



Effect of Pressurized Cement Insertion on Cardiopulmonary Parameters during Cemented Hip Hemiarthroplasty: A Randomized Prospective Study

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Purpose: We aimed to investigate the cardiopulmonary effects of pressurized cement insertion in elderly patients undergoing cemented hip hemiarthroplasty.

Materials and Methods: We conducted a randomized prospective study on elderly patients undergoing cemented hip hemiarthroplasty. Patients were divided into pressurized and non-pressurized groups based on the pressure application during cement insertion. We measured mean arterial blood pressure (MAP), systolic blood pressure (SBP), diastolic blood pressure (DBP), heart rate (HR), arterial blood gases and serotonin concentration in blood. These variables were measured before bone cement insertion, and 3 and 5 minute after insertion. They were also measured immediately and 15 minutes after reduction.

Results: In cemented hip hemiarthroplasty, there were no significant change in MAP ($P=0.92$), SBP ($P=0.85$), DBP ($P=0.98$), HR ($P=0.97$) and serotonin concentration over time. There were no statistically significant difference between the two groups in MAP, SBP, DBP, HR, PO_2 , $PaCO_2$, SaO_2 and serotonin concentration, though three minutes after cement insertion, both groups showed decreases in SBP, DBP and MBP.

Conclusion: The pressurization method in cemented hip hemiarthroplasty was not found to be related with development of bone cement syndromes in elderly patients.

Key Words: Bone cement syndrome, Hip arthroplasty, Pressurization, Elderly patients

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INTRODUCTION

Along with the substantial growth of the elderly population thanks to the improved life expectancy, there is an increase in the number of elderly patients receiving hip hemiarthroplasty due to femoral neck fractures. Bone cement is widely used to fix the artificial prostheses in the hip joint of the elderly patients in cemented hip hemiarthroplasty. However, cement-related complications are reported increasingly. Hypotension^{1,2)}, hypoxemia^{1,3,4)}, arrhythmia and cardiac arrest^{5,6)},

pulmonary arterial hypertension⁷⁾, or a combination of these complications, which is called bone cement syndrome (BCS), may occur during fixation of the hip joint with bone cement implants⁸⁾. The suggested causes of BCS are increase in intramedullary pressure with insertion of bone cement, air embolism, bone marrow embolism or fat embolism^{1,3,4,9,10)}, histamine release, complement activation with cement or prosthesis insertion and release of vasoconstriction mediators through the reactions triggered by the embolus (e.g., serotonin, endothelin, and platelet-derived growth factors)^{7,11)} (Fig. 1).

In the pressurization method, the proximal segment of the femoral medullary canal is sealed to obtain better clinical outcomes in the elderly patients undergoing cemented hip hemiarthroplasty. In this study, we aimed to identify the cardiovascular and respiratory effects of the pressurization method.

MATERIALS AND METHODS

In this study, we randomly recruited 24 patients, using a table of random numbers, from the patients aged 65 years and above, who underwent cemented hip hemiarthroplasty under spinal anesthesia. Sample size was determined using the Creative Research System Survey software (Creative Research System; Petaluma, CA, USA) with 95% confidence level.

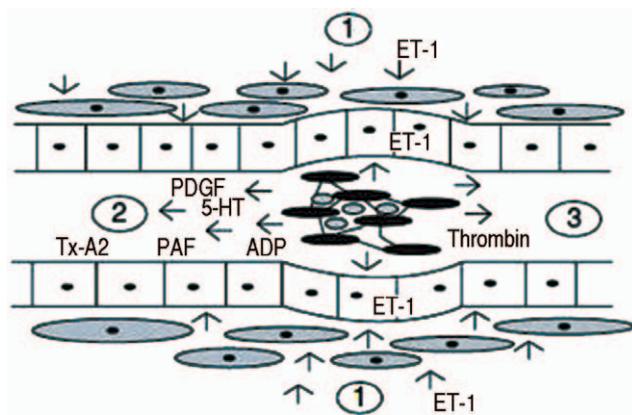


Fig. 1. Pulmonary vessel with the embolus comprising fat, platelets, fibrin and marrow debris. ① Reflex vasoconstriction and endothelial production of endothelin 1 (ET-1). ② Release of vasoconstriction mediators; platelet derived growth factor (PDGF), serotonin (5-HT), thromboxane A2 (Tx-A2), platelet activating factor (PAF) and adenosine diphosphate (ADP). ③ Vasoconstriction attributable to non-cellular components of the embolus including thrombin.

Following the institutional review board's approval and acquisition of written consent, in our prospective randomized comparative study, 12 patients were placed in each of the pressurized and non-pressurized groups. All patients received spinal anesthesia. Mean arterial blood pressure (MAP), systolic blood pressure (SBP), diastolic blood pressure (DBP), heart rate (HR) and arterial blood gas analysis (SaO₂) were measured as control variables before bone cement insertion into the intramedullary canal. Surgical procedures were performed through an anterolateral approach using the C-stem[®] (DePuy, Warsaw, IN, USA) in 16 patients and the Exeter stem (Stryker, Mahwah, NJ, USA) in 8 patients. Before insertion of cement, the medullary canal was sufficiently washed. A soaked gauze in 1:100,000 epinephrine was inserted into the intramedullary canal for vasoconstriction. To clean the intramedullary canal, blood clots and the tightly packed gauze were removed before cement injection. Cement was injected with a cement gun in both groups. Pressurization was applied in the pressurized group by sealing the proximal segment of the femoral medullary canal. Patients started ambulation with hip abduction braces on the second postoperative day.

To identify the cardiopulmonary effects of pressurization, we measured MAP, SBP, DBP, HR, arterial blood gases, serotonin levels before cement insertion, and then 3 and 5 minutes after insertion. Also, immediately and 15 minutes after reduction, we measured the serotonin level, MAP, SBP, DBP, HR, partial pressure of oxygen (pO₂), partial pressure of carbon dioxide (pCO₂) and oxygen saturation (SaO₂) in both groups.

The variables were presented as mean \pm standard deviation. All statistical analyses were performed using IBM SPSS Statistic program version 21.0 (IBM Co., Armonk, NY, USA). Multivariate ANOVA was used to analyze repeated measurements of the hemodynamics, arterial blood gas and serotonin levels. We also used Tukey's test for statistical analysis. *P*-values of less than 0.05 were considered statistically significant.

RESULTS

The mean age was 80.3 years (range, 65-90 years) in two male and 22 female patients. Nine patients had the history of diabetes mellitus. Twelve patients had hypertension and one patient had apoplexy. All patients in the pressurized group were female and the two males

Table 1. Patient and Intraoperative Characteristics

Characteristic	Pressurized group	Non-pressurized group	P-value
Pre-operative			
Patient, n (% of women)	12 (100)	10 (83.3)	0.97
Age (yr)	79.4±8.6	80.4±9.00	0.39
Diabetes mellitus	5 (41.7)	4 (33.3)	0.33
Hypertension	7 (58.3)	5 (41.7)	0.99
Cerebrovascular accident	0	1 (8.3)	0.04
Intra-operative			
Operation time (min)	111.67±16.23	112.92±12.00	0.02
Transfusion unit	1.42	1.58	0.41

Values are presented as number (%) or mean±standard deviation.

Table 2. Pulmonary Hemodynamic Effects of Pressure on Bone Cementation

Variable	Initial	After cementation			
		3 min	5 min	After reduction	After reduction 15 min
Pressurized group					
pO ₂ (mmHg)	81.42±18.84	82.78±16.36	89.54±18.44	85.12±9.47	86.30±6.61
pCO ₂ (mmHg)	35.62±3.02	36.35±3.55	37.20±1.85	34.43±2.45	36.31±2.82
Sat (%)	96.19±0.96	96.55±1.57	97.33±1.62	96.40±0.92	96.71±0.97
Serotonin (ng/mL)	6.18±8.35	8.05±7.91	10.98±13.84	5.86±7.45	7.87±10.09
Non-pressurized group					
pO ₂ (mmHg)	98.76±31.99	98.10±23.72	104.20±28.84	97.79±21.95	100.74±21.13
pCO ₂ (mmHg)	34.60±3.38	35.13±2.48	34.70±2.80	33.31±1.81	35.60±2.33
Sat (%)	95.79±1.73	96.25±1.50	96.60±1.18	95.88±1.53	96.61±1.05
Serotonin (ng/mL)	14.92±20.71	13.94±16.33	14.03±17.12	14.90±19.47	12.20±16.31

Values are presented as mean±standard deviation.

Sat: O₂ saturation.

P-values for pO₂, pCO₂, Sat and serotonin level differences between the pressurized and non-pressurized groups were 0.99, 0.87, 0.97 and 0.97, respectively.

Table 3. Cardiovascular Effects of Pressure on Bone Cementation

Variable	Initial	After cementation			
		3 min	5 min	After reduction	After reduction 15 min
Pressurized group					
SBP (mmHg)	141.83±29.64	133.41±20.70	136.25±25.71	135.91±22.03	138.41±22.21
DBP (mmHg)	63.91±12.37	62.16±10.24	63.08±11.27	64.58±8.26	63.58±9.19
MBP (mmHg)	89.83±17.35	85.66±12.62	87.25±15.35	80.50±24.37	88.16±13.03
HR (beat/min)	75.66±15.21	75.41±14.65	74.58±14.22	72.41±15.76	70.91±12.65
Non-pressurized group					
SBP (mmHg)	128.58±26.30	125.25±22.89	126.91±24.08	128.83±25.23	134.58±26.10
DBP (mmHg)	60.41±12.59	59.25±11.29	60.05±11.30	59.58±11.81	61.33±11.38
MBP (mmHg)	82.75±16.71	80.91±14.69	82.41±15.12	82.25±15.89	85.41±15.80
HR (beat/min)	74.58±10.05	75.91±11.95	74.91±10.26	74.41±9.57	76.50±9.82

Values are presented as mean±standard deviation.

SBP: systolic blood pressure, DBP: diastolic blood pressure, MBP: mean blood pressure, HR: heart rate.

P-value for SBP, DBP, MBP and HR differences between the pressurized and non-pressurized groups were 0.98, 0.99, 0.99 and 0.91, respectively.

were in the non-pressurized group. The mean operation time was 111.67 ± 16.23 minutes in the pressurized group and 112.92 ± 12.00 minutes in the non-pressurized group (Table 1). No significant difference was found between the two groups in blood gases and serotonin levels at the measurement time points (Table 2). SBP, DBP, and MAP decreased three minutes after bone cement insertion in both groups. Although HR showed a consistent decrease in the pressurized group, SBP, DBP, MAP, and HR were not significantly different in these patients (Table 3, Fig. 2-5).

DISCUSSION

Cemented hip arthroplasty has been the leading method of total hip replacements after its first introduction by Sir John Charnley in 1961. Since that time, this surgical method has been favored in elderly patients who have low bone density, yet the surgical procedures have continuously evolved to reach the current modern techniques¹². At the beginning, femoral components and cement were fixed with finger-packing without sealing the distal end of the medullary canal. Later, the medullary canal was washed with pressurized fluid and cement was inserted into the canal in an

upside-down position with the use of an intramedullary plug and a cement gun. Next, increased penetration of cement into the cancellous bone was achieved with reduction of cement porosity and cement pressurization. Later techniques added distal and proximal prosthesis centralizers to improve the stem position allowing for an optimal and even cement mantle¹³. Charnley¹⁴ reported intraoperative cardiac arrest in four out of 3,700 patients during total hip replacement with bone cement. Deburge¹⁵ claimed that cardiac arrest occurred in five and severe hypotension occurred in 14 out of 292 patients. Overall, the incidence of bone cement implantation syndrome (BCIS), the cardiovascular and respiratory complications following the use of bone cement, is known to range between 0.02-6.6%⁸. These complications commonly occur immediately after bone cement insertion.

The most common cause of BCIS is embolism. In hip arthroplasty without bone cement, intramedullary pressure is less than 100 mmHg. On the other hand, intramedullary pressure increases to more than 900 mmHg after cement insertion and expansion due to pyrogenic reactions^{4,16,17}. The increase in intramedullary pressure may lead to cardiac and pulmonary embolism by triggering the inflow of air, fat, bone marrow, cement

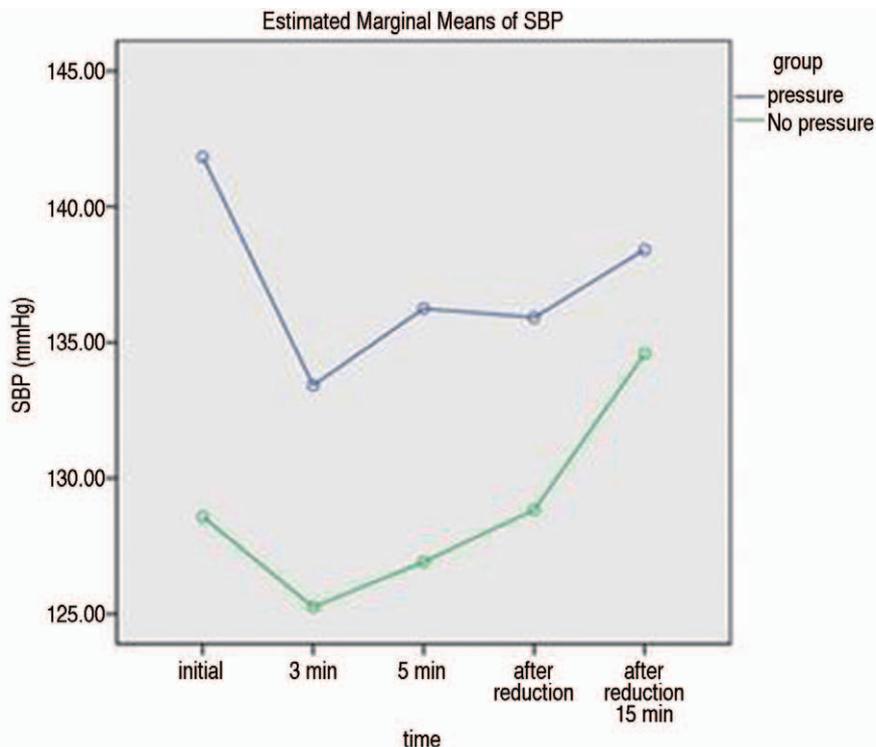


Fig. 2. Changes in the mean systolic blood pressure (SBP) over time in the two groups ($P=0.85$).

and other emboli into the femoral vein^{1,4,18}). Neurological injury or myocardial infarction could be seen with paradoxical arterial embolism. Arterial emboli can block the blood flow of the pulmonary artery. Consequently, pO₂ decreases and pCO₂ increases in the arterial blood by increasing the ratio of respiratory dead space and

intrapulmonary shunting. The partial pressure difference between the arterial blood and the end tidal pCO₂ increases as end tidal pCO₂ decreases¹⁹⁻²¹). Then, the increase in the pulmonary vascular resistance and the pulmonary artery pressure could be relayed to the cardiovascular system. Right-sided heart failure can

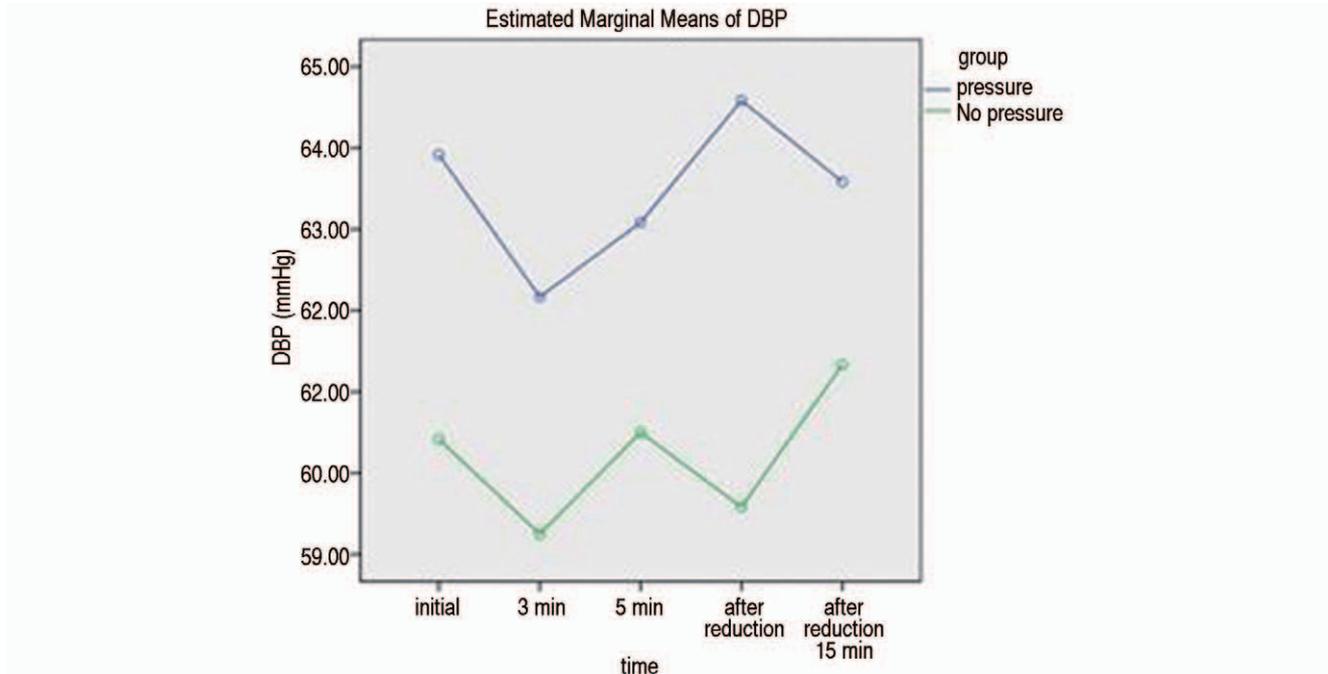


Fig. 3. Changes in the mean diastolic blood pressure (DBP) over time in the two groups ($P=0.98$).

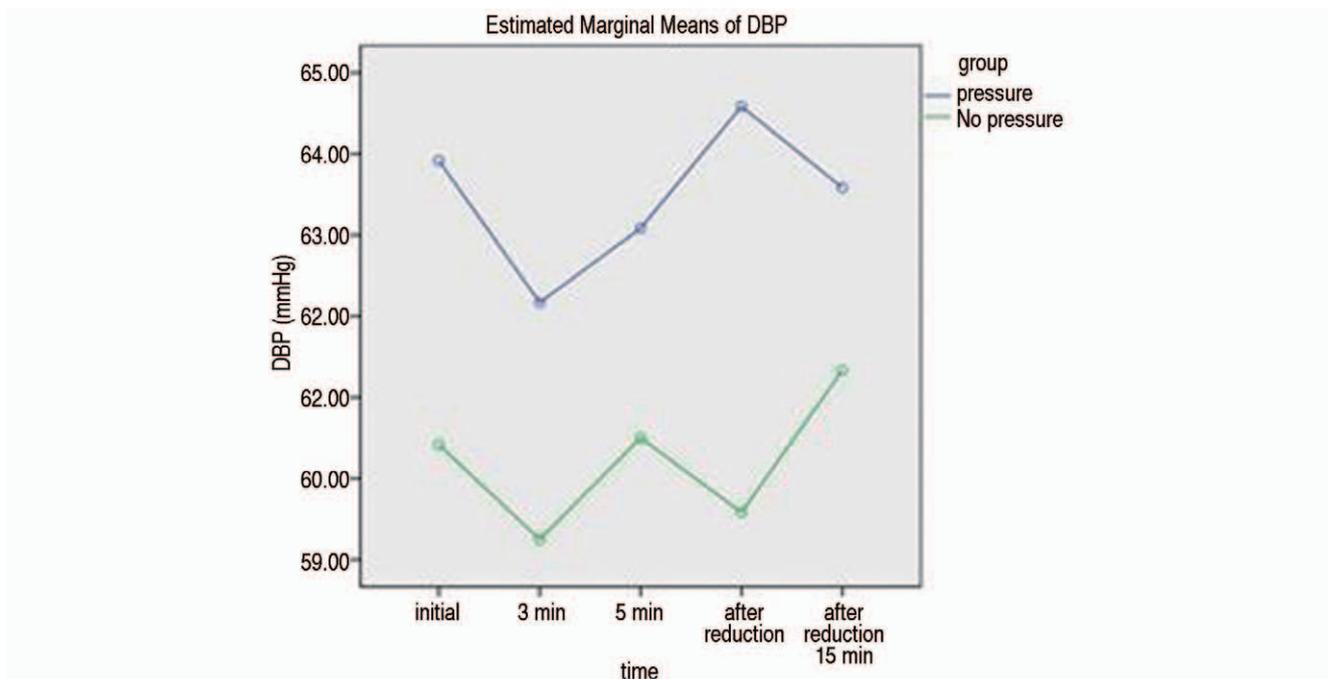


Fig. 4. Changes in the mean mean blood pressure (MBP) over time in the two groups ($P=0.92$).

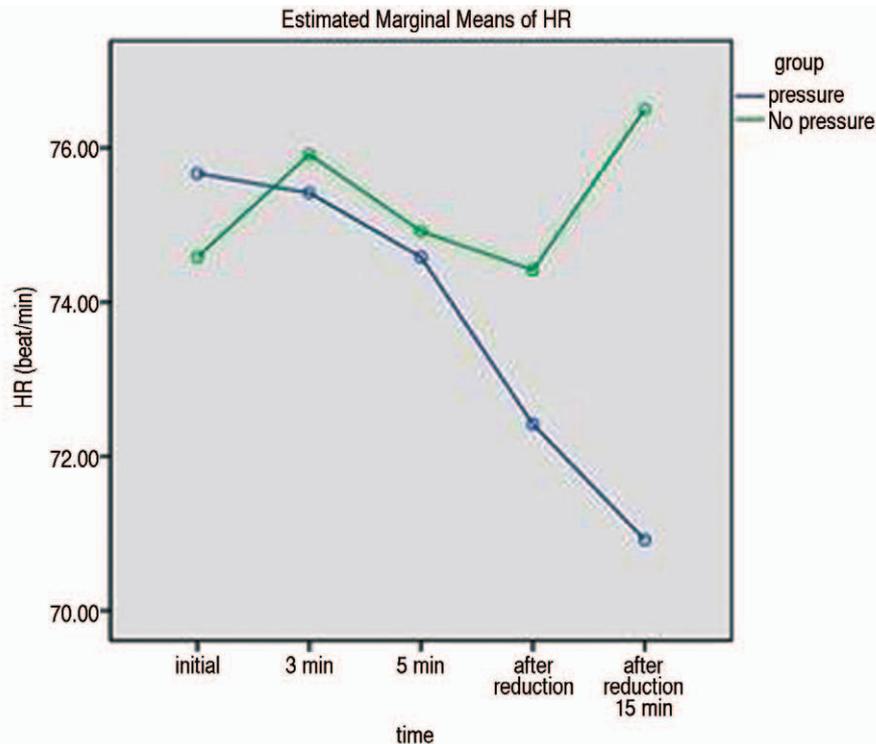


Fig. 5. Changes in the mean heart rate (HR) over time in the two groups ($P=0.97$).

develop due to increased right heart afterload and hypotension may occur due to reduced left heart preload⁷⁾. Consequently, pulmonary embolism can induce fatal hypoxemia, hypotension and heart failure, which can account for intraoperative death.

In our study, SBP, DBP, and MAP were reduced three minutes after bone cement insertion in both groups. Although HR consistently decreased in the pressurized group, SBP, DBP, MAP, and HR were not significantly decreased in these patients. Despite the possibility of development of fine emboli and BCS with the use of bone cement, pressure was found to have no effect on BCS. Likewise, there was no significant difference in SBP, DBP, MAP, HR, and changes in pO_2 , pCO_2 , and SaO_2 between the pressurized and non-pressurized groups. These findings could be attributed to the surgical procedures where the intramedullary canal was thoroughly washed before bone cement insertion, and an epinephrine soaked gauze was inserted into the canal to minimize the increase in the intramedullary pressure. In the pressurization method, which seals the proximal portion of the medullary canal during bone cement insertion, no statistically significant difference was found that could be related to pressure and development of BCS. Spinal anesthesia is expected to reduce the risk of embolism. In

planning for cemented hip hemiarthroplasty in elderly patients with femoral neck fracture, surgery needs to be performed after sufficient preoperative evaluation of cardiovascular and respiratory performance. The surgery team should be prepared for emergency measures in case of intraoperative complications as there is a potential risk of BCS development leading to hypoxemia, hypotension, arrhythmia and cardiac arrest.

One of the limitations of our study is lack of accurate measurement of cardiovascular parameters because cardiac output, pulmonary artery pressure, pulmonary artery closing pressure and central venous pressure were not measured. The presence of fat, air, bone marrow, cement and other emboli were not evaluated in the heart by transesophageal echocardiography. We were not able to directly associate the intramedullary pressure with the cardiopulmonary parameters, as we did not measure the intramedullary pressure after sealing of the proximal femur.

CONCLUSION

The pressurization method was not found to have a significant effect on the cardiopulmonary parameters in patients who received cemented hip hemiarthroplasty. However, due to a relatively small sample size, we are

in need of bigger studies to elucidate the relation between pressurization and the cardiopulmonary system.

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