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Perioperative Pulmonary Circulatory Changes During Bilateral Total Hip Arthroplasty Under Regional Anesthesia

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Abstract

Background and Objectives—The transient and rarely clinically relevant effect of bone and cement embolization during unilateral joint arthroplasty is a known phenomenon. However, available studies do not address events surrounding bilateral total hip arthroplasties, during which embolic load is presumably doubled. To elucidate events surrounding this increasingly utilized procedure and assess the effect on the pulmonary hemodynamics in the intra- and postoperative period, we studied 24 subjects undergoing cemented bilateral total hip arthroplasty during the same anesthetic session.

Materials—Twenty four patients without previous pulmonary history undergoing cemented bilateral total hip arthroplasty under controlled epidural hypotension were enrolled. Pulmonary artery catheters were inserted and hemodynamic variables were recorded at baseline, 5 minutes after the implantation of each hip joint, 1 hour and 1 day postoperatively. Mixed venous blood gases and complete blood counts were analyzed at every time point.

Results—An increase in pulmonary vascular resistance was observed after the second but not the first hip implantation when compared to values at incision. Pulmonary vascular resistance remained elevated 1 hour postoperatively. Pulmonary artery pressures were significantly elevated on post operative day 1 compared to baseline values. The white blood cell count increased in response to the second hip implantation but not the first compared to incision.

Conclusion—The embolization of material during bilateral total hip arthroplasty is associated with prolonged increases in pulmonary artery pressures and vascular resistance, particularly after the second side. The performance of bilateral procedures should be cautiously considered in patients with diseases suggesting decreased right ventricular reserve.

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Introduction

The pulmonary embolization of intramedullary contents including fat, bone debris and cement during total hip arthroplasty (THA) is a known phenomenon.^{1–5} While in most cases of limited clinical significance^{1,3–5} cardiovascular derangements manifesting in an increase in pulmonary arterial pressures, right heart strain², cardiovascular collapse and death have been described.^{2,6,7} Mechanisms for the various degrees of presentation of these events remain speculative to date but are thought to be related to the overall load and size of particles gaining access to the pulmonary vasculature.²

All studies exploring issues surrounding this so called “bone cement implantation syndrome” are subject to limitations with respect to bilateral procedures, as they were performed on patients undergoing single hip replacement.^{1–5} Thus these studies lack the ability to elucidate dose response phenomena and offer insight into events surrounding bilateral procedures. Further, observations made primarily by echocardiographic means may have been highly operator dependant and allowed for observation of intraoperative events only.^{1–5} In addition, with the rising utilization of single stage bilateral hip arthroplasties in the United States, which may provide increased patient convenience due to a single hospitalization and decreased overall rehabilitation time, the perioperative safety of this elective procedure remains a subject of debate^{8,9} and the impact on pulmonary hemodynamics remain thus far poorly understood. Significant pulmonary circulatory changes during bilateral THA may heighten awareness and lead to more careful evaluation of patients with pre-existing pulmonary circulatory disease as candidates for this procedure.

We therefore studied the hemodynamic changes of 24 patients undergoing elective, cemented, bilateral total hip arthroplasty performed sequentially under one anesthetic with controlled hypotensive epidural technique. By utilizing pulmonary artery catheterization, we collected intra- and post operative data, correlated specific surgical events to hemodynamic changes and analyzed the duration of the effects on the pulmonary and systemic circulation into the postoperative period.

We hypothesized that pulmonary hemodynamics would significantly change in response to events surrounding bilateral cemented total hip arthroplasty, especially after the embolic load received by the lung after the second hip implantation.

Materials and Methods

Following approval by the Hospital for Special Surgery institutional review board, 24 patients undergoing single-stage bilateral hybrid THA were enrolled in the study. All subjects gave their written informed consent for participation in the study. Patients with pre-existing pulmonary hypertension, coronary artery disease with inducible ischemia, known valvular abnormalities, significant chronic pulmonary disease and ASA status greater than 3 were excluded from the study. Anesthesia was administered according to the following protocol. After application of standard ASA monitoring equipment and application of oxygen via a non-rebreathing mask, the patients were sedated with intravenous midazolam 5mg. A radial arterial line and an in vitro calibrated Swan-Ganz continuous cardiac output/oximetry thermodilution catheter (Baxter, Irvine, CA) were inserted via the internal jugular vein. This catheter was used in conjunction with the Vigilance monitor (Baxter, Irvine, CA) for collection of data.

All patients received hypotensive epidural anesthesia as previously described.¹⁰ In brief, 15–25ml of bupivacaine 0.75% is injected in the L1–2 region with the goal to achieve motor and sympathetic blockade to a level of T4–T1. An intravenous infusion of epinephrine 4–7mcg/min is started and titrated to maintain cardiac output and a mean arterial pressure of 50mmHg

at a heart rate of 55–80bpm. Intravenous lactated Ringer's solution is administered to maintain euvolemia with heart rates above 80 bpm suggesting hypovolemia.

A continuous infusion of propofol was titrated to achieve sedation while maintaining adequate respiration. Mean systolic blood pressure was maintained at 45 to 55 mmHg as assessed by radial artery monitoring. All patients were operated upon in the lateral position by two surgeons using the posterolateral approach. The thigh was maintained in a neutral position during insertion of the acetabular component. The thigh was then flexed, internally rotated, and adducted to ream the femur. The canal was lavaged, and the cemented femoral component impacted. Following completion of the first side the patient was repositioned and surgery on the contralateral side ensued.

Hemodynamic variables (pulmonary and systemic pressures, cardiac output) as well as mixed venous oxygen saturation were measured and pulmonary vascular resistance (PVR) was calculated at set points perioperatively by the same operator: at baseline (before epidural placement), upon incision (after surgical anesthesia was established), 5 minutes after the relocation of each hip joint, 1 hour and 1 day postoperatively. Complete blood counts were analyzed at every time point.

Although not restricted by the protocol, no blood transfusions were given intraoperatively and blood products as well as lactated Ringer's were administered as deemed necessary postoperatively by the patients' physicians with the goal to maintain left ventricular filling pressures.

Statistical analysis

The primary outcomes were changes in PVR, mean, systolic, and diastolic pulmonary pressures, and white blood cell count. Further changes in mean arterial pressure, heart rate, wedge pressure, cardiac output, mixed venous oxygen saturation, and hematocrit were studied over time. Each outcome was repeatedly measured at the time points mentioned previously. Multivariate regression analysis based on the generalized estimating equations method¹¹ was performed for each outcome to assess trend over time while controlling for age, gender, BMI, and ASA class. The general estimating equations method approach provides more robust inference for modeling longitudinal data by taking into account the correlation of outcomes at different time points. A p-value of <0.003 was considered significant after employing Bonferroni adjustment to account for the multiple comparisons performed in our study. All statistical analyses were performed using SAS version 9.2 (SAS Institute, Cary, NC).

Results

All 24 patients completed the study. No major perioperative complications were recorded. Table 1 details patient demographics and intraoperative fluid data. The range of patient age was 40 to 87 years. Intraoperative mean arterial pressures were significantly reduced whereas heart rate and cardiac output were maintained throughout surgery in accordance with the controlled hypotensive protocol (Table 2). Right and left sided filling pressures remained unchanged, except for an increase in the central venous pressure 1 hour postoperatively (Table 2).

Changes in pulmonary artery pressures are shown in figure 1. No significant changes in pressures were recorded after the implantation of both hips from values measured at baseline. However, a 12% and 26% increase in the mean pulmonary pressure compared to baseline values was observed 1 hour and 1 day post surgery, respectively. When evaluating changes in PVR a significant increase was recorded in response to the second hip implantation when compared to values at incision. The increase in PVR was maintained in the postoperative period

at 22% and 33% at 1 hour after surgery compared to preoperative values and the beginning of surgery, respectively (Figure 2). The increase of PVR on postoperative day 1 was 11% compared to base line and 21% compared to the beginning of surgery, but this finding was not statistically significant.

Interestingly, a significant increase in the white blood cell count occurred in response to the second hip implantation compared to the time of incision, followed by a decline postoperatively (Figure 3).

Data on trends in hematocrit, mixed venous oxygen saturation, pH, arterial pCO₂ and pO₂ are shown in Table 3 respectively. An intraoperative decline in all values at some point of surgery except for arterial pCO₂ was seen, but no difference in either value was recorded between the first and second hip implantation. Of note is an increase in the mixed venous saturation after induction of anesthesia. Postoperatively, patients were transfused an average of 2+/-0.8 units of blood of which 96% (48/50) were autologous. Further, the average crystalloid volume infused postoperatively was 2,298+/-593 ml. No significant differences in left heart filling pressures were seen over time (Table 2).

Discussion

In this study of 24 patients undergoing bilateral hybrid total hip replacement under regional anesthesia, we observed an increase in pulmonary vascular resistance that was pronounced after the implantation of the second hip. Interestingly, the increase in pulmonary vascular changes continued into the postoperative period. Pulmonary arterial pressures were significantly increased from baseline on postoperative day 1. Further, an increase in white blood cell count was associated with the second hip implantation but not with the first.

The impact of unilateral hip arthroplasty on the pulmonary vasculature has been described in the past.¹⁻⁷ Most trials however, have found little clinical significance of events surrounding the so called "bone cement implantation syndrome" and have described changes in pulmonary pressures and right heart function as small and relatively short lived.¹²⁻¹⁴ While most studies have employed transesophageal monitoring for hemodynamic assessment, López-Durán et al. using Swan Ganz catheters showed that during elective unilateral total hip replacement under general anesthesia pulmonary arterial pressures and pulmonary vascular resistance remained virtually unchanged,¹⁴ supporting our findings that no major significant changes were seen in these parameters intraoperatively in response to the first hip implant.

While reassuring when taking care of patients for unilateral procedures, no extrapolation of findings of studies assessing one sided approaches can be made to bilateral surgeries in which the embolic load of intramedullary debris and cement to the lung is presumably doubled. Outcome studies evaluating the impact of bilateral joint arthroplasty provide controversial results but seem to suggest higher incidence of perioperative complications despite younger average age and lower overall comorbidity burden, including complications presumably attributable to lung injury, i.e. adult respiratory distress syndrome.¹⁵ Indeed, when studying the impact of bilateral procedures on pulmonary vascular parameters, the addition of the second side results in a significant increase in pulmonary circulatory parameters as compared to values at incision in our study. This effect occurs in the absence of changed fluid conditions as measured by pulmonary arterial occlusion pressure, supporting that our findings are irrespective of left ventricular events. In addition to adverse hemodynamic changes in response to a second hip implantation, we found evidence of an increase in the inflammatory response as shown by a 45% increase in the white blood cell count compared to the first arthroplasty. White blood cell counts have been previously described as a reliable and timely marker of acute inflammation secondary to injury and stress.¹⁶ While white blood cell counts are known

to rise in response to increased plasma epinephrine levels, the exogenous administration of this drug used in conjunction with the controlled hypotension protocol as described previously,¹⁰ remained stable throughout the intraoperative period (range 1.7 to 1.9 mcg/min) ($P>0.1$ between all intraoperative comparisons).

We found that the induction of anesthesia and the use of a controlled hypotensive technique using a low thoracic epidural¹⁰ was accompanied by a reduction (although not significant in this study) in pulmonary arterial pressures and vascular resistance compared to baseline, while cardiac output was maintained. This approach may be viewed as beneficial when dealing with embolic phenomena to the lung. Animal studies have shown that the use of a thoracic epidural block improves hemodynamics by reducing mean pulmonary pressure and raising cardiac index in the setting of pulmonary embolism,¹⁷ a situation with similar hemodynamic consequences observed during intramedullary debris and cement embolization of the lung. The fact that thoracic but not lumbar epidural placement of the catheter has been associated with this beneficial effect seems to point to the role of a sympathetic blockade in this process.¹⁸ Thus, the anesthetic technique used in our study may have been beneficial in providing a “best possible scenario” to study the effects of intramedullary content embolization during hip surgery, leaving the question if the use of other forms of anesthesia may be associated with more significant changes in pulmonary hemodynamics.

To our knowledge, this study is the first to establish the prolonged adverse effect on pulmonary hemodynamics and inflammation after bilateral hybrid total hip replacement. This suggests that the stress on the right ventricle is sustained after implantation of the joint. Although speculative, this may expose particularly patients with pre-existing decreased reserve to perioperative problems. To ameliorate the impact of the debris load and its effects on the pulmonary vasculature a discussion with surgeons to thoroughly clean and dry the intramedullary canal prior to cementation and injection of cement in a retrograde fashion with a cement gun to minimize intramedullary pressure and venous extravasation during insertion of the femoral prosthesis should be encouraged as such approach may be associated with a decrease in debris load to the lung. Avoiding cemented prosthesis altogether in patients at risk poses another option to minimize adverse effects to the lung.⁴ However, the potential benefits of a low thoracic epidural with sympathetic blockade in the clinical setting remains speculative.

Our study is limited by a number of factors. First, we only included patients without pre-existing pulmonary pathology. Thus, we cannot predict what the effect of hip arthroplasty may be in the patient population in whom pulmonary vascular disease is present at baseline, although it is likely that these patients would be more susceptible to perioperative injury. However, our patient selection is in keeping with clinical practice in our hospital to pre-select candidates without significant cardiopulmonary disease for bilateral procedures under the assumption that a more complicated bilateral surgery may predispose patients with less reserve to more complications. Second, we did not collect data beyond the first postoperative day, as it would not have been feasible or necessary to leave the pulmonary artery catheter in situ beyond this time point. In addition, this study does not include a control group of unilateral total hip arthroplasty patients. The argument could be made that our findings of prolonged hemodynamic changes may at least in part reflect delayed effects of the first arthroplasty. However, anecdotal evidence from clinical experience and observations from previous studies suggest that pulmonary hemodynamic changes in response to unilateral procedures are small and transient.^{12–14} While conceptually results from a unilateral THA cohort would be interesting, performing pulmonary catheterization in healthy, elective unilateral hip arthroplasty recipients may further pose ethical limitations. Thus our data will have to be interpreted in the context of our study design, with the realization that the theoretical possibility exists that increases in pulmonary pressures and white cell count may partially be influenced by a timing effect related to the first hip implant.

Irrespective of these limitations, our study shows that in the setting of bilateral total hip arthroplasty pulmonary arterial pressures and vascular resistance remains increased beyond the immediate implantation phase.

In summary, our data suggests that cemented bilateral hybrid total hip arthroplasty is associated with increases in pulmonary artery pressures and vascular resistance, particularly after the second side. Keeping patient safety a priority, the performance of bilateral procedures should be cautiously considered and perhaps staged in patients with diseases suggesting decreased pulmonary reserve and increased right ventricular afterload, i.e. pre-existing pulmonary hypertension.

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Figure 1.

Shown are mean systolic, mean and diastolic pulmonary artery pressures over time. Increases compared to baseline and incision were found postoperatively. Error bars represent 95%-confidence intervals. $p < 0.003$ compared to: #Baseline; †Incision; ‡Hip1; §Hip2

Figure 2.

Mean values of pulmonary vascular resistance are depicted at the various time points. An increase compared to incision was seen after the second but not the first hip. This increase lasted into the immediate postoperative period. Error bars represent 95%-confidence intervals. $p < 0.003$ compared to: †Incision

Figure 3.

Mean white blood cell counts are shown over time. Values increased in response to the second but not the first hip implantation compared to incision. Error bars represent 95%-confidence intervals. $p < 0.003$ compared to: #Baseline; †Incision; ‡Hip1; §Hip2; ¶1 Hr

Table 1

Tabulated are demographic data of patients enrolled in the study. Categorical variables are shown as frequencies. Continuous variables are computed as mean and standard error.

Demographics and Intraoperative Fluid Data	
Age (years)	61 ± 11
Gender (Male/Female)	11/13
ASA Class I/II/III	4/13/7
Body Mass Index (kg/m ²)	28 ± 5
Estimated Blood Loss 1st hip (ml)	156 ± 60
Estimated Blood Loss 2nd hip (ml)	189 ± 56
Crystalloid (ml)	2433 ± 408

Table 2

Hemodynamic values shown over time.

	HR (bpm)	MAP (mmHg)	CO (L/min)	CVP (mmHg)	PWP (mmHg)
Baseline	Mean 68	93	5.3	5	10
	95% CI 65	87	4.8	4.5	8.5
					10.8
Incision	Mean 70	54 [#]	5.6	5	9
	95% CI 66	52	5.3	4.2	7.6
					9.4
Hip 1	Mean 69	51 [#]	5.5	5	9
	95% CI 65	49	5.1	4.0	7.4
					9.6
Hip 2	Mean 68	54 [#]	5.4	5	9
	95% CI 64	51	5.0	3.9	5.1
					7.7
					9.5
1 Hr	Mean 71	81 ^{#†‡§}	5.8	6 [§]	10
	95% CI 66	77	5.4	5.3	6.4
					8.3
					11.4
1 Day	Mean 81 ^{#†‡§¶}	87 ^{†‡§}	6.7 ^{#†‡§}	6	11
	95% CI 77	84	6.2	4.5	7.2
					8.7
					12.6

HR=heart rate; MAP =mean arterial pressure; CO=cardiac output CI=95% confidence interval P<0.003 compared to:

[#] Baseline,[†] Incision,[‡] Hip1,[§] Hip2,[¶] 1 hr

Table 3

Laboratory values shown over time.

	Hct (%)	SvO ₂ (%)	pO ₂ (mmHg)	pCO ₂ (mmHg)	pH
Baseline	Mean	79	451	46	7.4
	95% CI	33.7 35.8	77 80	416 486	44 49
Incision	Mean	84 [#]	464	52 [#]	7.3 [#]
	95% CI	32.8 35.0	83 86	434 494	49 56
Hip 1	Mean	81 [†]	416 [†]	52 [#]	7.3 ^{††}
	95% CI	30.5 32.4	80 83	392 441	48 57
Hip 2	Mean	80 [†]	417	54	7.3 ^{††}
	95% CI	28.5 31.2	78 81	386 447	47 60
1 Hr	Mean	75 ^{††§§}	379 [†]	46 ^{†‡}	7.3 ^{†‡§§}
	95% CI	27.7 29.8	72 77	330 428	43 48
1 Day	Mean	79 ^{†¶}	423	43 ^{†‡§§¶}	7.4 ^{†‡§§¶}
	95% CI	29.5 32.0	77 81	388 457	40 45

Hct=hematocrit; SvO₂=mixed venous oxygen saturation; pO₂=arterial oxygen partial pressure; pCO₂=arterial carbon dioxide partial pressure

CI=95% confidence interval

P<0.003 compared to:

[#] Baseline,

[†] Incision,

[‡] Hip1,

[§] Hip2,

[¶] 1 hr