting the femoral shaft does not totally protect the patient from the effects of air embolism. This is not surprising if one considers that the cement traps air along the cylindrical circumference in addition to the blind end of the femoral shaft; voiding of all the air would thus require several vents.

During this study we were unable to show that the surgical position of the patient influenced the frequency of detection of air emboli or their sequelae. None of our patients had ECG or neurological evidence of paradoxical left sided emboli.

Doppler ultrasonography was a sensitive detector of air embolus; in decreasing order of frequency, supporting physiological evidence included arterial pressure changes, increased central venous pressure, arrhythmias, altered heart rate and decreased $P_{\text{E}_2\text{CO}}$. Cardiovascular abnormalities were variable, increase in arterial pressure being more frequent than depression. Changes in $P_{\text{E}_2\text{CO}}$ were a late finding in our patients.

Recently, other methods of air emboli detection have been described. These include end-tidal nitrogen [19], oesophageal Doppler ultrasonography [20] and oesophageal echocardiography [17]. Although these methods are more sensitive than precordial Doppler ultrasound, our data would suggest that such sensitivity is not required to detect clinically significant embolism.

ACKNOWLEDGEMENTS

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REFERENCES

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