Safe Intrahospital Transport of Critically Ill Ventilator-dependent Patients

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Study Objective: To determine whether manual ventilation during intrahospital transport of mechanically ventilated critically ill patients results in blood gas and/or hemodynamic abnormalities.

Design: A single-blind prospective study evaluated arterial blood gas, blood pressure, heart rate, and arrhythmia changes during mechanical ventilation and manual transport ventilation.

Setting: University hospital ICUs and various diagnostic or treatment areas.

Patients: Twenty mechanically ventilated critically ill patients during intrahospital transport. Intervention: Each patient received mechanical ventilation (MECH) with a volume ventilator while in the ICU and at the study/treatment area. They were manually ventilated (MAN) by a respiratory therapist during transport between areas.

Measurements and Main Results: The MECH settings were: VT = 0.75 ± 0.17 L; f = 16 ± 4; V̇E = 12.6 ± 4.3 L/min; FIO₂ = 0.46 ± 0.2. Mean peak Paw = 31 ± 12 mmHg and mean effective CST = 44 ± 15 mmHg. No hemodynamic abnormalities were observed. Arterial blood gas values did not vary to any clinically significant degree, except in two patients: one patient had a reduced PaO₂ and increased PaCO₂ associated with an accidental O₂ disconnection and clamped chest tube; another patient had an increased pH by 0.13 units with only a 9 mm Hg fall in PaCO₂.

Conclusions: Manual ventilation during intrahospital transport of critically ill mechanically ventilated patients is safe provided the person performing manual ventilation knows the inspired oxygen fraction and minute ventilation required before transport and is trained to approximate them during transport.

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Mechanically ventilated critically ill patients frequently require procedures that cannot be performed at the bedside. Patients are either manually or mechanically ventilated during the intrahospital transport to the diagnostic or treatment area. If the procedure is very brief or the ventilator cannot be in the procedure area, such as most ventilators in magnetic resonance imaging, the patient is often manually ventilated. At our institution, patients are manually ventilated during transport and mechanically ventilated during most procedures with the same volume ventilator used to ventilate them in the ICU.

In contrast to our long-term experience that ventilatory complications during transport of manually ventilated patients is extremely infrequent, Braman et al† reported frequent and potentially life-threatening hemodynamic consequences during transport attributed to blood gas abnormalities. They monitored 36 transports, in which 20 patients were manually ventilated during transport (group 1) and the remaining 16 were ventilated using a portable volume ventilator (group 2). Clinically significant hemodynamic and blood gas changes occurred in 75 percent of group 1 vs 44 percent of group 2. Most of the changes were in arterial blood gas values—70 percent in group 1 and 38 percent in group 2. Hypercapnia and acidemia occurred in 20 percent of group 1 (mean PaCO₂ increase of 15 mm Hg and decrease in pH of .09), while 50 percent of this same group showed hyperventilation (mean decrease of 11 mm Hg) and alkalemia (mean increase of .11 pH units). They concluded that patients should be transported using a volume ventilator. We therefore conducted a prospective single-blind study to evaluate the safety of manual ventilation (MAN) during intrahospital transport of critically ill patients at our institution.

Material and Methods

Twenty mechanically ventilated (MECH) patients were prospectively studied. The only selection criteria were: (1) an indwelling

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artrial catheter already in place, and (2) the availability of a senior therapist to gather data. Portable ECG monitors were used during transport to monitor rate and rhythm according to our standard protocol. We recorded the nearest arterial blood gas values (ABG) during the 8-h period before transport while mechanically ventilated (MECH-1) ABGs, blood pressure (BP), and heart rate (HR) immediately before transport mechanically ventilated (MECH-2); on arrival to the study area manually ventilated (MAN-1); at the end of the study mechanically ventilated (MECH-3); on return to the ICU manually ventilated (MAN-2); and the nearest ABG value during the 8-h period following the transport mechanically ventilated (MECH-4). Figure 1 summarizes this protocol. Manual ventilation was performed by a registered or registry-eligible respiratory therapist using a Puritan-Bennett PMR-2 resuscitation bag connected to 10 to 15 L/min of oxygen. The therapist assigned ventilator management for the patient in the ICU accompanied the patient on transport, as is normal practice; he/she was blind to the study goals and protocol.

We used Branan's definitions to determine clinically significant changes: (1) hypotension (systolic BP <90 mm Hg or a fall >20 mm Hg from baseline); (2) a cardiac arrhythmia that was not present before transport; and (3) deterioration in ABGs (ΔPaCO₂ >10 mm Hg, ΔpH >0.05, and a PaO₂ <50 mm Hg). The paired two-tailed t test was used for statistical analyses. P values equal to or less than 0.05 were considered statistically significant.

**RESULTS**

The patient population had a mean age of 50±19 years (range, 17 to 81). Nine patients were male, the remaining 11 female. The diagnoses and type of study performed are given in Table 1. Fifty-five percent of the patients went for one of the various CT scans. Mean MECH-2 settings were: (a) VT = .75 ± .17 L, (b) f = 16 ± 4 breath/min, (c) Vc = 12.6 ± 4.3 L/min, and (d) FiO₂ = .46 ± .2. Eighteen patients were ventilated in the assist/control mode of ventilation and two (patients 4 and 7) in the intermittent mandatory ventilation (IMV) mode. Mean peak airway pressure (Paw) was 31 ± 12 cm H₂O and mean effective static compliance (Cst) was 44 ± 15 ml/cm H₂O (Table 1). The MECH-3 settings were identical to MECH-2.

In this group of critically ill patients there were no untoward hemodynamic consequences. Mean BP in mmHg and HR in beats/min (±1 SD) were: MECH-2 = 134/80 (± 19/14) and 106 (±17); MAN-1 = 139/78 (± 22.13) and 103 (±20); MECH-3 = 134/80 (± 18/12) and 106 (±22); and MAN-2 = 136/77 (± 21/12) and 103 (±20). There were no statistically significant differences between mechanical ventilation (MECH-2&3) and manual ventilation (MAN-1&2).

The ABG values did not vary to any clinically significant degree, except in two patients. Patient 1 had a reduced PaO₂ from 51 mm Hg to 22 mm Hg associated with an accidental O₂ disconnection during MECH-1, and a fall from 47 to 33 mm Hg associated with a clamped chest tube during MAN-2. There were no hemodynamic or other observable consequences. In this same patient, with a VE of 25 L/min during mechanical ventilation, manual ventilation resulted in a PaCO₂ increase of 13 mm Hg and a pH decrease of 0.12 units. Another patient had a pH increase of 0.13 units with a 9 mm Hg drop in PaCO₂.

Mean values for PaCO₂ (in mm Hg) ± 1 SD were: MECH-1 = 35.6 ± 9.5; MECH-2 = 34.0 ± 7.7; MAN-1 = 31.9 ± 5.8; MECH-3 = 33.0 ± 7.5; MAN-2 = 32.0 ± 7.3; and MECH-4 = 34.8 ± 7.9. These differences were not statistically significant. The 95 percent confidence intervals (CI) were: MECH-1 = 31-40; MECH-2 = 30-37; MAN-1 = 29-35; MECH-3 = 30-37; MAN-2 = 28-35; and MECH-4 = 31-39 (Fig 2A). Six patients had a slight increase in PaCO₂ (mean of 4.8 mm Hg with a range of 2 to 13), while 14 had a
### Table 1—Information for Patients Manually Ventilated*

<table>
<thead>
<tr>
<th>Patient</th>
<th>Age/Sex</th>
<th>Diagnosis</th>
<th>Procedure</th>
<th>Ventilator Settings</th>
<th>PaCO2 Max Change, mm Hg</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Vr L</td>
<td>Vt f</td>
</tr>
<tr>
<td>1</td>
<td>17/M</td>
<td>MVA</td>
<td>CT (head)</td>
<td>1</td>
<td>25</td>
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<tr>
<td>2</td>
<td>35/F</td>
<td>Liver transplant</td>
<td>Ultrasound</td>
<td>0.7</td>
<td>18</td>
</tr>
<tr>
<td>3</td>
<td>76/F</td>
<td>X-ray</td>
<td></td>
<td>0.55</td>
<td>14</td>
</tr>
<tr>
<td>4</td>
<td>36/F</td>
<td>Cerebral aneurysm</td>
<td>CT (head)</td>
<td>0.7</td>
<td>8</td>
</tr>
<tr>
<td>5</td>
<td>35/M</td>
<td>MVA, flail chest</td>
<td>Angiography</td>
<td>1</td>
<td>14</td>
</tr>
<tr>
<td>6</td>
<td>59/M</td>
<td>Brain cancer</td>
<td>Radiation therapy</td>
<td>0.7</td>
<td>13</td>
</tr>
<tr>
<td>7</td>
<td>21/F</td>
<td>CHI</td>
<td>CT (head)</td>
<td>0.8</td>
<td>10</td>
</tr>
<tr>
<td>8</td>
<td>59/M</td>
<td>Cancer</td>
<td>CT (head)</td>
<td>0.7</td>
<td>14</td>
</tr>
<tr>
<td>9</td>
<td>63/M</td>
<td>GI bleed</td>
<td>Angiography</td>
<td>0.8</td>
<td>18</td>
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<tr>
<td>10</td>
<td>81/M</td>
<td>Bacterial meningitis</td>
<td>CT (head)</td>
<td>0.7</td>
<td>12</td>
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<tr>
<td>11</td>
<td>36/F</td>
<td>Cerebral aneurysm</td>
<td>Angiography</td>
<td>0.7</td>
<td>17</td>
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<tr>
<td>12</td>
<td>48/M</td>
<td>CVA</td>
<td>CT (head)</td>
<td>1.2</td>
<td>14</td>
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<tr>
<td>13</td>
<td>37/M</td>
<td>C-5 Quad, LLL pneumonia</td>
<td>XR, spine x-ray</td>
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<td>15</td>
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<tr>
<td>14</td>
<td>68/F</td>
<td>FTW, GI bleed, pneumonia</td>
<td>CT (head)</td>
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<td>24</td>
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<tr>
<td>15</td>
<td>60/F</td>
<td>Aortofemoral bypass</td>
<td>CT (abdomen)</td>
<td>0.6</td>
<td>18</td>
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<tr>
<td>16</td>
<td>74/M</td>
<td>Myasthenia gravis</td>
<td>CT (head)</td>
<td>0.75</td>
<td>19</td>
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<tr>
<td>17</td>
<td>41/F</td>
<td>GI bleed, diabetes, pneumonia</td>
<td>Angiography</td>
<td>0.8</td>
<td>20</td>
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<tr>
<td>18</td>
<td>76/F</td>
<td>FTW</td>
<td>Intra-ICU transport</td>
<td>0.65</td>
<td>12</td>
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<tr>
<td>19</td>
<td>53/F</td>
<td>Cerebral art-venous malformation</td>
<td>CT (head)</td>
<td>0.75</td>
<td>15</td>
</tr>
<tr>
<td>20</td>
<td>26/F</td>
<td>MVA, CHI, pulmonary confusion</td>
<td>CT (head)</td>
<td>0.55</td>
<td>20</td>
</tr>
</tbody>
</table>

* MVA = Motor vehicle accident; FTW = fail to wean from mechanical ventilation; CHI = closed head injury; quad = quadriplegic; LLL = left lower lobe; f = respiratory frequency; Cst = static compliance; PaCO2 = maximum change in arterial carbon dioxide.

† Includes a spontaneous Vr of 0.20 L and f of 20.
‡ Includes a spontaneous Vr of 0.40 L and f of 20.

**Figure 2A**: Mean arterial carbon dioxide tension (PaCO2) in mm Hg with 95 percent confidence intervals. See Figure 1 for study design and definition of abbreviations. **B**: Mean arterial pH and 95 percent confidence intervals. See Figure 1 for study design and definitions of abbreviations. **C**: Mean arterial oxygen tension (PaO2) and 95 percent confidence intervals. All but one patient with a brief accidental disconnection from oxygen had a PaO2 >100 mm Hg during transport. **D**: Mean arterial oxyhemoglobin saturation and 95 percent confidence intervals. One patient with a brief accidental disconnection from oxygen had a saturation of 39 percent during MAN-1 and 73 percent during MAN-2. See Figure 1 for study design and definitions of observations.
slight decrease (mean, 4.8; range, 1 to 8). The 95 percent CI for the absolute maximum change was 3.2 to 6.4 mm Hg. Arterial pH changes correlated with PaCO2 changes in all cases (Fig 2B).

Mean PaCO2 ± 1 SD of the stable 8-h period before and after transport (MECH-1&4) of 35.2 ± 8.7 vs the combined value immediately before and after transport (MECH-2&3) of 33.6 ± 7.5 was statistically significant (p < .01) but clinically unimportant. Similarly, the combined PaCO2 values immediately before transport (MECH-2&3) of 33.6 ± 7.5 vs the combined value during transport (MAN-1&2) of 31.7 ± 6.5 was statistically significant (p < .02) but clinically unimportant.

The PaO2 was significantly higher during manual ventilation than mechanical ventilation (p = .0001) because patients received a higher FIO2 during transport (Fig 2C). All but one patient had a PaO2 greater than 100 mm Hg during transport; 12 patients had a PaO2 greater than 250 mm Hg. Several patients had a transport PaO2 in the 100- to 150 mm Hg range; in follow-up it was determined that these patients had an increased minute ventilation, a mean of 13.8 L/min (range, 9.6 to 18 L/min), and were transported using 10 L/min of oxygen instead of 15 L/min, resulting in an FIO2 less than 1.0. The difference in SaO2 between MAN-1&2 vs MECH-2&3 was not statistically significant, since all but one patient had a PaO2 > 100 mm Hg (Fig 2D).

Mean transport time, or the time being manually ventilated one-way, to or from the appointment, was 14.9 min/patient (range, 5 to 40 min). The mean time spent performing the procedure was 35 min (range, 10 to 40 min).

**DISCUSSION**

Transporting critically ill patients within the hospital is a serious endeavor. Measures must be taken to ensure patients' safety and stability. Protocols defining required equipment and personnel are necessary to safely transport critically ill patients. Various devices are available to provide or monitor the adequacy of ventilation, including end-tidal CO2 monitors, transcutaneous CO2 and O2 monitors, oximeters, spirometers, and portable ventilators.

Gervais et al. compared three methods of ventilation during intrahospital transport: (1) manual ventilation, (2) manual ventilation using a spirometer to monitor expired volume, and (3) a portable ventilator. They concluded that manual ventilation monitored with a spirometer most closely matched the patients' ABGs on the mechanical ventilator. In this study, both unmonitored manual ventilation and ventilation with a portable volume ventilator resulted in hyperventilation and alkalemia. Insel et al. studied seven patients manually ventilated during transport from an ICU to a diagnostic or therapeutic procedure area and found no significant changes in heart rate or blood pressure.

A spirometer to monitor exhaled volume provides a direct and relatively inexpensive measure of the adequacy of ventilation. However, special adapters are required with some devices to allow collection of expired gas, making it cumbersome if not nearly impossible to collect.

A minimum requirement is that the person providing manual ventilation know the capabilities and limitations of the manual ventilator and be aware of the approximate volume ejected with each "squeeze of the bag." Respiratory therapists are trained to be aware of the capabilities and limitations of such equipment and to evaluate the patient's ventilation requirements prior to transport. Observation of one's own capabilities should be a regular event. This can be accomplished either by (1) connecting a spirometer directly to a resuscitation bag, realizing that it is much harder to eject the same volume into a lung with low compliance or high resistance, or preferably by (2) using a test lung capable of simulating varying compliances and resistances.

Thorson et al. have reported the variability of PaCO2 in stable ICU patients over a 50-min period to range from 1 to 8 mm Hg (3.0 ± 1.9). The changes in PaCO2 over our six data collection points (MECH-1, MECH-2, MAN-1, MECH-3, MAN-2, and MECH-4) compare favorably with these results. The clinically unimportant differences in mean PaCO2 of MECH-1&4 vs MECH-2&3 and MECH-2&3 vs MAN-1&2 are also similar to those of Thorson et al. If a steady-state carbon dioxide production and dead space ventilation is assumed in our patients, mean VE varied only 6 percent during MECH-2, MAN-1, MECH-3, and MAN-2.

Our data confirm our previous extensive experience that manual ventilation of patients requiring intrahospital transport is safe, in contrast to that of Braman et al. Unfortunately, those authors do not provide data on minute ventilation or FIO2 prior to or during transport. This essential information makes a comparison of the severity of respiratory dysfunction difficult. However, only four of these 20 manually ventilated patients received PEEP and only one was at a level greater than 10 cm H2O. This would suggest that the patients were similar. There is no prospective data available concerning very high minute ventilation (eg, > than 25 L/min) and very high FIO2 requirements (eg, .8 or .7). In such patients, portable transport ventilators, expired volume monitors, end-tidal CO2 monitors, transcutaneous CO2, O2 monitors, and/or oximeters may be of value.

The need for intrahospital transport of critically ill mechanically ventilated patients should not limit necessary studies which are often the cornerstone of critical decision making. Manual ventilation during transport can

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adequately maintain ABG values, provided the person performing ventilation is well trained and is cognizant of the patient's minute ventilation and inspired oxygen requirements. Although portable transport ventilators, end-tidal CO₂ monitors, transcutaneous CO₂ and O₂ monitors, and/or oximeters may be of value in selected patients, our data do not support their routine use. They will add unnecessary costs in time and equipment in most cases. Mechanical transport ventilators or monitoring should not replace well-trained and vigilant personnel, trained to provide the necessary FIO₂ and minute ventilation as determined prior to transport.

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