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Pulmonary circulatory changes after bilateral total knee arthroplasty during regional anesthesia

Anna Maria Bombardieri, MD^{a,b,*} [Clinical and Research Fellow], Stavros G. Memtsoudis, MD, PhD, FCCP^a [Associate Professor and Associate Attending], George Go^a [Research Assistant], Yan Ma, MD, FCCP^c [Assistant Professor], Thomas Sculco, MD^d [Professor and Chairman], and Nigel Sharrock, BMedSci, MB, ChB^a [Associate Professor and Associate Attending]

^aDepartment of Anesthesiology, Hospital for Special Surgery, New York, NY 10021, USA

^bUniversity of Florence, Ospedale di Careggi, Florence, Italy

^cDepartment of Biostatistics, Hospital for Special Surgery, New York, NY 10021, USA

^dDepartment of Orthopedic Surgery, Hospital for Special Surgery, New York, NY 10021, USA

Abstract

Study Objective—To monitor the pulmonary hemodynamics of patients undergoing bilateral total knee arthroplasty (BTKA) intraoperatively and up to 24 hours following surgery.

Design—Prospective observational study.

Setting—University-affiliated teaching hospital.

Patients—30 ASA physical status 2 and 3 patients scheduled for single-stage, cemented, BTKA during epidural anesthesia.

Interventions—Pulmonary artery catheters attached to all patients.

Measurements—Systemic vascular resistance (SVR), pulmonary vascular resistance (PVR), the ratio of PVR to SVR at baseline, at the beginning of surgery, and after each knee implantation were recorded and compared with measurements taken one day postoperatively (POD 1).

Main Results—On POD 1, PVR/SVR was increased by 30% compared with baseline ($P < 0.0001$) and by 20% versus the end of surgery ($P < 0.0001$). Systemic vascular resistance decreased during surgery and was significantly lower than baseline at 24 hours after surgery ($P < 0.0001$). No significant change in PVR was noted during surgery.

*Correspondence: Anna Maria Bombardieri, MD, Department of Anesthesiology, Hospital for Special Surgery, 535 East 70th St., New York, NY 10021, USA. Tel: (646) 797-8419; fax: (212) 517-4481; bombardieri.am@gmail.com.

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Conclusion—The PVR/SVR ratio on the day following BTKA was increased. This change may represent the different effects of inflammatory perioperative stresses on the pulmonary and systemic vasculature.

Keywords

Bilateral knee arthroplasty; epidural anesthesia; pulmonary hemodynamics

1. Introduction

The embolization of fat, bone marrow, and cement during total knee arthroplasty (TKA) [1-4] resulting in pulmonary gas exchange and hemodynamic changes has been described [5>]. The degree of cardiopulmonary compromise is thought to be related to overall embolic load [2]. For this reason, when bilateral procedures are performed the effect may be more pronounced and prolonged. Indeed, pulmonary artery pressures (PAPs) and pulmonary vascular resistance (PVR) are significantly increased up to one day postoperatively compared with baseline in patients undergoing bilateral hip arthroplasty [6].

Despite the increase in bilateral TKAs (BTKA) in the United States in the last decade [7], the perioperative safety of this elective procedure remains a subject of debate [8] and its effect on pulmonary hemodynamics remains poorly understood. We undertook a prospective study of the hemodynamic changes of 30 patients undergoing elective, bilateral, single-stage TKA during epidural anesthesia.

Using pulmonary artery (PA) catheterization, we collected intraoperative and postoperative data, correlated specific surgical events to hemodynamic changes, and analyzed the duration of effects on the pulmonary and systemic circulation into the postoperative period. The primary goal was to determine if, or to which extent, PA hemodynamics were impacted beyond the surgical period. We hypothesized that PA hemodynamics would be significantly altered in response to events surrounding bilateral TKA on the first postoperative day (POD 1) compared with baseline in patients with no pulmonary pathology.

2. Materials and methods

After obtaining approval by the Hospital for Special Surgery Institutional Review Board, and patients' written, informed consent, we enrolled 30 patients undergoing single-stage BTKA by a single surgeon. Exclusion criteria were ASA physical status > 3, preexisting pulmonary disease, pulmonary hypertension, coronary artery disease (CAD) with inducible ischemia, or peripheral vascular disease preventing tourniquet use.

Anesthesia was standardized and administered according to the following protocol: after application of standard ASA monitors and oxygen via a non-rebreathing mask, patients were sedated with intravenous midazolam 5 mg. A radial arterial catheter and an in vitro calibrated Swan-Ganz continuous cardiac output/oximetry thermodilution catheter (Baxter, Irvine, CA, USA) via the right internal jugular vein were inserted. This catheter was used with the Vigilance monitor (Baxter) for data collection.

All patients received epidural anesthesia in the lateral decubitus position at the L₃-L₄ interspace with an injection of 20-25 mL of 0.75% bupivacaine in 5 mL aliquots via a 17-gauge Tuohy needle. A catheter was inserted and each patient was repositioned supine. A continuous infusion of propofol was titrated to achieve sedation while maintaining adequate respiration.

Cemented posterior stabilized TKA using intramedullary guides for the femur and extramedullary systems for the tibia were used in all patients. The most symptomatic knee was operated on first. Thigh tourniquets were applied and inflated to 350 mmHg following exsanguination of the limb with an Esmarch bandage. Surgery on the second knee began as the wound on the first side was being closed, but after tourniquet deflation on the first limb.

Hemodynamic variables [pulmonary and systemic pressures and cardiac output (CO)] as well as mixed venous oxygen saturation (SvO₂) were recorded. Pulmonary vascular resistance was calculated at multiple time points perioperatively by the same operator: at baseline (before epidural placement), at the beginning of surgery (after tourniquet inflation on the first knee), 5 minutes after tourniquet deflation of either side, and on POD 1. Arterial blood gases were analyzed at baseline, after tourniquet deflation of either side, and on POD 1.

Although transfusion was not restricted by the protocol, patients did not receive blood during surgery but were transfused as required postoperatively. Perioperative complications were recorded.

2.1 Statistical analysis

The primary outcome was a change in pulmonary hemodynamics compared with baseline. Pulmonary hemodynamic changes of interest were PVR, the ratio of PVR to systemic vascular resistance (SVR), and systolic, mean, and diastolic PA pressures. The PVR/SVR ratio may be the most suitable measure for pulmonary circulatory changes, as this measure takes into account absolute changes in hemodynamic pressures that may be influenced by overall fluid status and CO [9,10]. Changes in mean arterial pressure (MAP), heart rate (HR), pulmonary capillary wedge pressure (PCWP), CO, SvO₂, and PaCO₂ over time were secondary outcomes. Each outcome was measured at the time points listed above.

Multivariate regression analysis based on the generalized estimating equations (GEE) method [11] was performed for each outcome to assess trend over time while controlling for demographic variables (age, gender, body mass index, and ASA physical status), cardiovascular disease (ie, CAD and hypertension), and use of beta-blockers, calcium channel blockers, and other anti-hypertensive medications. The study outcomes were assessed at multiple time points. Using GEE, the correlations between the repeated measures on the same subject may be taken into account. In addition, GEE is a distribution-free method that does not require the assumption of normal distribution for the outcome, and therefore provides robust inferences when data are skewed. A *P*-value < 0.05 was considered statistically significant. All statistical analyses were performed using SAS version 9.2 software (SAS Institute, Cary, NC, USA).

3. Results

Of the 30 patients originally enrolled, 29 completed the study. One patient had an initial PAP of 53/25 mmHg, leading to conversion of the surgery to unilateral TKA. Patient demographics, intraoperative fluid data, and total surgical time are shown in **Table 1**.

Table 2 details hemodynamic values over time. Pulmonary artery pressure decreased during surgery compared with baseline and increased on POD 1. Pulmonary artery pressure increased from baseline to 24 hours after surgery, but this increase was not statistically significant.

Changes in PVR followed a similar pattern to PAP and showed a 13% increase from baseline to 24 hours following surgery; however, this difference was not significant ($P = 0.120$). Systemic vascular resistance decreased during surgery and was significantly lower than baseline at 24 hours following surgery ($P < 0.0001$).

The PVR/SVR ratio postoperatively represented a 30% increase compared with baseline ($P < 0.0001$; **Fig.1**). Cardiac output remained stable during surgery but increased from 6 to 8 L/min on POD 1 ($P < 0.0001$).

Data on trends in SvO₂, PaCO₂, and PaO₂ are shown in **Table 2**. Compared with baseline, increases in PaCO₂, PaO₂, and SVO₂ were seen on POD 1. **Fig. 2** shows levels of mean PAP and PVR over time.

4. Discussion

In patients undergoing BTKA during epidural anesthesia, we observed a significant increase in the PVR/ SVR ratio on POD 1. It is noteworthy that these changes were observed in the absence of significant changes in left and right heart filling pressures. Pulmonary embolization of intramedullary contents including fat, bone debris, and cement during arthroplasty procedures leading to increased right heart strain, is a well known occurrence [1-3].

In a previous study evaluating the hemodynamic effects of intramedullary and extramedullary instrumentation during BTKA, an increase in PVR was noted on POD 1, believed to be related to the release of medullary fat and debris into the pulmonary vascular compartment [12]. Most trials assessing the effects of knee arthroplasty on the pulmonary vasculature have used transesophageal echocardiographic monitoring for hemodynamic measurement, and have focused on embolic events related to tourniquet deflation during unilateral procedures [1-4]. However, these studies found little clinical significance of events surrounding the so-called bone cement implantation syndrome, and have described changes in PAPs and right heart function as small and relatively short-lived. No measurement of pulmonary hemodynamics was obtained following surgery in these studies. Furthermore, extrapolation of findings of studies assessing one-sided approaches are not applicable to bilateral surgeries in which the embolic load to the lung is presumably doubled.

In a recent study, we showed a PVR increase in patients undergoing bilateral hip arthroplasty [6]. An increase in pulmonary circulatory parameters was noted after the second hip implantation and continued in the postoperative period, implying a dose-response phenomenon.

In this study of BTKA, no changes in PVR were recorded intraoperatively, suggesting that intraoperative factors may be more important during total hip arthroplasty. The medullary canal exposed during hip arthroplasty is, in fact, much wider than it is during knee arthroplasty, enabling a higher embolic load to gain access to the vascular compartment and reach the lungs during surgery.

Another possible reason for the attenuation of the increase in PVR intraoperatively in this study was a decrease in right and left filling pressures. In fact, central venous pressure and PCWP decreased in the intraoperative period but reverted to baseline values on POD 1, possibly explaining the less prominent increase in PVR during surgery. To minimize the influence of factors such as fluid loading on our interpretation, we chose to analyze our data using PVR and PVR/SVR ratios. This circulatory index may provide more comprehensive information by taking into account factors affecting the overall circulatory system [9,10]. The observation of the increase in PVR/SVR ratio was made in the setting of a trend towards an increase in PVR and a significant decrease in SVR.

Our findings may represent the different effects of inflammatory perioperative stresses on the pulmonary and systemic vasculature. Dorr et al [13] measured cardiopulmonary hemodynamics intraoperatively in patients undergoing single-stage BTKA and found an increase in PVR, although not statistically significant. They also measured the PVR/SVR ratio and found an increase of 8.3% from baseline in patients who had both knees replaced, whereas they found an increase of 87.5% from baseline in patients whose second knee replacement was cancelled. Therefore, the authors recommend cancellation of surgery on the second knee in the event of a greater than 60% increase from baseline for the PVR/SVR ratio after replacement of the first knee.

Despite the differences in the intraoperative period seen between bilateral hip and knee procedures, in both studies we found a PVR increase on POD 1. These findings may suggest that the immediate increases in PAPs and PVR seen during bone marrow embolization are largely due to mechanical and chemical factors, while the sustained increase extended beyond surgery is likely due to inflammatory effects on the pulmonary vasculature. Indeed, we recently studied the perioperative inflammatory response in patients undergoing unilateral TKA and showed a significant increase in inflammatory markers (ie, interleukin-6, tumor necrosis factor- α , c-reactive protein), more pronounced 24 hours after surgery [14]. In this study, inflammatory markers were not measured, but an increase in CO and a decrease in SVR was noted following surgery, consistent with an enhanced inflammatory state.

The adverse effects on pulmonary hemodynamics prolonged in the postoperative period suggest that the stress on the right ventricle is sustained after implantation of the joint and not limited to the intraoperative period. This impairment may be subclinical for patients with

good cardiopulmonary reserve, but clinically detrimental to those with preexisting pulmonary circulatory disease.

We recently showed that patients with pulmonary hypertension are at increased risk for perioperative morbidity and mortality after THA and TKA [15]. We showed an increased rate of pulmonary embolism, deep venous thrombosis, and acute respiratory distress syndrome in this patient population, suggesting a common pathologic pathway induced by debris embolization to the lung, leading to right heart strain and venostasis. In light of our results, careful consideration of the benefits of performing bilateral procedures in individuals with preexisting pulmonary pathologies seems prudent.

Our study was limited by a number of factors. First, our patient sample included only patients with no preexisting pulmonary pathologic diagnosis. Thus, we cannot predict what the effect of bilateral knee arthroplasty may be in patients with preexisting pulmonary pathologies, although it is likely that these patients are more susceptible to perioperative injury. Second, we collected data only up to POD 1 because it would not have been feasible or necessary to leave the PA catheter in situ beyond this time point. This study did not include a control group of unilateral TKA patients. Thus, it may be argued that our findings of prolonged hemodynamic changes may at least, in part, reflect the delayed effects of the first arthroplasty. In concept, although results from a unilateral TKA cohort would be interesting, performing pulmonary catheterization in healthy, elective unilateral knee arthroplasty recipients may pose further ethical limitations. Thus, our data must be interpreted in the context of our study design, with awareness of the possibility that increases in pulmonary hemodynamics may be influenced partly by a timing effect related to TKA in general.

In conclusion, bilateral TKA is associated with a postoperative increase in the PVR/SVR ratio, which may represent the effect of the perioperative inflammatory response on the pulmonary and systemic vasculature.

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Fig. 1.

Pulmonary vascular resistance (PVR) to systemic vascular resistance (SVR) ratio over time. Values increased in response to the first and the second knee implantation and on postoperative day 1 (1 Day). Error bars = 95% CI. $P < 0.0001$ vs baseline* and after completion of the second knee[§]. Baseline = before epidural placement; incision = beginning of surgery after inflation of the tourniquet on the first knee; Knee 1, Knee 2 = 5 minutes after the tourniquet deflation of either side.

Fig. 2.

Pulmonary vascular resistance (PVR) and mean pulmonary artery pressure (mean PAP) over time. Mean PAP decreased after completion of the first and second knees vs baseline ($P < 0.0001$) and after completion of the second knee vs incision ($P < 0.05$). Mean PAP increased on postoperative day 1 (1 day) vs closing of the first knee (Knee 1; $P < 0.03$) and second knee (Knee 2; $P < 0.004$). PVR increased on POD 1 vs incision ($P < 0.05$) and second knee ($P < 0.004$). Baseline = before epidural placement, incision = beginning of surgery after inflation of the tourniquet on the first knee; Knee 1, Knee 2 = 5 minutes after tourniquet deflation of either side.

Table 1

Patient characteristics and surgical time

Age (yrs)	68 ± 5
Gender (M/F)	12/18
ASA physical status (2/3)	16/14
Body mass index (kg/m ²)	30 ± 5
Surgical time (min)	114 ± 17
Intraoperative crystalloids (mL)	1,942 ± 342

Continuous variables are means ± SD. Categorical variables are shown as frequencies.

Table 2

Hemodynamic values shown over time

	Baseline	Incision	Knee 1	Knee 2	POD 1
HR (bpm)	70 (67-74)	75 (70-80)	73 (70-77)	76 [*] (71-89)	85 ^{†,‡,§,#} (81-90)
MAP (mmHg)	94 (90-98)	74 (70-79)	81 [†] (77-85)	75 [†] (71-79)	88 ^{*,‡,§,#} (83-92)
CO (L/min)	6 (5.8-6.7)	7 (6.5-7.8)	6 [#] (5.6-6.7)	6 [#] (5.5-6.7)	8 ^{†,‡,§} (6.8-8.2)
CVP (mmHg)	5 (4.3-5.8)	5 (3.9-5.1)	4 ^{*,#} (3.2-4.6)	3 ^{†,‡} (2.8-4.0)	5 ^{†,§} (4.3-5.9)
PCWP (mmHg)	12 (10.9-13.3)	10 [*] (9.5-12.1)	9 ^{*,#} (7.5-10.6)	9 ^{*,#} (7.4-9.7)	11 ^{†,§} (10.0-12.4)
Systolic PAP (mmHg)	28 (27-30)	28 (25-30)	23 ^{†,‡} (21-25)	22 ^{†,‡} (20-24)	30 ^{†,§} (28-32)
Diastolic PAP (mmHg)	13 (12-25)	13 (11-14)	11 [†] (10-12)	10 ^{*,†} (9-11)	14 ^{†,§} (13-15)
Mean PAP (mmHg)	18 (17-20)	18 (16-19)	15 [*] (14-16)	14 ^{*,#} (13-15)	20 ^{†,§} (18-21)
PVR (Dyn sec cm ⁻⁵)	80 (71-90)	72 (62-82)	79 (68-90)	77 (67-87)	92 ^{§,#} (80-103)
SVR (Dyn sec cm ⁻⁵)	1,159 (1,080-1,237)	839 (707-971)	1,075 (966-1,185)	1,013 (897-1,130)	915 ^{†,‡} (846-984)
SvO ₂ (%)	82 (79-83)	/	83 (80-84)	79 ^{*,‡} (76-80)	76 ^{†,‡,§} (74-78)
PaO ₂ (mmHg)	422 (385-459)	/	378 [#] (331-424)	386 [#] (344-427)	379 [*] (345-414)
PaCO ₂ (mmHg)	46 (43-47)	/	47 (44-49)	45 [†] (42-47)	42 ^{*,‡,§} (40-43)

Values are means [95% confidence intervals (CI)].

Baseline=before epidural placement, incision=beginning of surgery after tourniquet inflation on the first knee, Knee 1, Knee 2=5 minutes after tourniquet deflation of either side, POD 1=postoperative day 1, HR=heart rate, MAP=mean arterial pressure, CO=cardiac output, CVP=central venous pressure, PCWP=pulmonary capillary wedge pressure, PAP=pulmonary artery pressure, PVR=pulmonary vascular resistance, SVR=systemic vascular resistance, SvO₂=mixed venous oxygen saturation, PaO₂=partial pressure of arterial oxygen, PaCO₂=partial pressure of arterial CO₂.

* $P < 0.04$ vs baseline.

† $P < 0.0001$ vs baseline.

‡ $P < 0.03$ vs knee 1.

§ $P < 0.004$ vs knee 2.

$P < 0.05$ vs incision.