dynamic changes and of high monomeric methylmethacrylate concentrations after cemented total condylar knee prosthesis in our small group of patients does not, however, eliminate the potential risk of complications. A beta (type II) error is possible. Indeed, Svarling et al., studying the blood levels of monomeric methylmethacrylate in nine patients after total condylar knee prosthesis inserted with cement, observed low levels ranging between 0.1–1.44 μg/ml and a high level of 119.8 μg/ml in one patient who presented ventricular extrasystoles after release of the tourniquet.

In conclusion, our prospective study showed that total replacement surgery with total condylar prosthesis is followed only by acute systemic hemodynamic changes related to inflation and release of the tourniquet.

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REFERENCES

The Use of Ventilation/perfusion Lung Scans to Predict Oxygenation during One-lung Anesthesia

WILLIAM E. HURFORD, M.D.*, ANNE C. KOLKER, M.D.,† H. WILLIAM STRAUSS, M.D.‡

Selective ventilation of one lung provides a quiet surgical field and isolation of the operative bronchus during thoracic surgery. Ten to forty per cent of patients undergoing this technique develop significant intraoperative hypoxemia. It is difficult to anticipate, however, which patients will develop hypoxemia during surgery.

Kerr et al. reported that patients undergoing one-lung ventilation for non-pulmonary surgery had a lower mean PaO₂ than patients who underwent one-lung ventilation for a pulmonary resection. They postulated that the perfusion to the unventilated operative lung of patients undergoing a pulmonary resection may have been reduced chronically. This increase of pulmonary vascular resistance might apply with the development of a large pulmonary shunt and hypoxemia during one-lung ventilation. Subsequently, others have shown that, when blood flow to the operative lung is limited by intraoperative occlusion of the pulmonary artery, the PaO₂ during one-lung anesthesia improves. The influence of the preoperative distribution of pulmonary vascular resistance and, therefore, blood flow upon oxygenation during one-lung anesthesia has not been systematically studied.


* Instructor in Anesthesia, Harvard Medical School, and Assistant in Anesthesia, Massachusetts General Hospital.
† Instructor in Anesthesia, Harvard Medical School, and Assistant in Anesthesia, Massachusetts General Hospital. Current address: Memorial Sloan-Kettering Cancer Center, New York, New York.
‡ Professor of Radiology, Harvard Medical School, and Radiologist, Massachusetts General Hospital.

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Address reprint requests to Dr. Hurford: Department of Anesthesiology, Massachusetts General Hospital, Boston, Massachusetts 02114.

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The goal of our study was to test the clinical impression that the greater the preoperative blood flow to the operative lung, the more likely it is that intraoperative hypoxemia might occur from persistent pulmonary blood flow during one-lung anesthesia. Accordingly, we estimated the relative perfusion of the operative and non-operative lungs using preoperative ventilation and perfusion lung scans, and retrospectively compared this value to arterial blood gas values during one-lung anesthesia. Our results suggest that unpaired perfusion of the operative lung (>45% of total pulmonary blood flow) is a major risk factor for developing hypoxemia during one-lung anesthesia.

### MATERIALS AND METHODS

We examined the records of 30 consecutive patients who had received quantitative ventilation/perfusion lung scans, and subsequently underwent thoracic operations. Data collected included age, sex, arterial blood gas tensions during room air breathing, the results of preoperative pulmonary function tests by spirometry, and lung volume by plethysmography. All patients had a ventilation and perfusion lung scan performed as a part of their clinical evaluation for surgery and medical management.

Regional ventilation was assessed after 740 MBq (20 mCi) of $^{133}$Xe gas was inhaled by each patient while sitting. Initial breath, equilibrium, and elimination images were recorded with a large field-of-view camera fitted with a low-energy all-purpose collimator and positioned behind the patient. The pulse-height analyzer was set at 81 keV with a 20% window. Following the ventilation study, the patient was placed supine and 148–160 MBq (4–4.3 mCi) of $^{99m}$Tc labeled human albumin microaggregates, averaging 25 μ in diameter, were injected intravenously. Approximately 200,000–700,000 particles were administered. Following injection, the patient was again studied in the same position and perfusion images were obtained using the same instrument with the pulse-height analyzer set at 140 keV with a 20% window. The activity over each lung field in the equilibrium ventilation and perfusion images were expressed as percentage of total lung activity, producing a relative measure of the ventilation and perfusion of each lung.

In all patients, anesthesia was induced with iv thiopental and maintained by inhalation of enflurane or halothane. Laryngoscopy and tracheal intubation were facilitated by the iv administration of succinylcholine. Subsequently, neuromuscular blockade was provided by the iv administration of a nondepolarizing muscle relaxant. The non-operative, dependent bronchus was then intubated with a Robertshaw tube in all patients but one, who had a permanent tracheostomy and underwent endobronchial intubation with a single lumen tube. The patients were operated upon in the lateral jackknife position. The position of the endobronchial tube was confirmed by inspection and auscultation of the chest in the supine and lateral positions. Fiberoptic bronchoscopy was performed to confirm the tube’s position in one patient. All patients received controlled ventilation with 100% oxygen at a rate and volume appropriate to maintain the $\text{Paco}_2$ at approximately 40 mmHg.

Samples of arterial blood were obtained via a radial artery catheter at least 10 min after the operative lung was collapsed, confirmed by observing lung atelectasis, and prior to ligation of the pulmonary vessels. $\text{Paco}_2$, $\text{PaCO}_2$, and pH were measured with an automated blood gas analyzer (Corning® 175) calibrated by blood tonometered with gases of known concentration.

The data were subsequently analyzed using single or multiple linear regression, t tests, or Chi squares. A P value of less than 0.05 was considered significant.

### RESULTS

Nineteen men and 11 women were studied. Their ages averaged 60 ± 2 yr (mean ± SEM, range 38–78 yr of age). Twenty-four of the patients had lung cancer, two had empyema, two had recurrent pleural effusion, one had a bronchogenic cyst, and one had a bronchial stenosis. Nineteen had right-sided lesions and 11 had left-sided lesions. Their preoperative pulmonary function measurements are summarized in table 1. Fifteen of the patients underwent lobectomy; seven, segmentectomy or wedge resection; three, pneumonectomy; three, total decortication; and two, exploratory thoracotomy.

The $\text{PaO}_2$ measured during one-lung anesthesia correlated inversely with the relative perfusion of the oper-
ative lung as measured by the perfusion scans ($r = -0.72$; $P < 0.001$; fig. 1). Those patients with relatively little flow to the operative lung had only a small shunt and a high PaO$_2$. Patients with normal or excessive blood flow to the operative lung were often hypoxemic, which we defined as a PaO$_2 < 75$ mmHg during one-lung ventilation with 100% oxygen.

With preserved preoperative perfusion, i.e., greater than 45% of the cardiac output going to the operative lung, the PaO$_2$ averaged 115 ± 15 mmHg (mean ± SEM) during one-lung ventilation. When reduced preoperative perfusion, i.e., 45% or less of the cardiac output going to the operative lung, was documented, the PaO$_2$ averaged 290 ± 43 mmHg ($P < 0.002$).

Eight of the patients had a PaO$_2$ of less than 75 mmHg during one-lung anesthesia, despite ventilation with 100% oxygen (mean PaO$_2$ 55 ± 4 mmHg). The likelihood of developing this degree of hypoxemia increased progressively with additional perfusion of the operative lung, as determined by the preoperative perfusion scan (fig. 2). This is not a specific predictor, however, since many patients with preserved preoperative perfusion maintained an adequate level of oxygenation during one-lung anesthesia.

Since preoperative regional ventilation was well matched to perfusion ($r = 0.87$, $P < 0.001$), the percent of total ventilation to the operative lung was also correlated with the PaO$_2$ during one-lung anesthesia ($r = 0.73$, $P < 0.001$).

Neither age, sex, side of operation, preoperative analysis of arterial blood gas tensions while breathing room air, the values recorded during preoperative pulmonary function testing (FEV$_1$, etc.), nor preoperative lung volume correlated with oxygenation during one-lung anesthesia. Multivariate regression models using these variables did not improve the correlation between preoperative lung perfusion or ventilation and oxygenation during one-lung anesthesia.

**FIG. 1.** The relative preoperative perfusion to the operative lung correlated with the PaO$_2$ after 10 min of one-lung anesthesia. Relative perfusion to the operative lung was measured by scintigraphy performed after the intravenous injection of $99m$-Technetium macroaggregated human albumin.

**FIG. 2.** The proportion of patients with a PaO$_2 < 75$ mmHg during one-lung anesthesia grouped according to the relative preoperative perfusion to the patients' operative lung. The proportion of patients with a PaO$_2 < 75$ mmHg during one-lung anesthesia increased with increasing preoperative perfusion of the operative lung. The ratios within the figure refer to the number of patients with PaO$_2 < 75$ mmHg during one-lung anesthesia, as compared to the number of patients within each of the four groups.

**RESULTS**

The most important finding of this study is that preoperative ventilation/perfusion scans appear to identify those patients at greatest risk of hypoxemia during one-lung anesthesia. The extent of perfusion or ventilation to the operative lung, measured prior to operation, correlates inversely with the level of oxygenation achieved during one-lung anesthesia. Other preoperative tests, such as analysis of arterial blood gases while breathing room air or routine pulmonary function tests, are not significantly correlated with arterial oxygenation during one-lung anesthesia. These results provide evidence that hypoxemia during one-lung ventilation usually results from persistent blood flow to the operative lung.

Preoperative lung scans, while demonstrating the effect of tumors upon ventilation and pulmonary blood flow, do not reflect the influence of posture, anesthesia, and surgery upon pulmonary shunt and ventilation/perfusion matching. The correlation of the results of preoperative lung scans to oxygenation during one-lung anesthesia probably would have been increased if the scans had been performed with the patient in the appropriate lateral decubitus position. In this way, the effect of posture upon regional ventilation and perfusion would have been assessed.

Benumof$^{14}$ estimated that, in the lateral decubitus position, approximately 40% of the cardiac output perfuses the normal, ventilated nondependent lung. During one-lung anesthesia, the effect of gravity and hypoxic pulmonary vasoconstriction could reduce the expected pulmonary shunt to 20% of the cardiac output.$^{14}$

The level of PaO$_2$ measured during one-lung anesthesia in some of our patients with normal preoperative perfusion to the operative lung suggests a total pulmonary shunt of greater than 50%, although we did not place
pulmonary artery catheters, and thus could not directly measure the shunt fraction. An increase of pulmonary shunt normally accompanies general anesthesia and thoracic surgery. An increased shunt fraction may be caused by the presence of an open chest, mediastinal compression of the lower lung, elevation of the inferior hemidiaphragm, and interstitial edema in lung regions lying below the level of the heart. An increase of pulmonary vascular resistance in the ventilated lung or a decrease of cardiac output would also increase the pulmonary shunt during one-lung ventilation. In addition, intraoperative hypoxemia may result from improper location of the double lumen tube or the accumulation of secretions.

In summary, we used quantitative ventilation/perfusion lung scans to estimate the relative perfusion and ventilation of each lung in 30 patients who subsequently underwent one-lung anesthesia for thoracic surgery. We found that the degree of preoperative perfusion and ventilation of the operative lung correlated inversely with intraoperative oxygenation during one-lung anesthesia. Unimpaired preoperative perfusion and ventilation of the operative lung appeared to be major risk factors for developing intraoperative hypoxemia during one-lung anesthesia.

REFERENCES

Anesthesiology

Exacerbated Spinal Neurologic Deficit during Sedation of a Patient with Cervical Spondylosis

RICHARD A. MILLER, M.D.,* GREGORY CROSBY, M.D.,† PENNATHUR SUNDARAM, M.D.*

New or worsened neurologic deficits associated with "awake" tracheal intubation in patients with instability or narrowing of the cervical spinal canal are generally attributed to injudicious movement of the neck. However, we recently encountered a patient with cervical spondylosis who became substantially weaker after receiving diazepam and droperidol prior to intubation, despite neck stabilization, normal arterial blood pressure, and normal arterial blood gases. Consequently, we speculate that, under some conditions, sedative-hypnotics and tranquilizers can exacerbate or unmask underlying spinal cord dysfunction.

REPORT OF A CASE

A 74-yr-old woman with a long history of osteoarthritis (treated with aspirin), type II diabetes (well-controlled on NPH and C5I insulin),