Acta Orthop. Belg., 2009, **75**, 671-677

ORIGINAL STUDY

Intra-operative cerebral microembolisation during primary hybrid total hip arthroplasty compared with primary hip resurfacing

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Fat embolism during total joint arthroplasty or intramedullary procedures is well documented and is infrequently fatal. Considerable morbidity is associated with fat embolism syndrome, and post operative cognitive dysfunction is frequently seen, yet the exact pathophysiology remains unclear.

Intraoperative cerebral microemboli can be detected using transcranial Doppler ultrasound and moreover the presence of a patent foramen ovale (PFO) may be examined for using a validated technique employing this modality. Persistent patent foramen ovale may act as a conduit for embolic material to traverse from the venous to the systemic circulation and consequently affect cerebral function.

We wished to 1) investigate the incidence of cerebral microembolisation during primary hybrid total hip arthroplasty and compare this with hip resurfacing, 2) examine the influence of patent foramen ovale on cerebral microembolisation and 3) assess the influence of cerebral microemboli on the outcome of patients undergoing these procedures.

We prospectively compared 12 patients undergoing hip resurfacing with 12 patients undergoing hybrid total hip replacement (THR) for the incidence and load of intraoperative cerebral microemboli, using transcranial Doppler. All patients were tested for the presence of a patent foramen ovale using a validated technique. Outcome was assessed using the WOMAC, Harris Hip Score, Oxford Hip Score and EuroQoL quality of life measure.

No patient in the hip resurfacing group demonstrated intra-operative cerebral microembolisation. Five patients in the THR group showed transcranial Doppler evidence of microemobli during the procedure. With the small numbers of patients available, there was not a significant difference in microemboli load between the groups (p = 0.09). There was no significant difference between the groups regarding the incidence of PFO (p =0.78). There was no significant relationship between the incidence and total microemboli load and the incidence of PFO (p = 0.56). There was no significant difference in outcome at six months between patients who demonstrated microemboli and those who did not.

The incidence of cerebral microembolisation during hip resurfacing appears to be very low. Although our study demonstrated cerebral microemboli in a significant proportion of patients undergoing primary hybrid THR, the numbers of microemboli were low and the presence of a patent foramen ovale did not

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No benefits or funds were received in support of this study

influence microemboli incidence or load. Finally, patients who demonstrated cerebral microemboli did not have a worse outcome than patients who did not.

Keywords : total hip arthroplasty ; hip resurfacing ; cerebral microembolisation.

INTRODUCTION

The incidence of fat embolism after long bone fracture has been recognised for over a hundred years but the clinical manifestation of this, Fat Embolism Syndrome (FES) was described by Gurd and Wilson as recently as 1974 (*11*). Moreover, it has only been recently recognised in endoprosthetic surgery, when the increase in intramedullary pressure, during the insertion of the stem seems to be the decisive pathogenic factor for the development of emboli (*18*). Furthermore, with the use of conventional cementing techniques, the intramedullary pressures are raised further (*30*) and the major component of cement, polymethylmethacrylate, has been implicated in producing a hypercoagulable state both locally at the site of the operation and systemically via marrow embolisation of tissue thromboplastin into the veins. Activation of clotting, cytokine and kinin cascades occurs and thrombogenesis ensues (*26,32*). The ultimate fate of these microemboli and their effect is unknown. Presence of embolic material in the right heart is well known during hip surgery (*4,14,21,31*), but animal studies have shown microemboli deposition in several end organs including the brain (*1,25*).

Few studies have been performed assessing the true incidence of intra-operative cerebral microembolisation during total joint arthroplasty ; the incidence until now has been reported to be between 40% and 60% (*9,23,30*). Hip resurfacing is accepted as a less invasive method of joint arthroplasty in terms of intramedullary instrumentation, but no study has examined the incidence of cerebral microembolisation during this procedure. Finally, the route by which microemboli reach the end organs is under investigation and hypotheses have been put forward, but much work thus far has been in the animal model (*3*). A proposed route of passage for microemboli is across a patent foramen ovale (PFO), a congenital / neonatal conduit between the right and left chambers of the heart which may persist asymptomatically in adult life. At autopsy, this congenital defect was found in 27% of adults (*12*). The presence of such a conduit was examined for in this study.

The purpose of this study was to compare the incidence and load of cerebral microembolisation during hip resurfacing and primary hybrid hip arthroplasty and to assess the role of PFO as a potential conduit for microemboli to reach the systemic circulation. We also wished to assess whether cerebral microembolisation affected patient outcome.

PATIENTS AND METHODS

We studied 12 consecutive patients undergoing hip resurfacing (HR) performed by the senior author (FSH). We then compared these patients to 12 hybrid total hip arthroplasties (THA) reviewed retrospectively in patients matched for gender and age at surgery. The patients in the THA group formed part of a larger study assessing intra-operative cerebral microembolisation and neuropsychological outcome and underwent surgery not more than a year prior to the HR patients. Full local ethics committee approval was obtained for all studies mentioned.

The pre-operative pathology was osteoarthritis in all cases.

All HR patients received the Birmingham hip resurfacing (Midland Medical Technologies, Birmingham, UK). This comprised of a cemented femoral component and an uncemented hemispherical flanged hydroxyapatite and porous-coated acetabular component.

The hybrid THA comprised of the Spectron (Smith & Nephew Orthopaedics, UK) cemented femoral component and the Trilogy (Zimmer Ltd, UK) uncemented acetabular component. In all cases a 28 mm Cobalt Chrome or Oxinium femoral head was used.

Both types of procedure were carried out through a posterior approach, which was extensile for the resurfacing procedure.

Exclusion criteria for both groups included history of transient ischaemic attack or stroke or previous history of cerebral injury or other ongoing cerebral disease e.g. tumour, carotid artery stenosis (patients were screened with auscultation of the neck ; if a bruit was audible the patient was excluded and carotid duplex scanning was arranged) and history of atrial fibrillation or prosthetic heart valve replacement as they are both sources of arterial emboli.

Patients fulfilling the criteria were then invited to participate. The trial was explained verbally to patients who were then given a written information sheet to read. Patients were requested to sign a consent form if they agreed to participate.

Outcome assessment

All patients were asked to complete the WOMAC (*3,28*), Oxford Hip Score (*5*) and EuroQol quality of life score (*10,22*) ; the Harris Hip Score was completed by the author (RP) (*13*). All scores were completed pre-operatively and six months post-operatively in the out-patient setting. Cognitive function data was not collected in this study. They were then followed up yearly. The EuroQol score describes health status in terms of five dimensions : mobility, self-care, usual activity, pain/discomfort and anxiety/depression. Each dimension is divided into three levels : no problem ; some problem ; extreme problem. A unique health state is defined by combining scores and comparing with a value set for the local population (UK value set used). Scores range from -0.594 (poor) to 1.000 (best outcome). Outcome assessment was carried out in the out-patient clinic setting by the author. All scores are validated. Operation time and day to discharge were also recorded.

Intra-operative cerebral microemboli detection

All the cases were carried out using general anaesthesia. Intra-operative transcranial Doppler (TCD) was used to measure cerebral microemboli load. Monitoring was continuous, commencing before the operation started i.e. before the skin incision and ending after the dressing was applied and the patient had been returned to the supine position.

The Doppler machine used was a Nicolet EME Pioneer 2020 Transcranial Doppler system. The middle cerebral artery was insonated using a 2 MHz pulsed wave transducer and the probe was secured to the skull using an elasticated headset, which allowed for prolonged monitoring. The side was dependent on the side for surgery. Microembolic events were recorded onto videotape for subsequent playback and analysis. The microemboli were counted manually “off line” (i.e. after the operation) using their unique auditory and visual characteristics. International consensus criteria were used for defining microemboli (*24*). Briefly, high intensity transient signals (HITS) are detected which correspond to gaseous or solid microembolic materials. The key is to recognise genuine microemboli from artefact ; a characteristic sudden “chirp” is the typical sound of a HITS and hearing HITS is the most important tool for detection. The HITS is so characteristic to the human ear that after several hours training a high level of interobserver agreement can be obtained. HITS are also visualised in the Fourier transform (FFT). Based primarily on a signal analysis approach, three criteria for defining HITS were proposed : the signal increase lasts shorter than 300ms, the sound exceeds the background by at least 3 dB and is unidirectional within the Doppler velocity spectrum.

Patent foramen ovale detection

All patients were prepared with an 18-gauge intravenous catheter inserted into an ante-cubital or a large forearm vein and a connecting short flexible tube (*16*).

Microcavitation saline contrast was generated by mixing 9 ml of normal saline and 1 ml of air between two 20 ml syringes connected to a three-way stopcock (*6*). The contents of the syringes were exchanged energetically and rapidly between each other at least ten times. After preparation, the contrast was injected as a bolus immediately with a two minute interval between each test.

A validated technique for TCD detection of PFO was used (*8,27*) : A Valsalva manoeuvre was created by increasing and holding end inspiratory pressure. This was facilitated in the intubated patient by positive pressure ventilation for 5 seconds after the start of the injection and release after 5 seconds had elapsed.

The diagnostic time window for a microembolic signal to appear was 25 seconds after injection. One or more microembolic signals in the diagnostic time window was deemed a positive result. If a positive test occurred, no further tests were carried out. A total of three such tests were performed. All testing was performed before surgery commenced.

Statistical analysis

The data were analysed using the SPSS v12.0.1 (SPSS Inc, Chicago, Illinois). An independent two-tailed t test was used to compare operative time, microemboli, discharge day and all outcome scores between the groups. Chi squared test was used to compare the incidence of PFO between the groups. An independent t test was used to establish whether there was a relationship between the presence of a PFO and microemboli load. The sample population was then divided into those who were positive for microemboli (MEP) and those who were negative for microemboli (MEN) and the data was reassessed for outcome measures and a relationship of microemboli to operative time and discharge day, using Mann-Whitney U tests. A p value < 0.05 was considered to be significant.

RESULTS

There was no loss to follow-up in either group. Satisfactory outcome and transcranial Doppler data, including PFO detection, was available for all 24 patients.

The HR group consisted of nine males and three females with an average age of 55.9 yrs (range : 42-70). In comparison the average age of the THA group (9 males and 3 females) was 57.8 yrs (range : 44-69).

Mean operative time was 88.6 min (72-104, SD +/-9.6) for the HR group and 90.8 min (range : 75-114, SD 14.5) for the THA group. The average time before discharge for the HR and THA groups was 6.5 (3-10, SD 1.9) and 8.1 (3-13, SD 2.8) days respectively. No significant difference between the groups was found for either of these variables ($p = 0.84$, $p = 0.10$ respectively).

Mean preoperative and post-operative outcome scores are shown in table I. No significant differences in orthopaedic outcome or quality of life were seen between hip resurfacing and total hip arthroplasty patients. We then compared all outcomes between those patients that demonstrated microemboli (MEP) and those that did not (MEN). No significant difference was found between these groups (table II).

No patient in the HR group demonstrated intra-operative cerebral microembolisation. Five patients in the THR group showed TCD evidence of microemboli during the procedure ; total emboli counts were one, two, two, three and three (median 0, mean 0.92 per patient). This was not a significant difference between the groups ($p = 0.09$ using the Mann-Whitney test).

There was no significant difference between the groups regarding the incidence of PFO : two patients in the HR group and one in the THA group tested positive for PFO, (12.5% overall, $p = 0.78$). There was no significant relationship between the total microemboli load and the incidence of PFO ($p = 0.56$). Out of the five patients who demonstrated emboli in the THA group, one tested positive for PFO, for whom TCD analysis revealed a single intra-operative microembolus.

Finally the relationship of microemboli to operative time and discharge day was assessed. Therefore the patients were divided again into those who were positive for microemboli (MEP) and those who were negative for microemboli (MEN). Results are shown in table III.

There were no post-operative complications.

DISCUSSION

Intra-operative cerebral microembolisation only occurred in patients undergoing hybrid THA in this study. Thus a difference was observed between the groups, which however did not reach statistical significance. Since invasion of the intramedullary canal is not required for hip resurfacing, this finding is consistent with the theory that it is the increase in intramedullary pressure within the femur, which promotes release of microemboli into the circulation, and in particular, instrumentation of the intramedullary canal itself. The use of cement introduced under high pressures logically serves to further increase this pressure although embolic material has been detected by trans-oesophageal echocardiography in the right side of the heart in patients undergoing uncemented arthroplasty (*4*), but the volume of material appears to be less and to persist for a shorter period.

Our study appears to support the theory of transpulmonary passage of embolic material proposed by Byrick *et al* (*3*) as there was no correlation between the presence of PFO and cerebral microemboli incidence or load. However, this theory was demonstrated in an animal model and human studies are required to accurately determine exactly how emboli reach the end organs.

Orthopaedic and quality of life outcomes were comparable between the groups and were satisfactory six months post surgery. The incidence of

Table I. — Mean (SD) orthopaedic and quality of life outcome scores for each group (HHS = Harris Hip Score, OHS = Oxford Hip Score, EQoL = Euro Quality of Life score)

	Pre-op WOMAC	6 month WOMAC	Preop HHS	6 month HHS	Preop OHS	6 month OHS	Pre-op EQoL	6 month EQoL
HR	43.8 (16.3)	6.8 (2.2)	60.2 (12.6)	88.3 (3.4)	36.8 (6.5)	16.9 (3.7)	0.47 (0.3)	0.93 (0.2)
THA	47.7 (10.7)	9.5 (3.6)	56.1 (10.6)	85.6 (7.5)	38.6 (7.5)	23.3 (9.3)	0.49 (0.2)	0.90 (0.2)
p value	0.51	0.07	0.22	0.44	0.51	0.05	0.56	0.74

No significant differences were found between the groups for any outcome measure.

Table II. — Mean (SD) orthopaedic and quality of life scores for patients who were microemboli positive (MEP) and microemboli negative (MEN) (HHS = Harris Hip Score, OHS = Oxford Hip Score, EQoL = Euro Quality of Life score)

	Pre-op WOMAC	6 month WOMAC	Preop HHS	6 month HHS	Preop OHS	6 month OHS	Pre-op EQoL	6 month EQoL
MEP	45.6 (12.6)	9.2 (4.1)	50.6 (11.8)	83.2 (7.8)	39.0 (6.5)	26.6 (11.8)	0.48 (0.3)	0.90 (0.2)
MEN	45.7 (14.2)	7.9 (3.0)	60.1 (11.0)	17.9 (5.0)	37.4 (7.2)	18.4 (5.3)	0.46 (0.2)	0.91 (0.2)
p value	0.89	0.58	0.09	0.33	0.63	0.05	0.35	0.64

No significant differences were found between the groups for any outcome measure.

Table III. — Mean (SD) operative time and days to discharge for patients who were microemboli posistive (MEP) and microemboli negative (MEN).

	MEP	MEN	p value
Operation time(min)	89.4(15.4)	89.8(11.6)	0.84
Days to discharge	8.0(1.6)	7.1(2.7)	0.45

No significant difference was found between the groups.

microemboli did not appear to confer poorer scores in this study.

We recognise that sample population size is small and that one arm of the study was a retrospective review. Therefore the results need to be interpreted with caution. Certainly studies with greater numbers would determine whether our findings are valid. However, cerebral or end-organ microembolisation does occur during conventional joint arthroplasty, and at risk patients need to be identified so that protective strategies can be put in place to optimise outcomes. The standard techniques of cemented THR generate extreme intramedullary pressures within the femoral canal, which often exceed the pressures in the general venous circulation and cause a disruption of the thin-walled medullary vessels. The disruption of the vessels allows the intravasation and flow of fat, bone marrow, bone debris, and polymethylmethacrylate through the natural drainage system of the diaphysis. Fibrinolytic and lipolytic enzymes within the pulmonary circulation may diminish the effects of the embolic insult and may explain the erratic clinical occurrence of complications (*4*). Nevertheless, the sequelae of severe fat embolism in patients who have pre-existing cardiopulmonary damage can be detrimental and can even lead to death (*15,19*).

Strategies to be considered may include intramedullary pressure reduction by vacuum suction (*7,18,20*), cannulated broaching systems or medical interventions such as filters to decrease embolic load to the heart.

We conclude that hip resurfacing, on account of the low invasion of the femoral canal, appeared to result in fewer or no cerebral microemboli intraoperatively. Furthermore, the presence of a PFO did not appear to influence the incidence or load of microemboli. Thus, the lungs may bear the brunt of the insult of embolic phenomena that occur during arthroplasty procedures and serve as an effective filter in most patients, thereby protecting other end organs. However, it should be borne in mind that patients with compromised respiratory function or disease may be less effective at this filtering process and indeed vulnerable to respiratory distress. We advocate close monitoring of these at risk individuals and thought should be given to reducing the microembolic load to the lungs either via surgical technique or venous filters. Although our study suggests that numbers of microemboli that reach the cerebral circulation are low for hybrid THA, patient samples in this study were small and greater microembolic loads may occur. Further investigation may yet show this to be true, in which case patients with existing neurological compromise or disease may be vulnerable to further cerebral damage. Similar protective strategies as discussed earlier may need to be considered.

Although many factors govern implant choice such as the age, gender, weight, and activity level of the patient as well as the quality of the bone and the anatomy of the proximal part of the femur, which are thought to be associated with the success or failure of the fixation of an implant in bone, not forgetting the personal experience of the surgeon, if suitable, hip resurfacing may be considered as an alternative to total hip arthroplasty on account of the apparent conferred neuro-protection.

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