EFFECT OF POSITIONING ON OXYGENATION IN SINGLE-LUNG TRANSPLANT RECIPIENTS

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- **BACKGROUND** Many benefits and adverse effects of positioning are related to changes in ventilation and perfusion. A number of unique factors related to the allograft make the effects of positioning difficult to determine in single-lung transplant recipients.
- **OBJECTIVES** To determine the effect of 3 body positions (supine, lateral with allograft lung down, and lateral with native lung down) on oxygenation and blood flow in single-lung transplant recipients in the 24 hours immediately after surgery.
- **METHODS** A quasi-experimental repeated-measures design with stratified assignment to 1 of 3 different sequencing patterns for turning group was used to study 15 transplant recipients, 9 with emphysema and 6 with fibrosis. Oxygenation, ventilation, and blood flow measures (heart rate, blood pressure) were assessed after each turn. The effect of ischemic reperfusion injury was also explored.
- **RESULTS** The oxygenation, ventilation, and blood flow variables did not differ significantly across group, diagnosis, or time. Oxygenation variables measured when the allograft lung was dependent did not differ significantly from such measurements obtained when the native lung was dependent.
- **CONCLUSIONS** No single position maximizes oxygenation in the immediate postoperative period in single-lung transplant recipients. Although a single standard protocol for positioning cannot be supported, the study does support the idea that transplant recipients can be safely turned in the immediate postoperative period without compromising oxygenation or hemodynamic status. (American Journal of Critical Care. 2002;11:66-75)

Lung transplantation is an established treatment option for end-stage lung disease in certain patients with parenchymal or vascular pulmonary disease. Current options include transplantation of 1 lung, 2 lungs, or a heart-lung bloc. Heart-lung transplantation is reserved for patients who cannot be treated by lung transplantation alone. Bilateral lung transplantation is mandatory for patients with chronic pulmonary infections such as cystic fibrosis and bronchiectasis. Single-lung transplantation extends the limited number of donor organs to more patients and is the most commonly used procedure for patients with emphysema and interstitial pulmonary fibrosis.

**Review of Relevant Literature**

**Positioning**

For patients undergoing single-lung transplantation, the immediate postoperative period is particularly critical. After lung transplantation, as with any thoracic surgery, side-to-side positioning offers a number of benefits, including increased comfort for the patient, reduced prevalence of pneumonia and phlebitis, and decreased risk of pressure ulcers. Furthermore, turning a patient can alter oxygen delivery to tissues by improving ventilation-perfusion matching if unilateral lung disease is present. However, repositioning patients has potential adverse effects, including
increases in resting energy expenditure and mean heart rate. Positioning can also lead to a decrease in heart rate as a result of stimulation of the autonomic nervous system. Changes in heart rate and oxygen consumption due to turning are a concern, because they can potentiate problems commonly encountered in the immediate postoperative period, such as cardiac dysrhythmias, low cardiac output, and hypotension.

**Ventilation and Perfusion**

Many of the benefits and adverse effects of positioning are related to changes in ventilation and perfusion that occur in response to a change in position. In the normal lung, ventilation and perfusion are greater in the dependent regions of the lung than in nondependent regions. If a patient with unilateral lung disease is positioned with the most involved lung dependent, perfusion will increase in the dependent lung. However, this increase in blood flow is not matched by added ventilation and promotes shunting. Depending on the extent of the disease, the patient can experience a substantial decrease in $P_AO_2$. Conversely, lateral positioning with the good lung down tends to improve ventilation-perfusion matching and increase $P_AO_2$.

In patients with bilateral lung disease, response is varied. Ventilation in patients with chronic obstructive pulmonary disease is predominantly distributed to the nondependent lung when patients are in lateral decubitus position. In patients with bilateral lung disease characterized by an increase in interstitial fluid (eg, the early edematous phase of acute respiratory distress syndrome), fluid tends to pool in the dependent lung regions. Therefore, when the patient is supine, fluid tends to collect in the more dependent posterior areas of the lung, the area that also receives more perfusion. With prone positioning, better aerated areas of the lung are dependent, resulting in better ventilation-perfusion matching. Furthermore, prone positioning may cause pleural pressure to become more negative, a situation that favors alveolar recruitment and a reduction in positive end-expiratory pressure (PEEP). Reasons for these favorable changes are not fully understood but may be related to a downward shift of the diaphragm and improved lymphatic drainage.

Although previous research provides a basis for understanding the effects of positioning in patients with unilateral and bilateral lung disease, a number of additional unique factors make the effects of positioning difficult to determine in recipients of a single-lung transplant. After single-lung transplantation for emphysema, ventilation favors the compliant, native lung. Results of studies of the distribution of perfusion to the allograft vary. Starnes et al. reported that approximately 50% of the pulmonary perfusion goes to the allograft of emphysema patients, whereas Trulock reported that 70% to 80% of pulmonary perfusion goes to the allograft. The distribution of ventilation and perfusion after single-lung transplantation in patients with emphysema differs from the ventilation and perfusion that occur after single-lung transplantation in patients with fibrosis or interstitial lung disease. In patients with fibrosis or interstitial lung disease, both ventilation and perfusion favor the allograft because of the poor compliance and high vascular resistance in the native lung.

Another factor that affects early postoperative oxygenation in recipients of a single lung is ischemic reperfusion injury. Graft dysfunction may occur during the first few days after transplantation in as many as 15% to 35% of lung transplant recipients. Diverse terms have been applied to this clinical condition, which is characterized by diffuse pulmonary infiltrates and poor oxygenation. Severity ranges from mild acute lung injury to a severe pattern that radiographically resembles acute respiratory distress syndrome. The prevalence of ischemic reperfusion injury does not correlate well with the ischemic time of the organ, the type of preservation solution used, or other donor-related factors. Another problem is that diagnostic criteria have not been standardized; therefore, the prevalence of early graft dysfunction cannot be determined precisely. How early graft dysfunction influences the effect of body positioning in recipients of a single lung is unknown. No studies have addressed the effect of supine and lateral turning in recipients of a single lung in the immediate postoperative phase of recovery.

**Purpose**

The purpose of this study was to determine the effect of 3 body positions (supine, lateral with the allograft down, and lateral with the native lung down) on oxygenation and blood flow in recipients of a single lung in the 24 hours immediately after surgery. In addition, we examined the effect of diagnosis (emphysema, fibrosis) and ischemic reperfusion injury on oxygenation and blood flow in the 3 positions. The following research questions guided this study:

1. Are there differences in oxygenation ($P_AO_2$), mixed venous oxygen saturation ($S_VO_2$), or ventilation ($PACO_2$, minute ventilation $[V_{min}]$) related to turning group (sequence of positions), time (measurement interval), or diagnosis (emphysema, fibrosis) when recipients of a single-lung transplant are positioned supine, lateral with the allograft down, or lateral with the native lung down?

2. Are there differences in blood flow (heart rate, mean arterial pressure), related to turning group?
(sequence of positions), time (measurement interval), or diagnosis (emphysema, fibrosis) when recipients of a single-lung transplant are positioned supine, lateral with the allograft down, or lateral with the native lung down?

3. Does the position of the allograft (dependent, nondependent) alter oxygenation (\( \text{PaO}_2, \text{SvO}_2 \)) in recipients of a single-lung transplant who have fibrosis or emphysema?

4. Does the amount of ischemic reperfusion injury affect \( \text{PaO}_2 \) or \( \text{SvO}_2 \) when recipients of a single-lung transplant are positioned supine, lateral with the allograft down, or lateral with the native lung down?

**Methods**

**Site and Sample**

Participants were recruited from the lung transplantation program of the University of Pittsburgh Health System. This medical center has an active lung transplantation program: 498 lung transplants were performed before the initiation of data collection (internal records, July 18, 1997). The recipients included 116 patients with the primary diagnosis of chronic obstructive pulmonary disease (emphysema and \( \alpha_1 \)-antitrypsin deficiency) and 27 with the diagnosis of fibrosis. Study inclusion criteria required that subjects (1) have a preoperative diagnosis of emphysema or fibrosis, (2) have received a single-lung transplant (left or right), (3) be receiving mechanical ventilation and be intubated with a conventional single-lumen endotracheal tube or a double-lumen endobronchial tube, (4) be scheduled to receive their first lung transplant, (5) not be receiving extracorporeal oxygenation, (6) have a functional arterial catheter, (7) have a functional oximetric catheter for \( \text{SvO}_2 \) measurement, (8) be in hemodynamically stable condition, that is, no unstable arrhythmias and no hypotension (mean arterial pressure <90 mm Hg), and (9) have approval of the attending critical care medicine and transplant physician in the intensive care unit for lateral changes in position.

The recruitment goal was 15 adult recipients of a single-lung transplant with a primary diagnosis of emphysema or fibrosis. The sample size was based on data extrapolated from a previous study of positioning. In each group, at each turn, data were collected for 30 minutes as follows. At baseline (\( T_1 \)), 5 minutes after each turn (\( T_2 \)), 15 minutes after each turn (\( T_3 \)), the variables measured were \( \text{PaO}_2, \text{PaCO}_2, \text{SvO}_2, V_{\text{min}} \) mean arterial pressure, and heart rate. At 25 minutes after each turn (\( T_4 \)), the variable measured was cardiac output. Finally, at 30 minutes after each turn (\( T_5 \)), the variables measured were mean arterial pressure and heart rate. These intervals were chosen to allow assessment of immediate (1-5 minutes), short-term (15 minutes), and long-term (25-30 minutes) response to the turning procedure.

The effects of allograft position (dependent, nondependent) and ischemic reperfusion injury on \( \text{PaO}_2 \) and \( \text{SvO}_2 \) also were examined. Ischemic reperfusion injury was rated by examining the chest radiograph obtained closest to the time of data collection. All ratings were made by the same physician (A.B.), who was experienced in the postoperative care of lung transplant recipients, was not involved in data collection, and was blinded to the group.

For this study, the allograft lung fields were evaluated by using a scoring system with a scale of 0 to 4 devised by one of the authors (A.B.). The score was determined by dividing the allograft lung into upper and lower halves and first scoring each half as 0 (no infiltrate), 1 (mild infiltrate), or 2 (moderate to severe infiltrate). Addition of the scores resulted in a total score for ischemic reperfusion injury (0 = none, 1 = mild, 2 = moderate, 3 = severe, and 4 = very severe). For example, scoring of an allograft lung with mild infiltrate in the upper half (score = 1) and moderate infiltrate in the
lower half (score = 2) would result in a score of 3 (1 + 2), or severe ischemic reperfusion injury.

**Instrumentation**

Arterial blood gas samples for determination of PaO₂ and PaCO₂ were obtained anaerobically from an arterial catheter and analyzed by using the ABL System blood gas analyzer (Model 625/620; Radiometer Medical A/S, Copenhagen, Denmark). An oximetric pulmonary artery catheter (Swan Ganz Oximetry TD System, Model 93A-741H-7.5f; Baxter Healthcare Corporation/Edwards Critical Care Division, Irvine, Calif) was calibrated and assessed for reliability for intermittent recording of continuously displayed digital values. V̇O₂ min was measured with the mechanical ventilator (Puritan Bennett 7200, Carlsbad, Calif). Mean arterial pressure was measured with an arterial catheter and calibrated, leveled, and zeroed transducers by using the bedside monitor (Siemens, Danvers, Mass), which was also used to measure heart rate. Data were recorded from the digital display. Cardiac output was measured by a closed-system room-temperature thermodilution technique that used 3 cardiac output measurements with thermodilution curves examined for appropriate technique. The 3 measurements were averaged by the Siemens cardiac output computer (Model 8792129E2501).

Patients’ comfort was quantified by using a 4-point Likert scale (0 = none to 4 = a great deal) completed in response to the following question: How much discomfort are you experiencing now? If the patient was unable to respond to the question (still anesthetized), a rating of zero was recorded. Patients’ comfort was assessed at T₁, T₅, and T₃₀. If the rating was greater than 2, pain medication was administered per the prescribed analgesia protocol. This approach ensured that all subjects had similar pain intensity scores throughout the study, as pain intensity might affect the variable measured.

**Procedure**

Approval to conduct the study was obtained from the institutional review board at the University of Pittsburgh. Potential subjects were found after placement of their name on the list of candidates for a lung transplant and were informed about the study by lung transplant coordinators. Informed written consent was obtained from each subject. Postoperatively, the subjects were randomized to turning group, and data were collected as previously described. Data collection was terminated if an untoward response such as ectopy, desaturation (oxygen saturation <85%) as measured by pulse oximetry), or a mean arterial pressure less than 90 mm Hg occurred.

**Data Analysis**

The SPSS statistical package (Version 8, SPSS Inc, Chicago, Ill) was used for statistical analysis. Summary descriptive statistics were generated to describe the characteristics for the total sample and for each group, with means and ranges used for the continuous variables and frequency counts used to describe categorical variables.

A 3 × 2 × 2 multivariate analysis of variance (ANOVA) was used to determine any significant differences in oxygenation and hemodynamic variables related to turning group, diagnosis, time, or interactions between group, diagnosis, and time. A repeated-measures ANOVA was used to determine if oxygenation and hemodynamic variables differed depending on the sequence of turns. A univariate ANOVA was used to determine if the dependent oxygenation variables differed in these patients with fibrosis or emphysema when the allograft was dependent compared with when the native lung was dependent. An α level of .05 was used for all analyses.

**Results**

Fifteen recipients of a single-lung transplant (9 patients with emphysema and 6 with fibrosis) were enrolled during a 16-month period (Table 1). Baseline data on demographics and medical condition did not differ significantly by turning group or by diagnosis (all P > .05). Most subjects (n = 10) received a left-sided transplant. The mode for the chest radiograph score was 1, indicating mild ischemic reperfusion injury in 47% of the sample. Only 2 subjects had scores greater than 2 for ischemic reperfusion injury.

Before data collection, all subjects rated their discomfort as zero. Subsequent ratings were zero or 1, except for 3 subjects who had ratings greater than 2. Each subject with a rating greater than 2 was given pain medication per routine orders; afterwards, they rated their discomfort zero. With this exception, administration of pain medications was at the discretion of the bedside nurse.

Cardiopulmonary bypass was not used for surgery in any of the subjects. The mean time ± SD from the end of the operation to the start of data collection was 337 ± 298 minutes. Some transplantation procedures were performed simultaneously, resulting in 2 subjects being recruited at a time. Therefore, the time frame to initiation of data collection varied depending on which subject was first admitted from the operating room to the intensive care unit (subjects 6 and 7 and subjects 12 and 13).
Eleven subjects received synchronized intermittent mandatory ventilation, and 4 received differential lung ventilation. Mean baseline values ± SDs for ventilatory parameters for the total sample were fraction of inspired oxygen, 0.43 ± 0.06; PEEP, 8.5 ± 3.1 cm H2O; tidal volume, 0.60 ± 0.19 L; and Vmin, 7.3 ± 3.0 L. Baseline fraction of inspired oxygen, PEEP, respiratory rate, tidal volume, and Vmin did not differ significantly among groups. Hematocrit and hemoglobin values were obtained at baseline for calibration of oximetry measurements. Baseline hematocrits ranged from 0.25 to 0.44, and hemoglobin values ranged from 97 to 151 g/L.

**Oxygenation and Ventilation**

Differences in oxygenation and ventilation variables were not significant for the multivariate main effects or for the interaction effect of group, diagnosis, and time (Table 2). Further, oxygenation and ventilation did not differ depending on the sequence of turns.

When individual variables within each set were examined, univariate analysis revealed a significant difference for PaO2 between turning groups (P = .03), with a higher value in group 3 (NSA). The means ± SDs for PaO2 were 112.27 ± 6.1, 97.33 ± 3.66, and 145.03 ± 5.2 mm Hg for groups 1, 2, and 3, respectively. A significant difference was found for Vmin between

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**Table 1** Demographic and medical condition data by group (turning sequence) and diagnosis*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Total</th>
<th>Group 1 (n = 5)</th>
<th>Group 2 (n = 5)</th>
<th>Group 3 (n = 5)</th>
<th>Emphysema (n = 9)</th>
<th>Fibrosis (n = 6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, years</td>
<td>54 (8)</td>
<td>51 (5)</td>
<td>58 (7)</td>
<td>52 (12)</td>
<td>54 (5)</td>
<td>51 (12)</td>
</tr>
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<td>Sex, % male</td>
<td>54</td>
<td>100</td>
<td>80</td>
<td>80</td>
<td></td>
<td>44</td>
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<td>Transplant, % left lung</td>
<td>67</td>
<td>80</td>
<td>40</td>
<td>80</td>
<td></td>
<td>78</td>
</tr>
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<td>Score on chest radiograph</td>
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<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>3</td>
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<tr>
<td></td>
<td>1</td>
<td>7</td>
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<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
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<td>4</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
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<td>Pain intensity score, mean</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Baseline</td>
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<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
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</tr>
<tr>
<td>5 minutes (over 3 turns)</td>
<td>0.24</td>
<td>0.51</td>
<td>0.25</td>
<td>0.47</td>
<td>0.48</td>
<td>0.33</td>
</tr>
<tr>
<td>30 minutes (over 3 turns)</td>
<td>0.02</td>
<td>0.00</td>
<td>0.00</td>
<td>0.06</td>
<td>0.05</td>
<td>0.00</td>
</tr>
<tr>
<td>Duration of surgery, minutes</td>
<td>271 (80)</td>
<td>232 (93)</td>
<td>322 (34)</td>
<td>249 (92)</td>
<td>240 (80)</td>
<td>318 (56)</td>
</tr>
<tr>
<td>Time from end of surgery to start of data collection, minutes</td>
<td>337 (298)</td>
<td>269 (135)</td>
<td>322 (181)</td>
<td>389 (519)</td>
<td>405 (363)</td>
<td>235 (127)</td>
</tr>
<tr>
<td>Fraction of inspired oxygen, proportion of 1.00</td>
<td>0.43 (0.06)</td>
<td>0.48 (0.08)</td>
<td>0.40 (0.00)</td>
<td>0.42 (0.04)</td>
<td>0.43 (0.05)</td>
<td>0.43 (0.08)</td>
</tr>
<tr>
<td>Positive end-expiratory pressure, cm H2O</td>
<td>8.5 (3.1)</td>
<td>10.0 (4.0)</td>
<td>8.0 (2.7)</td>
<td>7.5 (2.5)</td>
<td>7.7 (3.4)</td>
<td>9.6 (2.5)</td>
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<td>Tidal volume, L</td>
<td>0.60 (0.19)</td>
<td>0.55 (0.11)</td>
<td>0.55 (0.16)</td>
<td>0.70 (0.27)</td>
<td>0.57 (0.16)</td>
<td>0.63 (0.22)</td>
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<tr>
<td>Minute ventilation, L</td>
<td>7.3 (3.0)</td>
<td>6.6 (1.8)</td>
<td>6.6 (3.9)</td>
<td>8.6 (2.7)</td>
<td>6.1 (2.5)</td>
<td>9.1 (2.6)</td>
</tr>
</tbody>
</table>

*Values are mean (SD) unless otherwise indicated. Turning sequence was as follows: group 1, NAS: native lung dependent, allograft lung dependent, supine; group 2, SAN: supine, allograft lung dependent, native lung dependent; group 3, NSA: native lung dependent, supine, allograft lung dependent.
the 2 diagnoses \((P = .02)\), with a higher \(V_{\text{min}}\) for the patients with fibrosis. The means ± SDs for \(V_{\text{min}}\) were 7.02 ± 0.20 L for the patients with emphysema and 9.42 ± 0.53 for the patients with fibrosis. Also, \(P_{\text{Aco}_2}\) differed significantly among the times of measurement \((P = .04)\). On the basis of summary data, \(P_{\text{Aco}_2}\) values were slightly higher at the 5-minute measurement than at the 15-minute measurement.

**Blood Flow**

Differences in mean arterial pressure and heart rate were not significant for the multivariate main effects or for the interaction effect of group, diagnosis, and time (Table 3). In addition, mean arterial pressure and heart rate did not differ significantly with the different sequences of turns.

**Allograft Position**

\(P_{\text{aO}_2}\) in patients who received a single-lung transplant because of fibrosis or emphysema did not differ significantly when the allograft lung rather than the native lung was dependent. Furthermore, \(P_{\text{aO}_2}\) did not differ significantly between patients with fibrosis and patients with emphysema for the main effects of position and time, and none of the interactions among factors were significant (Table 4).

Similarly, \(S_{\text{vO}_2}\) did not differ significantly for the main effects of position and time, and none of the interactions among factors were significant (Table 5).

The mean values (±SE, where SE = SD/square root of n) for \(P_{\text{aO}_2}\) and \(S_{\text{vO}_2}\) for each of the 3 positions were within normal clinical ranges for all subjects irrespective of sequence group (Table 6).

To further evaluate the effect of allograft position (dependent, nondependent), we calculated the mean and the SE of the mean as indices for comparison. Overall, for all positions irrespective of sequencing, the highest mean \(P_{\text{aO}_2}\) values were for subjects in group 3 (NSA; range, 143-147 mm Hg). The lowest mean \(P_{\text{aO}_2}\) values were for subjects in group 2 (SAN; range, 95-101 mm Hg). No trends in \(P_{\text{aO}_2}\) were found that related to which lung (native vs allograft) was in the dependent position. For group 1 (NAS), the lowest mean \(P_{\text{aO}_2}\) was for the position with the native lung dependent (107 ± 11 mm Hg); for group 2 (SAN), the lowest mean \(P_{\text{aO}_2}\) was for the position with the allograft lung dependent (95 ± 7 mm Hg); and for group 3 (NSA), the lowest mean \(P_{\text{aO}_2}\) was for the supine position (143 ± 10 mm Hg).

Mean \(S_{\text{vO}_2}\) values ± SE by group (NAS, SAN, and NSA) for each position were also calculated. Mean \(S_{\text{vO}_2}\) values ranged from 63% to 73% (within normal limits) for all positions irrespective of sequencing group. No trends were found that were related to which lung (native or allograft) was in the dependent position. The lowest mean \(S_{\text{vO}_2}\) values were obtained with patients in the same positions they were in when the lowest \(P_{\text{aO}_2}\) values were obtained.

**Diagnosis**

Mean values for \(P_{\text{aO}_2}\) and \(S_{\text{vO}_2}\) by diagnosis (emphysema and fibrosis) for each position are given in Table 7. The highest mean \(P_{\text{aO}_2}\) for the emphysema group was for the native lung dependent (120.22 ± 11.08 mm Hg), and the lowest mean \(P_{\text{aO}_2}\) was for the supine position (113.22 ± 12.34 mm Hg). For those subjects with fibrosis, the highest mean \(P_{\text{aO}_2}\) was for the allograft dependent position (127.83 ± 15.26 mm Hg), and the lowest mean \(P_{\text{aO}_2}\) was for the position with the native lung dependent (114.25 ± 13.58 mm Hg). These mean values did not differ from a normal clinical range, regardless of
which of the 3 different positions or the 2 different diagnoses were involved (mean range, 68%-72%).

Because of the small number of subjects in each group and the large amount of variability, individual values for $\text{PaO}_2$ also were examined. No consistent pattern was found when patients were positioned with the allograft lung dependent rather than the native lung dependent. For subjects with emphysema or fibrosis, no consistent pattern was seen for $\text{PaO}_2$ values when patients were positioned with the allograft lung dependent rather than the native lung dependent.

### Ischemic Reperfusion Injury

Only 2 patients had scores for ischemic reperfusion injury that were greater than 2. Therefore, statistical analysis was not done. However, the individual values for the 2 subjects were examined. The subject with a score of 4 had a diagnosis of fibrosis (from group 2). The $\text{PaO}_2$ was higher with the native lung dependent, but findings were affected by an increase in fraction of inspired oxygen (0.40 to 0.50) between turn 1 and turn 2. The subject with a score of 3 had a diagnosis of emphysema (from group 1). The highest

### Table 4 Source table for $\text{PaO}_2$ for lung position

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of squares</th>
<th>df</th>
<th>Mean square</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position*</td>
<td>491.74</td>
<td>2</td>
<td>245.87</td>
<td>0.38</td>
<td>.69</td>
</tr>
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<td>Position* by diagnosis</td>
<td>1232.18</td>
<td>2</td>
<td>616.09</td>
<td>0.95</td>
<td>.40</td>
</tr>
<tr>
<td>Time</td>
<td>3.59</td>
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<td>3.59</td>
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</tr>
<tr>
<td>Time by diagnosis</td>
<td>2.96</td>
<td>1</td>
<td>2.96</td>
<td>0.12</td>
<td>.74</td>
</tr>
<tr>
<td>Position* by time</td>
<td>209.03</td>
<td>2</td>
<td>104.51</td>
<td>2.21</td>
<td>.13</td>
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<tr>
<td>Position* by time by diagnosis</td>
<td>93.92</td>
<td>2</td>
<td>46.96</td>
<td>0.99</td>
<td>.38</td>
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</table>

*Positions are allograft lung dependent, native lung dependent, and supine.

### Table 5 Source table for mixed venous oxygen saturation for lung position

<table>
<thead>
<tr>
<th>Source</th>
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<th>df</th>
<th>Mean square</th>
<th>F</th>
<th>P</th>
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<tbody>
<tr>
<td>Position*</td>
<td>69.03</td>
<td>2</td>
<td>34.52</td>
<td>1.55</td>
<td>.23</td>
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<td>Position* by diagnosis</td>
<td>52.90</td>
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<td>26.45</td>
<td>1.19</td>
<td>.32</td>
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<tr>
<td>Time</td>
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<td>5.81</td>
<td>0.45</td>
<td>.51</td>
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<tr>
<td>Time by diagnosis</td>
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<td>8.56</td>
<td>0.67</td>
<td>.43</td>
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<td>Position* by time</td>
<td>35.96</td>
<td>2</td>
<td>17.98</td>
<td>2.75</td>
<td>.08</td>
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<td>Position* by time by diagnosis</td>
<td>8.80</td>
<td>2</td>
<td>0.40</td>
<td>0.06</td>
<td>.94</td>
</tr>
</tbody>
</table>

*Positions are allograft lung dependent, native lung dependent, and supine.

### Table 6 Mean (SE) $\text{PaO}_2$ and mixed venous oxygen saturation*

<table>
<thead>
<tr>
<th>Position</th>
<th>$\text{PaO}_2$, mm Hg</th>
<th>Mixed venous oxygen saturation, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allograft dependent</td>
<td>121.72 (9.86)</td>
<td>68.80 (2.34)</td>
</tr>
<tr>
<td>Native dependent</td>
<td>118.06 (8.79)</td>
<td>68.35 (1.95)</td>
</tr>
<tr>
<td>Supine</td>
<td>116.24 (9.76)</td>
<td>70.43 (2.13)</td>
</tr>
</tbody>
</table>

*For the 3 positions irrespective of sequence group. SE = SD/square root of n.
PaO\textsubscript{2} occurred with the native lung in a dependent position (PaO\textsubscript{2} = 153 mm Hg at 15 minutes), and the lowest PaO\textsubscript{2} occurred with the allograft lung in the dependent position (PaO\textsubscript{2} = 75 mm Hg at 5 and 15 minutes; see Figure).

**Discussion**

The major findings of this study were as follows. (1) During the immediate postoperative period in recipients of a single-lung transplant, changes in oxygenation, ventilation, and blood flow were similar regardless of whether the patient was positioned supine, lateral with the allograft down, or lateral with the donor lung down. (2) Similarly, these variables did not differ significantly depending on the patient’s diagnosis (emphysema vs fibrosis). (3) One ideal position cannot be found for maximizing oxygenation in recipients of a single lung in the immediate postoperative period, as has been done for patients with unilateral lung disease. (4) Although a single standard protocol for positioning cannot be supported, the findings do support the idea that recipients of a single lung can be safely turned in the immediate postoperative period without compromising oxygenation or hemodynamic status. Of note, the study was done in the immediate (<24 hours) postoperative period, and at that time, ischemic reperfusion injury is less likely to be present. If more subjects had severe ischemic reperfusion injury, study findings might have been different, as suggested by the response of the 2 subjects with ischemic reperfusion injury (severe in 1 subject and very severe in the other).

For the main effects of group, diagnosis, and time, the PaO\textsubscript{2}, Sv\text{O}_2, PaCO\textsubscript{2}, or \textit{V}\textsubscript{min} did not differ significantly among the 3 turning groups. These findings are consistent with results previously reported for patients after coronary artery bypass graft surgery\textsuperscript{20-22} and support the idea that initial and subsequent positions selected for turning had no effect on study variables.

Univariate analysis yielded a statistically significant difference for a single oxygenation variable (PaO\textsubscript{2}) across groups. Group 3 (NSA) had a higher mean PaO\textsubscript{2} at baseline and subsequently for all turns than did groups 1 and 2. No factors related to diagnosis, treatment, or amount of ischemic reperfusion injury appeared to explain this difference. Therefore, this difference most likely occurred by chance, despite attempts to equalize groups by randomization, and was due to the small number of subjects. From a clinical standpoint, mean PaO\textsubscript{2} remained clinically stable for all groups for all 3 turns.

Univariate analysis also yielded a significant difference for one ventilatory variable (\textit{V}\textsubscript{min}) between the 2 diagnoses: patients with fibrosis had higher \textit{V}\textsubscript{min} than did patients with emphysema. The mean baseline

**Table 7** Change in PaO\textsubscript{2} and mixed venous oxygen saturation with position change by diagnosis*  

<table>
<thead>
<tr>
<th>Variable</th>
<th>Native lung dependent</th>
<th>Allograft lung dependent</th>
<th>Supine</th>
</tr>
</thead>
<tbody>
<tr>
<td>PaO\textsubscript{2}, mm Hg</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Emphysema</td>
<td>120.22 (11.08)</td>
<td>115.61 (12.46)</td>
<td>113.22 (12.34)</td>
</tr>
<tr>
<td>Fibrosis</td>
<td>114.25 (13.58)</td>
<td>127.83 (15.26)</td>
<td>119.25 (15.11)</td>
</tr>
<tr>
<td>Mixed venous oxygen saturation, %</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Emphysema</td>
<td>68.28 (2.47)</td>
<td>67.78 (2.97)</td>
<td>68.44 (2.70)</td>
</tr>
<tr>
<td>Fibrosis</td>
<td>68.42 (3.03)</td>
<td>69.83 (3.63)</td>
<td>72.42 (3.30)</td>
</tr>
</tbody>
</table>

*Values are mean (SE).
All Pa CO2 values were within normal limits. Those patients with fibrosis had lower mean Pa CO2 values than did patients with emphysema, but again the significant differences were small and not clinically important. This difference most likely represented different ventilatory status due to patient-initiated breaths because most subjects were receiving synchronized intermittent mandatory ventilation and could therefore vary their respiratory rate.

Hemodynamic measurements (mean arterial pressure, heart rate) did not differ significantly with different sequencing of position change for the main effects of group, diagnosis, and time. These findings are in contrast to reports of previous investigators. Chan and Jensen found a significant difference in mean arterial pressure (P = .03) and diastolic blood pressure (P = .009) in patients in the right and left lateral and supine positions after coronary artery bypass graft surgery. Pressures were highest in left lateral position and lowest in the supine position. Unlike patients recovering from coronary artery bypass graft surgery, recipients of a single-lung transplant may be better able to tolerate certain positions without changes in hemodynamic status because they have not undergone cardiac surgery. However, results have been inconsistent concerning change in heart rate after position changes, and the changes can be quite variable.

No significant differences in PaO2 occurred in patients with fibrosis or emphysema when the allograft lung was dependent compared with when the native lung was dependent for the main effects of position change for the main effects of position, diagnosis, and time. These findings were unexpected. After single-lung transplantation for emphysema, ventilation favors the native lung and perfusion favors the allograft. In contrast, for patients who received a single-lung transplant because of fibrosis, both ventilation and perfusion favor the allograft. West has described a model (zones of the lung) that explains changes in lung perfusion and ventilation due to body position. In numerous studies, mean PaO2 was higher when the “good” lung was dependent than when the worse lung was dependent in patients with unilateral lung disease.

Several explanations could account for this finding. First, only transplant recipients in stable condition were included in our study, and their status may have prevented any significant changes in monitored parameters. Also, the sample excluded patients with pulmonary hypertension. Finally, in recipients of a single lung, both lungs have some abnormality due to the disease and the transplantation. Therefore, it may be inappropriate to describe one lung as healthy and the other one as unhealthy.

For the main effects of position, Svo2 did not differ significantly in recipients of a single lung when the allograft lung was dependent compared with when the native lung was dependent. Also, no significant differences were found for any of the interactions of position, diagnosis, and time. The Svo2 values remained in the normal range (60%–80%) for 12 of the 15 patients. Therefore, Svo2 was not a sensitive dependent variable in this study. In earlier studies, SvO2 decreased initially (8.3%–11.3%) at 1 minute after positioning and then returned to baseline within 5 minutes. In our study, SvO2 measurements began after 5 minutes, a time most likely too late to detect a change.

Only 2 transplant recipients (13%) had severe or very severe ischemic reperfusion injury. Postoperatively, abnormalities peak at 24 hours, but unless change is marked, changes on a chest radiograph can have a 24-hour lag time. Therefore, radiographic manifestation may not be apparent until 48 hours after transplantation. In our study, chest radiographs were obtained as early as 2 hours and no later than 24 hours postoperatively, a situation that may explain the low incidence of ischemic reperfusion injury.

Limitations

The sample was obtained at a single center, a situation that limits the generalizability of the findings. Recruitment of subjects required 16 months because of the number of available subjects. During this interval, the protocols for management of recipients of a single-lung transplant changed. Early in the study, patients with emphysema were treated with differential ventilation and a double-lumen endobronchial tube. Later, one ventilator and a single-lumen endobronchial tube were used. Consequently, 4 of the 9 patients with emphysema had differential lung ventilation with a double-lumen tube, and the other 5 had conventional ventilation with a single-lumen tube. All patients with fibrosis had conventional ventilation with a single-lumen endobronchial tube.

Further, retrospective analysis indicated that the study was underpowered. A power analysis with data from the study indicated that 60 to 80 subjects would
being necessary to achieve a significant difference among groups. Recruitment of a sample this size would require an extended time, and practice most likely would change during that period, potentially confounding the results. An alternative option would be to use multiple sites, but this plan is associated with the inherent risk of differences in practice that might affect the findings. The large sample size also strongly implies that the between-group differences in the immediate postoperative period are minimal in recipients of a single-lung transplant and therefore not clinically significant. These findings might be different if the study were of subjects more likely to have severe ischemic reperfusion injury or severe rejection. However, such subjects would more likely have substantial decrement in oxygenation if positioned with the more involved lung dependent, making it difficult to complete the turning protocol.

**Nursing Significance and Implications**

Study findings do not indicate an ideal position for maximizing oxygenation in recipients of a single lung transplant in the immediate postoperative period. Although a single standard protocol cannot be supported, our findings do support the idea that recipients of a single lung can be safely turned in the immediate postoperative period without compromising oxygenation or hemodynamic status. In addition, the findings support the idea that recipients of a single lung who are intubated with a double-lumen endobronchial tube can be safely turned. Moreover, transplant recipients tolerated lateral positioning to allograft (surgical) and native (nonsurgical) sides in the postoperative period with minimal discomfort. Thus, for this select group of patients, the research findings support the application of standard nursing practice to reposition a critically ill patient every 1 to 2 hours.

Nurses who work with the heterogeneous population of recipients of a single-lung transplant should anticipate varied responses. In the immediate postoperative period, nurses should assess patients for changes in oxygenation with positioning. The type and extent of pulmonary pathophysiological changes and the presence of ischemic reperfusion injury must be considered in this assessment, because the pathophysiological changes may influence oxygenation in certain positions. Nursing research on positioning of patients is important because of the effects of positioning on both pulmonary functioning and patients’ comfort.

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**REFERENCES**

Effect of Positioning on Oxygenation in Single-Lung Transplant Recipients
Elisabeth L. George, Leslie A. Hoffman, Arthur Boujoukos and Thomas G. Zullo

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