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Intraoperative Monitoring for Safety of Bilateral Total Knee Replacement

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Cardiopulmonary hemodynamics in 79 consecutive patients who had one-stage bilateral total knee replacements were monitored prospectively with a pulmonary artery catheter. The pulmonary vascular resistance, wedge pressure, pulmonary artery pressure, and systemic vascular resistance were measured before skin incision, 5 to 10 minutes after implanting the first total knee replacement, and after the second knee replacement. The second knee replacement was cancelled in five patients because the pulmonary vascular resistance after the first knee replacement was more than double the baseline, or above 200 dyne/second/cm^5. No patient had clinical symptoms of fat embolism during the postoperative course. Patient predictive factors, or the use of pulse oximetry readings instead of a pulmonary artery catheter, were not predictive of intraoperative elevation of pulmonary vascular resistance. For this reason, the safety of this operation for the patient requires that intraoperative measurement of hemodynamic parameters of embolism be done.

Bilateral total knee replacements have a 1% mortality rate in the first month because of embolism and cardiopulmonary complications.[5,10,16] This mortality is at least 2.5 times that of unilateral or bilateral two-stage total knee replacements.[10,16] Ritter et al[16] reviewed Healthcare Finance Administration reports of total knee replacements done between 1985 and 1990. There were 62,730 bilateral total knee replacements and 12,922 were simultaneous. The 30-day mortality rate with simultaneous bilateral total knee replacements was 0.99% versus a 3- to 6-month staged total knee replacement mortality rate of 0.39%. The increased mortality rate with simultaneous bilateral total knee replacements is mostly because of emboli of fat, blood, or both.[5,10] An increased risk of fat embolic complications was reported by Jankiewicz et al,[9] Lane et al,[10] and Dorr et al.[5] Jankiewicz et al[9] reported no patient deaths, but 8% of patients had mental status changes attributed to fat emboli. Lane et al[10] had 1% mortality and 29% of the patients had mental status changes with simultaneous bilateral total knee replacements compared with no deaths and 7% of patients with mental status changes with unilateral total knee re-

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placements. Dorr et al[5] reported one death in 64 patients with bilateral total knee replacements and 12% with mental status changes caused by fat emboli. Fahmy et al[7] observed bone marrow contents and fat retrieval samples of blood in the right atrium during total knee replacement done with a femoral intramedullary rod. Berman et al[2] measured echogenic material in the right ventricle imaged by transesophageal echocardiogram. They sampled blood from one pulmonary artery catheter and 10 femoral vein catheters and found fresh blood thrombus, but no fat or bone marrow.

Ritter et al[16] and Lane et al[10] suggested that one-stage bilateral total knee replacements should not be done routinely unless the safety and mortality risk of this operation could be improved. No predictive patient comorbidities have been identified which would allow preoperative knowledge of patients who should not have one-stage bilateral knee replacements.[5,9] Previous studies have focused on the benefits of one-stage bilateral total knee replacements by reduction of costs and decreased length of hospital stay.[4,15] The scientific justification of use of this operation has been studied by comparison with the unilateral knee replacement with complication rates, blood loss, deep venous thrombosis, and pulmonary embolism.[9,10,17] The current study showed that one-stage bilateral total knee replacements could be done safely if intraoperative measurements of hemodynamic parameters of embolism were monitored. Second, patient outcome assessments of efficacy and satisfaction were assessed to determine if performance of one-stage bilateral total knee replacements was justified.

MATERIALS AND METHODS

Seventy-nine consecutive patients were scheduled for one-stage bilateral primary total knee replacements by one surgeon between September 1997 and May 1999. Five patients had surgery for the second knee cancelled so that 153 knees were treated surgically. The Apollo Knee System (Sulzer Orthopedics, Austin, TX) was implanted by cementing all three components at one time in all knees.[3] Sixty-two knees had the cruciate-retaining design and 91 knees had the posterior-stabilized design. Seventy-six patients had osteoarthritis and three had rheumatoid arthritis. Preoperative comorbidities are shown in Table 1; the comorbidities mostly are associated with cardiovascular disease. Thirty-nine patients were men and 40 were women with a mean age of 69.4 ± 6.9 years (range, 50–82 years). The mean height was 168.7 ± 11.3 cm (range, 142–196 cm), and the mean weight was 83.7 ± 16.9 kg (range, 40–132 kg). This study was approved by the Institutional Review Board at the authors' institution.

Preoperatively, each patient received a complete medical evaluation by an internist to determine the medical safety of having surgery on both knees. The internist continued to observe the patient in the hospital. The medical exclusion criteria were active angina or cardiomyopathy and a history of previous pulmonary embolism. Each patient was classified by the American Society of Anesthesiologist's physical status classification which was graded from 1 to 5 with 1 being the healthiest rating.[6,19] This classification was used for comparison of the results in each group and in evaluation of patients who had the second knee operation canceled.

All patients received a combination of epidural and general anesthesia with the epidural catheter left in place for postoperative analgesia. A Swan-Ganz pulmonary artery catheter (Baxter Healthcare Corporation, Irvine, CA) was inserted via the right internal jugular vein in every patient. Throughout surgery, each patient's temperature was measured with an esophageal temperature probe. Patients' temperatures were between 36° and 36.8° for the duration of surgery, and temperature homeostasis was maintained using the Bair Hugger® electrically heated air blanket (Augustine Medical, Inc, Eden Prairie, MN).

TABLE 1. Preoperative Medical Conditions in the Current Study Group

Comorbidities	Number of Cases
Smoking	20
Hypertension	17
Cardiopulmonary disease	13
Diabetes mellitus	9
Hypercholesterolemia	6
Peripheral vascular disease	4
Cancer	3

The baseline hemodynamic parameters were monitored before surgical incision and repeat measurements were done 5 to 10 minutes after completion of implantation of the first knee replacements, and 5 to 10 minutes after implantation of the second knee replacement. These hemodynamic measurements included systolic and diastolic blood pressure, mean pulmonary artery pressure, pulmonary artery occlusion pressure, cardiac output, pulmonary vascular resistance, and systemic pulmonary vascular resistance. The oxygen saturation readings from the pulse oximeter also were recorded at the moment the pulmonary vascular resistance was measured. The intraoperative criteria used in this study for cancellation of surgery of the second knee were elevation of the pulmonary vascular resistance after the first knee replacement to more than double the baseline, or elevation above 200 dyne/second/cm^{5}.[2,5] All but two patients were placed in the intensive care unit at least for the first postoperative day and night for continued monitoring of the Swan-Ganz pulmonary catheter for 24 hours.

Femoral preparation was accomplished in 34 patients (67 knees) by the use of a standard 35-cm long fluted intramedullary alignment guide rod. In 40 patients (76 knees) a short 9-cm rod was used which stabilized the cutting block instrument during application of the cutting block to the bone. With both length rods, an external guide was used which pointed to two fingerbreadths medial to the anterosuperior iliac spine of the pelvis. For tibial preparation, only the short 9-cm rod was used to stabilize the cutting jig in all 74 patients (143 knees) and an external rod was used to position the cutting block. For each rod insertion, regardless of length, the insertion drill hole was enlarged to allow venting and reduce intramedullary pressure. To determine the effect on the pulmonary vascular resistance of the use of rods, in five patients (10 knees) no rods were used for the femur or tibia. In these knees, only extramedullary guides were used. A tourniquet was used in all but 13 patients who had a history of peripheral vascular disease or diabetes mellitus, or both, or who had radiographic evidence of atherosclerotic femoral or popliteal artery calcification, or both. The tourniquet was deflated before closure in all knees in which the tourniquet was inflated. If the pulmonary vascular resistance measurement indicated that the second knee operation could be done safely, this was begun during the closure of the first knee.

Patients were divided into three groups based on the length of intramedullary femoral alignment rod and tourniquet use. Group 1 was comprised of 31 patients (61 knees) and a long femoral intramedullary rod with a tourniquet was used. Group 2 was comprised of 30 patients (56 knees) and a short femoral intramedullary rod with a tourniquet was used and Group 3 was comprised of 13 patients (26 knees) and femoral rods, but not a tourniquet, were used. For each group there was a comparison of the baseline pulmonary vascular resistance and the pulmonary vascular resistance 5 to 10 minutes after completion of the first knee surgery and deflation of the tourniquet. Additionally, five patients (10 knees) who did not receive a femoral or tibial intramedullary rod, but did have a tourniquet inflated, were included to study the pulmonary vascular resistance changes if no rod was used. The intraoperative and postoperative data were documented for the anesthesia time, tourniquet time, operative time, blood loss, fluid and blood transfusion, intensive care unit and hospital stay time, rehabilitation unit stay time, and complications.

At the most recent followup (average, 13.1 ± 5.9 months) each patient completed a self-assessment questionnaire (Orthographics, Salt Lake City, UT), which included pain and functional assessment, and patient satisfaction with the surgery. The six questions in Table 2 were asked specifically to assess the patient's satisfaction with having bilateral total knee replacements at one operation.

TABLE 2. Six Specific Questions to Assess Patient's Satisfaction with One-Stage Bilateral Total Knee Replacement

Specific Questions
1. Was having bilateral total knee replacements done at the same operation worth it?
2. Would you have bilateral total knee replacements done at the same operation again?
3. Would you rather do one knee at a time with two surgeries?
4. Do both knees feel the same at this time?
5. How long postoperatively before both knees felt the same?
6. How long postoperatively before you felt completely recovered?

Statistical analysis was done using SPSS software (Statistical Software Inc, Chicago, IL). The correlation between cancellation of surgery of the second knee replacement to the length of femoral rod and the use of tourniquet was analyzed using a Logit loglinear analysis. A logistic regression analysis was used to correlate preoperative medical comorbidities with surgery cancellation. Continuous variables including tourniquet and anesthesia time, amount of blood loss and transfusion, and radiographic component position were compared using an independent Student's t test.

RESULTS

The overall mean preoperative pulmonary vascular resistance for all 79 patients was 98.2 ± 39.8 dyne/second/cm^5 (range, 13–194 dyne/second/cm^5) with elevation after the first knee operation to 108.1 ± 46.3 dyne/second/cm^5 (range, 25–266 dyne/second/cm^5; p = 0.075) and after the second knee operation (in 74 patients who had both knees replaced) to 107.6 ± 42.7 dyne/second/cm^5 (range, 23–216 dyne/second/cm^5; p = 0.083). Table 3 shows that no significant difference was found in the three groups of patients for the pulmonary vascular resistance before or after the first and second knee operations. In addition, the mean pulmonary vascular resistance in five patients (10 knees) without the use of femoral rods, but with tourniquet use, was similar with a baseline of 91.8 ± 63.0 dyne/second/cm^5; and 99.0 ± 30.6 dyne/second/cm^5 after the first knee replacement, and 100.0 ± 23.5 dyne/second/cm^5 after the second knee replacement.

Fluid loss during the series of total knee replacement surgeries using a tourniquet was limited to less than 250 mL of blood in all cases. The patients routinely received only crystalloid therapy during surgery, limited to 1200 mL to 1800 mL in normal saline or lactated Ringer's solution.

Phenylephrine also was used routinely to manage the acute changes of tourniquet release. If a patient's heart rate was below 50 beats per minute after tourniquet release, 5 mg bolus doses of ephedrine was titrated to bring the blood pressure to within 10% of baseline. Pulmonary vascular resistance measurements were done 5 minutes after release of the tourniquet to allow the confounding effects of pharmacologic agents to dissipate. In this respect, the empiric measurements of the pulmonary vascular resistance and systemic vascular resistance ratio also were useful because most pharmacologic agents tend to affect pulmonary vascular resistance and systemic vascular resistance in the same direction, resulting in little or no change in the ratio of pulmonary vascular resistance to systemic vascular resistance. The most significant changes of hemodynamic parameters were elevation of pulmonary vascular resistance accompanied by an increase in the pulmonary vascular resistance to systemic vascular resistance ratio.

There was no statistical correlation between the cancellation of the second knee operation to the length of intramedullary femoral alignment rod or the use of the tourniquet. In Group 1 (long femoral rod with tourniquet) the pulmonary vascular resistance increased from

TABLE 3. Average Peripheral Vascular Resistance in Each Group

Parameter	Group 1 (n = 61)	Group 2 (n = 56)	Group 3 (n = 26)	p Value
Baseline PVR dyne/second/cm^{-5}	103.0 ± 35.9 (44–184)	87.7 ± 40.8 (13–194)	111.1 ± 35.2 (67–185)	0.150
PVR after the first knee dyne/second/cm^{-5}	100.6 ± 41.1 (46–263)	123.7 ± 56.2 (26–266)	93.6 ± 27.8 (46–138)	0.070
PVR after the second knee dyne/second/cm^{-5}	105.2 ± 40.7 (45–187)	106.2 ± 51.3 (23–216)	108.6 ± 37.8 (29–167)	0.879

PVR = pulmonary vascular resistance.

the baseline after the first knee surgery in 13 of 31 patients (42%). In one patient, the surgery for the second knee was cancelled because the pulmonary vascular resistance increased to 263 dyne/second/cm^5. In the remaining 30 patients the pulmonary vascular resistance after the second knee surgery was higher than baseline in 17 patients (57%), but none exceeded the safety limits.

In Group 2 (short femoral rod with tourniquet use), the pulmonary vascular resistance increased after the first knee surgery in 21 of 30 patients (70%). The second knee surgery was cancelled in four patients because in three patients the pulmonary vascular resistance after the first knee replacement was higher than 200 dyne/second/cm^5 (219, 224, and 266), and in one patient because the pulmonary vascular resistance increased more than twice the baseline (62 to 177 dyne/second/cm^5). Twenty patients (77%) had increased pulmonary vascular resistance compared with the baseline after the second knee surgery and two had pulmonary vascular resistance higher than 200 dyne/second/cm^5 (209 and 216). Neither patient had fat embolism develop.

In Group 3 (femoral rod without tourniquet use), no second knee surgeries were cancelled. Six patients (46%) had increased pulmonary vascular resistance after the first knee replacement and seven patients (54%) after the second knee surgery, but none reached 200 dyne/second/cm^5.

The elevation of pulmonary vascular resistance and systemic vascular resistance was compared with elevation of pulmonary vascular resistance alone to determine if this measurement might be more predictive of embolism. During continuous epidural anesthesia as administered routinely for total joint surgery, a high degree of sympathetic block is achieved. As a result, frequent reductions in the normal systemic vascular resistance from approximately 1200 dyne/second/cm^5 to approximately 800 dyne/second/cm^5 or lower are seen. To alleviate the potentially deleterious effects of such a low systemic vascular resistance (and, by extension, systemic arterial blood pressure), intermittent bolus doses of phenylephrine 20 to 60 μg, or an infusion of phenylephrine at 5 to 60 μg/minute (0.1–1.0 μg/kg/minute) were administered and titrated to the patient's systemic arterial blood pressure and systemic vascular resistance. This vasoactive drug can cause an elevation of the systemic vascular resistance and pulmonary vascular resistance. The isolated elevation of pulmonary vascular resistance is more predictive of mechanical obstruction of the pulmonary vasculature if other causes of pulmonary vascular resistance elevation, including blood pH, pO_2, pCO_2, and ventilation pressure remained within normal limits, which they did in the operations in patients in this study (Tables 4,5). As seen in Table 6, the increase in the pulmonary vascular resistance to systemic vascular resistance ratio after the first knee replacement in patients whose second knee replacements were cancelled increased from the baseline by 87.5% compared with an increase of 8.3% in patients who received bilateral total knee replacements ($p < 0.001$).

There was no statistical correlation of cancellation of the second knee operation and preoperative comorbidities. The five patients whose second knee replacements were cancelled had a mean age of 70.8 ± 4.0 years compared with 69.3 ± 7.1 years in patients

TABLE 4. Blood Gas Analysis for the Entire Cohort of Patients

Parameter	Baseline	After First Knee	After Second Knee
P_aO_2 (mean)	257.1 mm Hg ± 91.7	217.2 mm Hg ± 82.2	222.6 mm Hg ± 80.9
O_2 sat	99.4%	98.9%	99.3%
pH	7.44	7.42	7.40
P_aCO_2	34.1 mm Hg ± 5.1	35.3 mm Hg ± 4.1	36.9 mm Hg ± 3.4

TABLE 5. Blood Gas Analysis of the Seven Patients who had the Second Knee Procedure Cancelled

Parameter	Baseline	After First Knee
P_aO_2	291.0 mm Hg ± 108	270.2 mm Hg ± 117
P_aCO_2	34.0 mm Hg ± 3.0	42.3 mm Hg ± 9.6

who had bilateral knee surgeries. Three patients who had their second knee replacement cancelled had no preoperative medical problems whereas the other two patients had hypertension and cardiac arrhythmia. One patient (20%) who had the second surgery cancelled had a history of smoking compared with 19 of 74 patients (26%) with a history of smoking who had bilateral surgery. Only two of these five patients had measurement of pulmonary vascular resistance readings after cancellation of the second knee replacement. In one patient, the pulmonary vascular resistance at 10 minutes after tourniquet deflation was 266 dyne/second/cm^5 and the second knee replacement was cancelled; 10 minutes later it was 314 dyne/second/cm^5; and 4.5 hours later it was 210 dyne/second/cm^5. In the other patient, the pulmonary vascular resistance was 210 dyne/second/cm^5 10 minutes after tourniquet deflation and had dropped to 111 dyne/second/cm^5 when measured again 3.5 hours later. In the five patients who had their second surgery cancelled, the mean preoperative oxygen saturation reading was 99.5% ± 0.6% (range, 99%–100%). The readings remained unchanged after the first total knee replacement despite an increase in the pulmonary vascular resistance above the safe limits.

The tourniquet time of 148 knees which had completion of bilateral surgeries averaged 42.2 ± 14.2 minutes for the first knee and 41.5 ± 11.1 minutes for the second knee. The total surgery time for bilateral total knee replacements averaged 135.6 ± 29.2 minutes and anesthesia time averaged 187 ± 37.9 minutes. With bilateral total knee replacements, the closure of the first knee was completed while the second surgery was progressing.

No patient experienced postoperative confusion or encephalopathy and there were no deaths. Thrombocytopenia occurred in three patients who had bilateral surgeries, but no other evidence of fat embolism was seen. Deep vein thrombosis in the calf occurred in three patients who had bilateral total knee replacements, but no propagation of thrombi was identified and no treatment was given. No pulmonary embolism developed during the postoperative course. Transient arrhythmia occurred in five patients who had bilateral surgeries and two patients who had only one knee replacement. In the five patients with transient arrhythmias who had bilateral surgeries, atrial fibrillation occurred in three, supraventricular tachycardia in one, and

TABLE 6. Comparison of the Pulmonary Vascular Resistance and Systemic Vascular Resistance Ratio Between Patients with Bilateral Surgeries and Patients with Cancelled Surgery after the First Knee Operation

Parameter*	Patients with Bilateral Surgeries	Patients With Canceled Surgery
Baseline PVR/SVR ratio	0.12 ± 0.05	0.08 ± 0.04
PVR/SVR ratio after the first knee	0.13 ± 0.05	0.15 ± 0.07
Increase of PVR/SVR ratio (%)	8.3	87.5

*PVR = pulmonary vascular resistance; SVR = systemic vascular resistance.

transient ventricular tachycardia of 3 seconds in one. In the two patients with transient arrhythmias, who had only one knee replacement, atrial fibrillation occurred in one and multifocal atrial tachycardia occurred in one. For the patients who had bilateral total knee replacements the stay in the intensive care unit averaged 1.1 ± 0.3 days. The acute care hospital stay averaged 5.1 ± 1.9 days. Sixty-four patients (86%) required a rehabilitation stay of 7.7 ± 5.8 days.

The patient self-assessment questionnaire was completed for 69 of 74 patients (93%) who had bilateral surgeries. One patient had traumatic rupture of the Achilles tendon at final followup and could not provide an accurate assessment. The other four patients did not return the questionnaire. Fifty-nine patients (86%) experienced significant improvement in pain in both knees, whereas eight patients (11%) had little improvement. Two patients (3%) thought the pain was worse but no sign of aseptic loosening, infection, malalignment, or patellofemoral maltracking was detected. Both of the patients had depression postoperatively. Forty-five patients (65%) resumed their usual activities after surgery, 14 (20%) moderately resumed their activities, five (7%) resumed their activities somewhat, and five (7%) resumed their activities only a little.

Forty patients (58%) rated the outcome of surgery as excellent, 18 (26%) as very good, seven (10%) as good, and two each (3%) as fair and poor. The patients who rated the results as poor had postoperative complications. One had a quadriceps rupture in the left knee after falling, required a repair and casting, and had an extension lag of 50°. This patient also had suffered a recurrent dislocation of the right posterior stabilized knee, which required a revision to a constrained tibial insert. The other patient experienced a partial peroneal nerve palsy involving only the sensory function in the left leg and depression developed postoperatively.

Sixty-four patients (93%) thought the one-stage bilateral total knee replacements were worthwhile and would have both knees replaced again at the same operation. Five patients (7%) preferred that the knee replacements be done with two operations. Two of these five were the previously mentioned patients who had postoperative complications. One patient had limited motion of 80° on the left knee and 90° on the right knee with a 5° extension lag, which precluded her from resuming usual activities. One patient was not satisfied with a one-stage operation despite rating the surgical outcome as very good because he had postoperative ileus and was uncomfortable staying in the hospital. The fifth patient did not achieve her expectations for activity.

At the most recent followup, 46 patients (67%) thought that the knees were equal in pain and function. The average time until the knees were the same was 3.8 ± 4.0 months (ranging from immediately after surgery to 36 months). The average time before patients had complete recovery in both knees was 6.7 ± 6.7 months (range, 0.5–36 months).

DISCUSSION

Patients who agree to simultaneous bilateral total knee replacements do so for relief of pain and improved function without two operations. However, simultaneous bilateral total knee replacements should not be done unless the patient can be assured that the operation is as safe as two unilateral total knee replacements. The hypothesis of this study was that simultaneous bilateral total knee replacements could be done safely using intraoperative measurements of hemodynamic parameters of embolism. This hypothesis was suggested by the findings of the study of Dorr et al[5] who concluded that a pulmonary vascular resistance elevation of 200 dyne/second/cm^5 or more was indicative of severe embolism and that a second total knee replacement should not be done. In this study the criteria of the pulmonary vascular resistance doubling its baseline value was used as an indication of severe embolism. The use of the pulmonary vascular resistance and the value of 200 dyne/second/cm^{-5} was confirmed by Berman et al[2] who

observed that the pulmonary vascular resistance increased to this level after tourniquet release only when venous emboli were as large as 0.5 cm or more. Furthermore, three of 55 patients in their study had pulmonary embolism and this did not occur without a pulmonary vascular resistance above 200 dyne/second/cm^5. The 52 patients who did not have pulmonary embolism did not have a pulmonary vascular resistance above 200 dyne/second/cm^5.

Intraoperative measurement is necessary because the increased mortality rate with bilateral total knee replacements done at one operation does not have patient predictive factors.[5,9,10] Dorr et al[5] stated that the occurrence of embolic complications was idiosyncratic. Jankiewicz et al[9] and Lane et al[10] could not identify any comorbidities or patient factors which would predict these problems. Berman et al[2] observed that the embolic risk measured by transesophageal echocardiogram was not predictive of complications. They did find that echogenic material that was 0.5 cm in diameter increased pulmonary vascular resistance. Parmet et al[11–13] also measured at 5.33-fold greater risk of large venous embolism when a tourniquet was used.

Safe intraoperative monitoring requires the use of a pulmonary artery catheter (Swan-Ganz catheter). The use of pulse oximetry has not been predictive of severe embolism of blood or fat. Dorr et al[5] reported that the use of blood pO_2 was not an accurate criteria for safe continuation to the second knee operation because in one patient who died, the pO_2 did not drop until the pulmonary artery pressure was above 50 mm Hg and the pulmonary vascular resistance was above 800 dyne/second/cm^5. Berman et al[2] observed that pulse oximetry was not predictive of embolization dangerous to the patient. Barre et al[1] studied bilateral total hip replacements and reported that pulse oximetry did not detect successive embolic phenomena before pulmonary artery hypertension caused left heart changes that led to hemodynamic accidents. They recommended the use of a Swan-Ganz catheter. In the current study, pulse oximetry was not sensitive to increased pulmonary vascular resistance. Oxygen saturation readings would only decrease below 90 mm Hg with massive pulmonary emboli.

The use of a pulmonary artery catheter has its own mortality rate if the pulmonary artery is punctured. The mortality rate with the use of a pulmonary artery catheter was 0.016% in 6245 patients in one study[20] and 0.07 % in 5306 patients in a second study.[14] The anesthesia task force on the use of pulmonary artery catheters suggests that the mortality and morbidity rates with the use of a pulmonary artery catheter is dependent on experience and volume of use.[18] In the experience of the current authors during a 5-year period (1995–1999) with 225 simultaneous bilateral total knee replacements (450 knees) only one complication occurred with a Swan-Ganz catheter. In one patient the catheter knotted in the right ventricle and required removal with a pigtail catheter inserted through the femoral vein under fluoroscopy. The critical factor in successful use of the Swan-Ganz pulmonary artery catheter is the frequency of use by the anesthesiologist. Any anesthesiologist with a large and current experience in the use of the Swan-Ganz pulmonary artery catheter can do this procedure with a very low incidence of complications. Anesthesiologists who have a large volume of experience with cardiac surgery have a large volume of experience with a pulmonary artery catheter.

For additional safety in decision-making, the pulmonary vascular resistance to systemic vascular resistance ratio can be used to augment the importance of the pulmonary vascular resistance measurement. The use of phenylephrine to counter the sympathetic blockade of continuous epidural anesthesia can cause a concomitant rise in pulmonary vascular resistance independent of any embolic phenomena. Phenylephrine was used routinely to manage the acute changes of hypotension without bradycardia secondary to tourniquet release. If a patient's heart rate was below 50 beats per minute after tourniquet release, 5 mg bolus doses of ephedrine (which elevates blood pressure and heart rate) were titrated to bring

the blood pressure to within 10% of baseline. Pulmonary vascular resistance measurements were done 5 minutes after release of the tourniquet to allow the confounding effects of the pharmacologic agents to dissipate. The differentiation of the elevation of the pulmonary vascular resistance from the pharmacologic therapy, and not embolic events, is that the pharmacologic elevation is seen even before surgical incision in patients in whom the vasoactive agent is given. To further distinguish between pulmonary vascular resistance increases from drug therapy as opposed to isolated pulmonary vascular resistance increases caused by embolic phenomena, the pulmonary vascular resistance to systemic vascular resistance ratio can be used. When the elevated pulmonary vascular resistance is secondary to vasoactive drug therapy the pulmonary vascular resistance to systemic vascular resistance ratio was preserved. In elevation of the pulmonary vascular resistance caused by embolic phenomena, the pulmonary vascular resistance increased whereas the systemic vascular resistance decreased leading to a significant increase in the pulmonary vascular resistance to systemic vascular resistance ratio. In patients whose surgeries were cancelled, the pulmonary vascular resistance to systemic vascular resistance ratio increased on average 88%. The use of absolute values of pulmonary vascular resistance and systemic vascular resistance and the ratio of these values allows more rational assessment of the likely events occurring in the pulmonary vascular bed during surgery in which embolic phenomena are not uncommon. The authors recommend that an increase of more than 60% of baseline of the pulmonary vascular resistance to systemic vascular resistance ratio after the first knee operation means that the second knee operation should be cancelled.

A study conducted by using controls would prove the safety of the use of the pulmonary vascular resistance. However, any control must be safe for the patient and this type of controlled study would require death of a patient for confirmation of a technique. This already was experienced without intraoperative monitoring.[5] Because no study has identified patient predictive factors[5,9,10] and Dorr et al[5] described the occurrence of fat emboli as idiosyncratic, it would be unethical to randomize patients into those with or without pulmonary vascular resistance measurements. Unilateral total knee replacement and staged bilateral total knee replacements do not have the danger of compounded emboli from two knee replacements, so these operations as a control do not provide any additional information as to the safety of bilateral total knee replacements done at the same operation.

By their own assessment, 93% of these patients thought that they benefited from having both knee replacement surgeries at the same operation. According to the patient self-assessment questionnaire, the satisfaction of this operation was 86%; 59 of 69 patients thought they experienced significant improvement in pain in both knees. These data are nearly equivalent to that of Hawker et al[8] who reviewed Medicare data and reported a national sample of 487 patients with knee replacements. Improvement in pain was reported in 403 of 487 patients (82.8%) and 415 of 487 patients (85.2%) were satisfied with the results of the total knee replacement. In the current study, 64 of 69 patients (92%) reported that function was recovered for usual activities or better. Hawker et al[8] found 418 of 469 patients (89.1%) resumed their function after total knee replacement. One-third of the patients thought that one knee had a better result than the other knee. The time for full recovery from the total knee replacement was nearly 7 months with many patients indicating that the time for them to heal completely was 1 year.

Stanley et al[22] also reported on a study of bilateral knee replacements that provided data on function. They studied 32 simultaneous bilateral total knee replacements and 18 staged bilateral total knee replacements. The functional data reported was that 11% of the patients were household ambulators and only 21% of the patients thought they could do a full range of housework. This functional data seem

to be worse than the data of the current patients and those of Hawker et al.[8]

Bilateral total knee replacements can be done with protection against severe emboli when an experienced team of anesthesiologists and orthopaedic total knee replacement surgeons work together. Intraoperative monitoring with a pulmonary artery catheter will indicate which patients are at increased risk for pulmonary vascular compromise after one total knee replacement and therefore are not eligible for a second total knee replacement at the same operation. Technically, a long fluted femoral intramedullary rod can be used and should be used with a large vent hole as recommended by Fahmy et al.[7] The tibia should be prepared with extramedullary tools which may include a short (9-cm) metaphyseal rod for stabilization of the tibial cutting tool. A long tibial intramedullary rod will produce more emboli than one used in the femur.[5] During patient selection one should not choose patients who clearly manifest a melancholy or depressed personality[21] because these patients do poorly with any surgery that is done. Otherwise, patient satisfaction was as good as that reported for unilateral total knee replacements,[8] and the ratings of results by patients were not different from unilateral or staged bilateral total knee replacements.[23]

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