Fat embolism occurs following fractures of a long bone or arthroplasty. We investigated whether paradoxical embolisation through a venous-to-arterial circulation shunt (v-a) could lead to cerebral embolisation during elective hip or knee arthroplasty.

Transcranial Doppler ultrasound (TCD), following the intravenous injection of microbubble contrast, identified the presence of a shunt in 41 patients undergoing hip (n=20) or knee (n=21) arthroplasty. Intra-operative cerebral embolism was detected during continuous TCD monitoring. Of the 41 patients, 34 had a v-a shunt of whom 18 had an embolism and embolism only occurred in patients with a shunt (p = 0.012). Spontaneous and larger shunts were associated with a greater number of emboli ($r_s = 0.67$ and $r_s = 0.71$ respectively, $p < 0.01$). Observations in two patients with large spontaneous shunts revealed 368 and 203 emboli and unexplained post-operative confusion and pancreatitis.

Paradoxical cerebral embolisation only occurred in patients with a shunt and may explain both post-operative confusion and fat embolism syndrome following surgery.

Received 19 December 2002; Accepted after revision 30 April 2003

Fat embolism may occur following fracture of a long bone or arthroplasty and may lead to coma or death.1,2 Emboli can be demonstrated in the right side of the heart by transoesophageal echocardiography (TOE) in most patients during major joint arthroplasty.3,4 Severe and fatal systemic embolisation has been linked with a patent foramen ovale (PFO),1,2 which is the most common venous to arterial (v-a) circulation shunt. This congenital defect is found at autopsy in approximately 27% of adults.5

Although a PFO can be clearly identified by TOE, a v-a shunt may be detected with similar sensitivity using a contrast transcranial Doppler ultrasound technique (TCD).6 This simple, non-invasive technique can also detect pulmonary arteriovenous shunting.7 We investigated the frequency of a v-a shunt in patients undergoing elective hip and knee arthroplasty and the relationship between a v-a shunt and cerebral embolisation during surgery.

Patients and Methods

We studied 41 consecutive patients, 25 men and 16 women, with a mean age of 67 years (49 to 84), who underwent primary total hip or total knee arthroplasty for osteoarthritis. Patients with a history of stroke or symptomatic carotid artery stenosis and those with a likely source of arterial emboli, such as atrial fibrillation or a prosthetic heart valve, were excluded. All patients gave informed consent before entering the study.

TCD detection of v-a shunt. Both middle cerebral arteries were insonated 24 hours pre-operatively using 2MHz TCD (Neuroguard, Medasonics, Newark, California) secured in an adjustable headband. A microbubble emulsion was prepared by mixing rapidly 1 ml of air with 0.5 ml of the patient’s blood, made up to 10 ml with sterile saline, and divided between two 10 ml syringes connected through a three-way tap attached to an 18 g intravenous cannula in an antecubital vein. The emulsion was injected immediately with the patient reclining at 45° on a couch. Air emboli were recognised as high intensity, predominantly unidirectional, short duration signals extending beyond the Doppler waveform envelope. If less than 25 spontaneous embolic signals were detected following either of the two injections at rest, the microbubble emulsion was injected twice more, with cough provocation for five seconds and twice with Valsalva provocation. The Valsalva manoeuvre was maintained at 40 mmHg for five seconds by asking the patient to blow through a mouthpiece attached to a manometer. The TCD
output was recorded on digital audiotape and analysed by two trained observers who reported the total number of air emboli entering the middle cerebral arteries, and the number of cardiac cycles between the microbubble injection and the detection of the first air embolus. Shunts were categorised according to whether they occurred at rest (‘spontaneous’) or only on coughing or the performance of the Valsalva manoeuvre (‘provoked’).

Spinal anaesthesia with heavy 0.5% Bupivicaine and Fentanyl was used. Knee arthroplasty was performed with a thigh tourniquet inflated to 30 mmHg after elevation of the leg. The Genesis knee prosthesis (Smith and Nephew Inc, Memphis, Tennessee) or the Charnley hip prosthesis, were cemented using Palacos cement (Biomet Merck, Sjöbo, Sweden).

**Intra-operative cerebral emboli detection.** The middle cerebral arteries were insonated again. Bilateral insonation was straightforward during knee surgery but, as hip arthroplasty was performed in the lateral position, only the ipsilateral middle cerebral artery could be insonated. The TCD signal was recorded onto digital audio tape throughout the operation and analysed subsequently by two trained observers. The detection of emboli was performed according to the international consensus.\(^8\)

**Analysis of results.** Fisher’s exact test was used to compare the frequency of intra-operative emboli in patients with and without a v-a shunt. The Mann Whitney U test was used to compare the number of intra-operative emboli during hip and knee surgery and between ‘spontaneous’ or ‘provoked’ shunts. Logistic regression analysis was used to explore whether the size of a v-a shunt influenced the number of cerebral emboli. The association between the size of a shunt and the number of intra-operative cerebral emboli, was assessed by Spearman’s rank correlation.

### Results

A v-a shunt was detected in 34 of the 41 patients (18 hip and 16 knee arthroplasties). Of these, 16 met criteria for a PFO with more than 15 microbubbles entering the cerebral circulation within 12 cardiac cycles.\(^9\) All these were ‘spontaneous’, whereas 12 of the 18 small shunts required ‘provocation’ (Fig. 1). Microbubbles usually appeared in the cerebral circulation, more than 12 cardiac cycles after injection in small shunts, suggesting a minor pulmonary arteriovenous shunt. Patients undergoing either hip or knee arthroplasty did not differ from each other in regard to the size or frequency of v-a shunts.

Intra-operative cerebral emboli were detected in 18 of the 34 patients (53%) with a shunt, compared with none in those without a shunt (p = 0.012). Cerebral emboli were detected from the time the bone was first breeched, but were most frequent during femoral reaming, injection of cement and insertion of the prosthesis. Twelve of the 18 patients (67%) undergoing hip arthroplasty and six (38%) of the 16 undergoing knee arthroplasty with a shunt also showed cerebral emboli (p = 0.68).

Shunts of a ‘spontaneous’ nature were seen in 16 of 22 patients, giving a median (interquartile range) of 6.5 (2.5 to 27) intra-operative cerebral emboli, compared with only one embolus in two of the 12 patients with a shunt demonstrable only on ‘provocation’ (p < 0.001, Fig. 2a). Multiple intra-operative emboli also occurred in 13 of 18 patients with shunt criteria indicative of a PFO compared with only 1 to 3 emboli in five of 18 patients with a small v-a shunt (Fig. 2b). The presence of a ‘spontaneous’ shunt was closely associated with intra-operative cerebral emboli (odds ratio 28, 95% CI 4 to 198, p = 0.007). Spontaneous and larger v-a shunts were associated with more cerebral emboli (\(r_s = 0.67\) and \(r_s = 0.71\) respectively, p<0.01). Two patients with large and ‘spontaneous’ shunts (108 and 52 microbubbles) had 368 and 203 cerebral emboli, respectively, during hip arthroplasty and suffered unexplained confusion and pancreatitis.

### Discussion

Intra-operative cerebral emboli occurred in over half of our patients undergoing hip or knee replacement. These emboli could only be detected in patients with a v-a shunt suggesting that they are paradoxical, arising from the veins draining the operative site. The number of cerebral emboli during surgery was related to the size and ‘spontaneity’ of the shunt. Their TCD characteristics and relationship to bone penetration suggest that these emboli were semi-solid rather than gaseous.

When comparing TCD with TOE for PFO detection, our criteria of more than 15 embolic signals within 12 cardiac cycles\(^9\) is similar to that previously reported.\(^10\) These large shunts were almost always associated with cerebral emboli during hip or knee arthroplasty. Although massive pulmo-
Fat embolisation may increase right heart pressures and v-a shunting, most patients experiencing cerebral emboli during surgery had a ‘spontaneous’ shunt before surgery. The small and delayed emboli probably pass through pulmonary a-v shunts and are unlikely to be clinically significant. This finding supports the ‘mechanical hypothesis’ for transpulmonary passage of fat emboli in patients without a PFO.11

The association between PFO and cryptogenic stroke in young adults has been established for many years.10,12 Cerebral embolisation during cardiac surgery is associated with cognitive impairment and biochemical evidence of neuronal damage.13,14 These paradoxical emboli during surgery may embolise widely throughout the arterial circulation to distant organs such as the gut, kidney and liver. The two patients with the largest numbers of cerebral emboli in the present study suffered complications. It is possible that paradoxical emboli may be a cause of the acute confusion that commonly complicates major surgery of any type. The importance of these intra-operative paradoxical emboli in causing post-operative confusion and possibly damage to other organs needs to be studied urgently.

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


