Cardiopulmonary and haemodynamic changes during total hip arthroplasty

L. López-Durán¹, A. García-López¹, L. Durán², J. Hurtado², C. Ruiz³, J. L. Rodrigo⁴

¹ Orthopaedic Surgery and Traumatology Service,

² Anaesthesiology and Reanimation Service

³ Clinical Analysis Service

⁴ Cardiopulmonary Service, University Hospital San Carlos, Madrid

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Summary. We report a prospective study of 30 patients who underwent total hip arthroplasty for osteoarthritis in order to investigate the haemodynamic and respiratory changes which occur during operation. Cement was used in 17 cases and the implants were not cemented in 13. Pulmonary and cardiac function, blood levels of methylmethacrylate monomer, intramedullary pressure and transoesophageal echocardiography were recorded. Two well differentiated echogenic patterns appeared consistently during the operation. The intramedullary pressure became raised as the cement was inserted. The following changes occurred within seconds and continued for some minutes: elevation of mean arterial pressure and mean pulmonary artery pressure; decrease of arterial oxygen tension and of mixed venous PO₂, and greater tissue consumption of oxygen. Although we recorded raised concentration of methylmethacrylate monomer in venous blood after the cement was inserted, there is no evidence that the monomer is responsible for the haemodynamic changes which take place.

Résumé. Pendant l'arthroplastie de hanche nous avons observé de multiples altérations hémodynamiques et cardiorespiratoires. Nous avons réalisé une étude prospective de 30 patients opérés de coxarthrose par prothèse totale avec le but de rechercher des données sur la nature et l'origine de ces phénomènes. La série a consisté en 17 prothèses cimentées et 13 non cimentées. Nous avons relevé des paramètres de la fonction cardio-

pulmonaire, et des paramètres hématologiques, les concentrations plasmatiques de méthyl-méthacrylate (MMM), la pression intramédullaire et réalisé une échocardiographie transoesophagienne pour contrôler par monitoring les phénomènes emboliques pendant toute l'intervention. Les résultats révèlent deux schémas écho-géniques bien différenciés qui apparaissent constamment à différents moments de l'arthroplastie. Nous avons observé une élévation importante de la pression intra-médullaire au moment de la cimentation et noté des modifications dans les paramètres hémodynamiques qui apparaissent quelques secondes après la fin de la cimentation et se maintiennent pendant quelques minutes: élévation de la tension artérielle moyenne, de la pression artérielle pulmonaire et de la pression capillaire pulmonaire; diminution de la pression partielle artérielle de O₂ et de la saturation veineuse mixte de O₂; une consommation supérieure de O₂ tissulaire. Même si nous avons enregistré des élévations significatives de MMM dans le sang veineux et artériel, après la cimentation, il n'y pas d'évidence du fait que le monomère soit le responsable des changements hémodynamiques dans le groupe avec une implantation cimentée.

Reprint requests to: A. García-López, Hospital Universitario San Carlos, Servicio Cirugía Ortopédica y Traumatología, C/Martin Lagos s/n, E-28040 Madrid, Spain

Introduction

During total hip arthroplasty (THA) changes in cardio-pulmonary function and haemodynamics include transient hypotension [6, 19, 20, 31, 35,

37], cardiac arrest [6, 11] and sudden death [3, 10, 23]. These phenomena have been associated with raised pulmonary artery pressure [4, 42] and transient hypoxaemia [22, 30, 31, 34].

An acrylic methylmethacrylate monomer (MMM) has been isolated from the general circulation which can act as an embolic agent [1, 19], have a direct toxic effect on the heart with myocardial depression [32], or produce vasodilatation [25, 29, 35]. Other mechanisms can cause fat, air or bone marrow embolism [2, 4, 11, 15, 17, 18, 31]; reflex autonomic effects [41]; thromboplastin generation [12, 16, 31], or vasodilatation from arachidonic metabolites [5]. Cement pressurisation, when used to achieve better fixation, causes raised intramedullary pressure and could be a factor responsible for particles entering the blood stream.

These changes are also found in knee replacement [4], intramedullary nailing [8, 36, 47] and during reaming when nailing pathological fractures.

We have previously shown, using transoesophageal echocardiography (TEE), that intracavitary embolism occurs in the right atrium with two distinct patterns: a 'smoke' appearing during reaming of the femoral canal, and well defined echodense masses during cementing [40]. However, no haemodynamic or biochemical changes were found in any patients during operations. The lack of correlation between the TEE changes and possible complications led us to design a prospective study aimed at detecting haemodynamic changes and their consequences during THA. The changes will be related to plasma levels of MMM and the surgical technique.

Patients and methods

Thirty patients with osteoarthritis of the hip underwent THA under general anaesthesia; they were selected randomly and gave informed consent. Their average age was 64.4 years and their relevant details are summarised in Table 1. The implant used in every case was a LD^R modular prosthesis [27]. For younger and active patients, a biological fixation stem was used. A femoral stem with hydroxyapatite coating was used in 13 patients (group A), and the other 17 had a cemented stem (group B). In every case the femoral canal was thoroughly washed. Retrograde filling with a gun and a canal plug was used in cemented cases; in some of them, a hole was drilled proximal to the plug so as to measure intramedullary pressure with a transducer. The uncemented stems were gently hammered into place until the correct position was achieved.

Monitoring during operation included an electrocardiogram (Siemens cardioscope), arterial blood pressure by a radial catheter (20 G), central venous pressure (CVP) with a Swan-Ganz catheter, pulmonary artery pressure (PAP), pulmonary capillary wedge pressure (PCWP), systemic and pulmonary

Table 1. Details of patients

Data	Cemented (B) (N = 17)	Uncemented (A) (N = 13)
Age*	70 ± 6	57 ± 4
Weight (Kg)*	66 ± 6	78 ± 6
Height (cm)*	161 ± 6	165 ± 7
Sex		
Males	4	7
Females	13	6
ASA		
I	5	7
II	8	6
III	4	—
IV	—	—

* Average value ± SD

ASA: American Society of Anaesthesiologist

I = healthy; II = mild systemic disease; III = severe systemic disease; IV = grave disease

vascular resistance (SVR and PVR), arterio-venous difference oxygen ($avDO_2$) and continuous mixed venous oxygen saturation (SvO_2) by fibre-optic catheter, cardiac output (CO) and cardiac index (CI) by thermal dilution, and transcutaneous oxygen tension (SaO_2).

Measurements were taken at specific times during operation starting before the skin was incised, during medullary reaming, during the insertion of cement, while the stem was being introduced and during reduction of the prosthesis. The pulmonary shunt value (QS/QT) was calculated each time; this is the percentage of cardiac output going through the lungs without taking part in any gaseous exchange. A formula is used with 95% confidence [38]. In group B patients, intramedullary pressure was measured by a catheter inside the canal before and after the insertion of cement.

Arterial and right atrial pressure were obtained at the same intervals to determine the plasma concentration of MMM. Free plasma MMM was estimated by high resolution liquid chromatography with previous extraction by Sep-Pack-C₁₈ cartridges [26] with dexamethasone as an internal quantification standard. Beckman equipment was used with reverse phase C₁₈ of 5 µ (250 × 4.6 mm-40 °C), mobile phase ratio of methanol: water of 65:35, and a UV detector in a 220–240 nm wavelength.

Complete TEE studies using a biplane probe (Ultramark 9.5 Mhz) were carried out before and after operation in 16 patients, 8 cemented and 8 without cement. After conventional TEE, a longitudinal view of the right atrium was obtained which allowed simultaneous visualisation and recording of both the superior and inferior vena cava. Care was taken to detect the presence and timing of the appearance of spontaneous autocontrast or mobile right atrial masses during reaming, when cement was inserted, during introduction of the femoral stem and reduction of the prosthesis. The relation of these phenomenon to the flow pattern in the superior and inferior vena cava was assessed.

All data were recorded as average (± standard deviation). The differences of basal values were analysed by Student's *t*-test. Statistical significance was established for *p* values equal or less than 0.05.

Table 2. Haemodynamic results

Parameter		Basal	Reaming	Cementation	Stem	Reduction
MAP	B	89 ± 15	118 ± 22*	110 ± 20*	112 ± 6*	103 ± 21*
	A	86 ± 14	120 ± 19*			104 ± 21*
PAP	B	22 ± 4	22 ± 5	21 ± 5	19 ± 5	19 ± 5
	A	23 ± 5	25 ± 5			23 ± 5
PCP	B	16 ± 2	16 ± 4	14 ± 4	15 ± 5	13 ± 3*
	A	18 ± 6	19 ± 3			17 ± 3
CO	B	1.3 ± 0.7	3.2 ± 0.4	3 ± 0.4	3 ± 0.5	2.9 ± 0.3
	A	4.1 ± 0.8	4.2 ± 0.7			4.1 ± 0.8
PVR	B	144 ± 71	165 ± 77	146 ± 71	104 ± 61	157 ± 93
	A	102 ± 41	121 ± 50			107 ± 46
SVR	B	1996 ± 820	2721 ± 623*	2632 ± 674*	2685 ± 437*	2293 ± 945
	A	1375 ± 145	2102 ± 469*			1668 ± 303

B = Cemented. A = uncemented

* = $P < 0.05$ **Table 3.** Pulmonary function results

Parameter		Basal	Reaming	Cementation	Stem	Reduction
PaO ₂	B	137 ± 34	129 ± 26	120 ± 32	129 ± 32	128 ± 27
	A	140 ± 29	135 ± 31			122 ± 27
Sv̄O ₂	B	77 ± 4	75 ± 4	74 ± 6	77 ± 9	73 ± 4*
	A	76 ± 8	76 ± 8			75 ± 7
SaO ₂	B	98.7 ± 0.9	98.7 ± 1.3	98.1 ± 1.5*	99 ± 0.8	98.5 ± 1.3
	A	99.1 ± 0.9	98.7 ± 0.6			98.4 ± 1
Qs/Qt	B	12 ± 3	13 ± 2	14 ± 3	12 ± 3	13 ± 2
	A	12 ± 4	13 ± 3			13 ± 5
avDO ₂	B	4 ± 1	4 ± 0.6	4 ± 0.7	3.7 ± 0.7	5 ± 3*
	A	3 ± 1	3 ± 1			3 ± 0.9

B = cemented. A = uncemented

* = $P < 0.05$

Results

The average age was higher in group B cemented prostheses compared with the uncemented in group A (Table 1). The data from the haemodynamic findings are shown in Table 2, and there were no statistically significant differences in the basic data of groups A and B. The MAP was slightly raised from the basal value in both groups, mainly during reaming. The PAP did not change significantly in either group, although there were isolated cases in group B with 30% increments.

These cases also had slightly raised PCP, although the average figure did not change significantly in either group, except for a decrease in the reduction phase in group B.

The mean value of CO was not changed in group A, but there was a nonsignificant change in group B after cementing which coincided with lower values of mean CVP. Mean basal values of SVR and PVR were greater in group B compared with A. Both groups showed a significant increase of SVR at the beginning of the operation which decreased after the stem was implanted. PVR also

Table 4. Average values of plasmatic MMM in mcg/ml

	Atrium	Artery
Basal	<0.05	<0.05
Cementation	0.14 (<0.05–1.02)	0.66 (<0.05–2.94)
Stem	0.49 (<0.05–1.10)	0.30 (<0.05–0.45)
Reduction	0.09 (<0.05–0.18)	0.07 (<0.05–0.2)

Extreme values in parenthesis

increased, but not significantly during reaming in either group. The higher value was maintained during the rest of the operation in group B, while it returned to normal in group A.

Pulmonary function tests are shown in Table 3. In group B, PaO₂ decreased with a minimum value after cementing and then a return to normal. In Group A, the PaO₂ was almost unchanged. This is the single most reliable evidence of tissue oxygenation and showed a decrease during cementing in group B, and this trend continued during the rest of the operation. In group A, the SvO₂ did not change. On the other hand, the QS/QT increased in 80% of patients in group B, although not statistically significantly. In group A, this value only increased slightly in 50%. The avDO₂ increased in group B and both the arterial and venous O₂ diminished compared with group A, which suggests a greater tissue consumption of O₂ when cement is used.

During TEE, there was an appearance of 'smoke' entering the right atrium from the inferior vena cava in 12 of the 16 patients studied. In 6 of them, two-thirds of the caudal aspect of the right atrium was covered by this 'smoke', but in the other 6 the spontaneous contrast was localised and dispersed rapidly. These findings occurred during the insertion of cement, implantation of the femoral component and reduction of the prosthesis. In addition, 8 patients in group B showed a mobile swirling well-delimited echodense right atrial mass, $10 \pm 3 \times 8 \pm 2$ mm in size, appearing while cement was being inserted and which rapidly disappeared into the right ventricle.

The highest intramedullary pressures were recorded during implantation of the femoral stem, but they were always less than 250 mmHg. These values are below those given by other authors [21, 47].

Haemoglobin and haematocrit values changed during the postoperative period within the expected range after this type of procedure. There was also a moderate, but not significant, increase of triglycerides.

MMM concentration was raised significantly just after the cement was inserted (Table 4), but we also found higher values in radial artery blood

compared with right atrial blood. In no case did it reach cytotoxic values for leucocytes or endothelium (5 mcg/ml) as reported by others [1, 28, 32].

One patient in group B needed vasoactive drugs (dopamine) to counteract hypotension. His CO was low during the operation, the PVR was raised and there was a 23% increase in basal QS/QT. He recovered satisfactorily. One other patient had an episode attributed to a deep vein thrombosis which resolved in 48 hours.

Discussion

Fat embolism has been suggested as a possible cause of these phenomena [7, 33, 36, 38, 39, 43] and attributed to reaming because of disruption of the medullary veins which might allow a direct shunt of bone marrow to the venous circulation and lungs [33]. The femoral vein has been shown to become distended during operation which could allow accumulation of emboli that might be released during reduction [14]. On the other hand, systemic embolisation could occur when fat emboli reach the pulmonary veins through the precapillary shunts, which increase by 28% when cement is used, but not in uncemented THAs. This, together with the differential increase in intramedullary pressure, could account for the different changes in cemented and uncemented THAs.

Retrograde cementing techniques, using a gun, reduce but do not eliminate the risk of hyperoxaemia and cardiovascular derangement. In the same way, lavage of the canal before inserting cement prevents CO reduction [9, 47] and other consequences of fat emboli. Venting the canal through a hole drilled at the supracondylar level allows a significant reduction of intramedullary pressure [2, 20, 21, 45]. These studies agree with our findings that where there are no changes in PAP, although CO and PaO₂ may drop in the cemented group, the patient's life is not threatened.

Prostaglandins have a vasoactive effect in the pulmonary and systemic circulation. THA has been associated with high levels of vasoactive products derived from arachidonic acid; namely TxB₂, a stable metabolite of TxA₂, and a pulmonary vasodilator, and 6-keto PGF_{1α} (prosta-ciclin). The latter is a systemic dilator [46] which probably originates in the lungs in response to fat emboli and could cause systemic vasodilatation with a reduction of SVR. We have not been able to confirm these data since in our study the SVR values were raised in most cases. Furthermore, like

others [33, 43], we have not found that a reduction of the MAP provided blood volume is maintained.

MMM is a powerful peripheral vasodilator, but the dose needed to produce this effect in experimental animals is far greater than the amount released during THA. We found that the concentration rose after cement was inserted, but was always below the toxic level of >5 mcg/ml [1, 28, 31]. The haemodynamic changes observed during uncemented THA are therefore independent of the action of the monomer.

Embolic phenomena have been detected by TEE during medullary reaming of long bones [8, 36, 47], and hip and knee arthroplasty [7, 8, 14, 40, 43]. The cascades and echogenic masses are bigger at the time of cementing and after reduction [14]. We observed these findings during reaming, cementing, stem placement and reduction. Recently these phenomena have been described when squeezing the extremity after reaming [7, 8] and are especially intense during reaming pathological fractures [8, 24]. Our TEE investigations did not allow us to quantify the amount of embolic material or specify the tissue involved. It is probable that the smallest embolic particles contain marrow and fat, and the biggest could be fibrinous and medullary clumps produced by rapid activation of clotting [13].

Emboli may begin an important pulmonary breakdown and there is evidence of increased intrapulmonary shunting and lowering of PaO_2 , SaO_2 and CO, but the changes are transient and remain within safe limits. Other underlying mechanisms, such as sudden hypovolaemia, can aggravated the situation.

Our studies emphasise the importance of preventing the effects of fat and medullary micro-embolism which can be done by using a correct surgical technique. The anaesthetist must ensure cardiovascular stability by maintaining intravascular volume, preventing hypoxia and using vasoactive agents.

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