THE DETECTION OF FAT EMBOLISM BY TRANSOESOPHAGEAL ECHOCARDIOGRAPHY DURING REAMED INTRAMEDULLARY NAILING

A STUDY OF 24 PATIENTS WITH FEMORAL AND TIBIAL FRACTURES

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We performed transoesophageal echocardiography on 24 patients during reamed intramedullary nailing of 17 tibial and seven femoral fractures. In 14 patients there was only minimal evidence of emboli passing through the heart, but in six copious showers of small emboli (< 10 mm maximum dimension) were observed. In four other patients, there were also multiple large emboli (>10 mm maximum dimension). Three of these patients developed fat embolism syndrome postoperatively and one died. Earlier nailing was associated with smaller quantities of emboli.

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The fat embolism syndrome (FES) develops in 0.5% to 2% of all patients with fractures of the long bones (Gossling and Pellegrini 1982) and has been associated with high morbidity and mortality (Fuchsig et al 1967). Since the early 1980s the use of intramedullary nailing for tibial and femoral fractures has become popular, and excellent results have been reported (Christie et al 1988; Court-Brown, Christie and McQueen 1990). The trend towards intramedullary nailing is even greater for patients with multiple injuries, partly because early fixation is thought to minimise the associated respiratory complications (Riska and Myllynen 1982; Johnson, Cadambi and Seibert 1985; Bone et al 1989). A number of reports, however, have linked intramedullary nailing and reaming with the development of fat embolism (Manning et al 1983; Talucci et al 1983), and it has been suggested that intramedullary reaming may precipitate or exacerbate the release of embolic material from the fracture site into the systemic circulation.

The use of transoesophageal echocardiography to detect such embolic material as it passes through the heart was suggested in a case report by Wenda et al (1989). We have used the technique to monitor a series of patients during reamed intramedullary nailing. Our aim was to record any evidence of embolism and to relate the findings to the subsequent clinical course of the patient.

PATIENTS AND METHODS

We studied 17 tibial fractures and 7 femoral fractures in 24 patients. There were 12 men and 12 women with a mean age of 38 years (17 to 85). The index fracture was the only injury in 19 patients, but the other 5 had multiple injuries, with Injury Severity Scores (Baker et al 1974; Baker and O’Neill 1976) of over 16. In three patients the tibial fractures were compound: two had Gustilo grade-I wounds and one had a grade-II wound. All the fractures were treated with a locking intramedullary GK nail. Nailing was performed within 24 hours of injury in 22 patients; one tibial fracture was nailed after three days and one femoral fracture referred from another centre was nailed at ten days.

Transoesophageal echocardiography was performed throughout the operation. After anaesthesia had been induced, a 5 MHz transverse-plane echocardiography probe (Siemens, Sonoline SI1200) was positioned in the patient’s oesophagus to provide continuous imaging of the right atrium and right ventricle. The probe was left in position throughout the procedure and was removed immediately before reversal of anaesthesia. VHS video tape recordings were made for subsequent analysis. Other intraoperative monitoring included heart rate, blood pressure, ECG, pulse oximetry, and end-tidal CO₂ levels. When a central venous catheter had been inserted for clinical purposes, 10 ml samples of right atrial blood were taken before surgery and when embolic material was
Table I. Major and minor criteria for the diagnosis of fat embolism syndrome (FES). A positive diagnosis requires at least one major and four minor signs (after Gurd 1970)

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<tr>
<th>Major criteria</th>
<th>Minor criteria</th>
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<tr>
<td>Petechial rash</td>
<td>Tachycardia &gt; 110/min</td>
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<tr>
<td>Hypoxaemia (PaO₂ &lt; 60 mmHg)</td>
<td>Pyrexia &gt; 38.5°C</td>
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<td>CNS depression</td>
<td>Retinal emboli on fundoscopy</td>
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<tr>
<td>Pulmonary oedema</td>
<td>Lipuria, Thrombocytopenia, Decreased haematocrit, Fat globules in sputum</td>
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demonstrated within the heart chambers. These samples were analysed for fat content using the method described by Gurd (1970).

Before operation, no patient had clinical evidence of FES. The diagnosis of FES postoperatively was based on the major and minor criteria of Gurd (1970) (Table I). The analysis of the echocardiographic images was performed by an experienced observer (ACHP) with no knowledge of the postoperative course of the patient.

RESULTS

Echocardiography. The patients were divided into three groups based on the appearance of embolic material within the right heart chambers:

Group I. The echocardiographic recordings in this group showed little or no evidence of embolic phenomena (Fig. 1). The 14 patients had 12 tibial fractures and two femoral fractures, all closed injuries. Four fractures were caused by high-energy trauma, and all were nailed within 24 hours. In all 14 cases, intraoperative physiological parameters remained within normal limits, and the postoperative recovery and subsequent clinical progress were uneventful. No patient developed evidence of fat embolism.

Group II. This group of six patients showed showers of moderate quantities of echogenic material 1 to 10 mm in diameter. They had three tibial and three femoral fractures. Three fractures were the result of high-energy injuries; one tibial fracture was a Gustilo type-I open injury, the others were closed. All fractures were internally fixed within 24 hours.

Little or no intracardiac embolism was observed during skin preparation, draping, or skin incision in any patient, but emboli usually appeared within 10 seconds of starting the closed reduction of the fracture. A shower of highly echogenic masses was seen within the right atrium (Fig. 2). Successive showers of emboli were also associated with the broaching of the intramedullary canal, the passage of the reamers and the insertion of the nail. The volume and duration of the appearance of embolic material varied, but tended to be greatest with reaming and nail insertion.

Despite these appearances, no intraoperative physiological abnormalities were recorded and no patient developed postoperative respiratory problems or other evidence of fat embolism.

Group III. Echocardiography in this group showed large quantities of echogenic material with multiple small masses of 1 to 10 mm diameter and also large discrete emboli 1 to 8 cm in maximum dimension (Fig. 3). There were four patients, with two femoral and two tibial fractures. Three of the fractures were caused by high-energy trauma and one tibial fracture was a Gustilo type-II open injury. Two of the nailings were performed within 24 hours, one after three days, and one after ten days following transfer from another hospital.

The passage of the reamers and of the nail was associated with the appearance of embolic material.
within the right atrium; all the large masses were seen at these stages of the operation. Three of the four patients developed FES, and this was severe enough in two to require ventilation.

One of these two patients had developed profound hypotension during reaming (BP from 152/80 to 72/40), with arterial desaturation (SaO₂ 98% to 75%) and a fall in end-tidal CO₂ (28.5 mmHg to 9 mmHg). Echocardiography had shown massive quantities of embolic material within the right heart chambers immediately after reaming had started. Although reaming was stopped, large quantities of embolic material continued to appear for 20 minutes. During this period there was right ventricular dilatation with the development of severe tricuspid incompetence. This precipitated paradoxical embolism through a patent foramen ovale, and large amounts of embolic material were seen to cross the interatrial septum into the left atrium, with subsequent passage through the left ventricle into the aorta (Fig. 4). This patient died of fat embolism 72 hours later.

**Histology.** We have performed a number of preliminary investigations into the composition of the observed emboli. Post-mortem examination of the patient who died of fat embolism showed the deposition of fat globules in the microvasculature of both pulmonary and systemic circulations, including renal and cardiac vessels (Fig. 5), but we were unable to locate any macroemboli corresponding to those observed during echocardiography. The right atrial blood samples obtained from five patients in groups II or III with moderate or severe emboli all showed a high lipid content on blood films examined by Gurd's method (1970).

**DISCUSSION**

Despite more than a century of research, the pathophysiology of FES remains contentious. Two theories have been proposed. The mechanical hypothesis considers that disruption of intramedullary veins allows marrow fat to gain direct access to the venous circulation and
then to the lungs (Peltier 1988). Systemic embolisation may occur when fat migrates through pulmonary precapillary shunts into the pulmonary veins. This theory is supported by the finding of bone-marrow material in lung sections of patients with fractures of the long bones (Meek, Woodruff and Allardycce 1972; Weinberg and Finsterbush 1972). The second, biochemical, hypothesis suggests that chemical mediators released from the fracture change lipid solubility in blood, causing coalescence and subsequent embolisation. It has also been suggested that fatty acids released at the time of injury are directly toxic to the pneumocyte (Levy 1990).

Two of our findings are inconsistent with either hypothesis and suggest that the pathogenesis of FES needs re-evaluation. The first unexpected observation was the demonstration of very large emboli in four of our patients. Small fat emboli have been shown in other studies of reamed nailing, but the appearance of large emboli has not previously been recognised. The composition of the large emboli remains uncertain, but the echocardiographic appearances are not typical of thrombus. None of the observed large emboli was retrieved at post-mortem, but the widespread microscopic fat emboli that were found suggest that the large masses were at least partly of lipid material.

The first appearance of emboli in the heart was directly related to the manipulation and reaming of the fracture. It is therefore reasonable to assume that the material originated from the fracture site or the adjacent soft tissues. The large masses probably arise from the coalescence of fat and possibly other material such as thrombus, which subsequently disintegrate in the lung microvasculature. Preliminary haematological study of the venous blood in the heart also suggested a high lipid content. Both hypotheses for the pathogenesis of FES are based on the assumption that the embolic material, whatever its content, is in small aggregations. The potential effect of large volumes of embolic lipid has not previously been considered.

Our second finding of particular interest was the demonstration of paradoxical embolism in one case. The systemic manifestations of FES have been assumed to result from the passage of fat emboli through pulmonary precapillary shunts, or directly across the pulmonary capillary bed. The demonstration of paradoxical embolism across a patent foramen ovale followed by the development of systemic FES, suggests that this route may be more significant than previously appreciated. Patent foramen ovale has a prevalence of 20% to 34%, and although we can find no description of paradoxical embolism of fat, it is well recognised that paradoxical embolism of air and thrombus can occur. Pulmonary fat embolism will increase right atrial pressure, and this may open the flap valve of the fossa ovalis, allowing embolic material to cross to the left side of the heart without passage through the lungs. We saw clinical FES only in our group-III patients, in all of whom large volumes of embolic material had passed through the heart. The most severe clinical symptoms were in the two patients who had nailing delayed beyond 48 hours.

The implication of our findings for intramedullary nailing and its relationship to fat embolus is not yet clear. Our preliminary results suggest that transoesophageal echocardiography may have a useful role in the prediction of patients at risk of FES after nailing. Further study is required of the relationship between echocardiographic findings, the severity of fracture, the timing of surgery and the development of FES.

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No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.
REFERENCES


