Hemodynamic Consequence of Hand Ventilation Versus Machine Ventilation During Transport After Cardiac Surgery

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Objectives: The hemodynamic consequences of ventilation of intubated patients during transport either by hand or using a transport ventilator have not been reported in patients after cardiac surgery. The authors hypothesized that bag-mask ventilation would alter end-tidal CO2 during transport and hemodynamic parameters in patients post-cardiac surgery.

Design: A prospective, randomized trial.

Setting: A university-affiliated tertiary care hospital.

Participants: Cardiac surgery patients.

Interventions: Thirty-six patients were randomized to hand ventilation or machine ventilation. Hemodynamic variables including blood pressure, heart rate, peripheral saturation of oxygen, and end-tidal carbon dioxide (ETCO2) were measured in these patients prior to transport, every 2 minutes during transport and upon arrival in the intensive care unit (ICU). Pulmonary artery pressure (PA) pressures were measured at origin and at destination.

Measurements and Main Results: Outcomes were changes from baseline in end-tidal CO2, hemodynamic changes from baseline and pulmonary artery pressure changes from origin to destination. The average transport time between the 2 groups was not different: 5 minutes for patients ventilated by hand and 5.47 minutes for patients ventilated with a transport ventilator (p = 0.369 by 2-sided t-test). The difference in all measured changes in ETCO2 between hand-ventilated and machine-ventilated patients during transport was 2.74 mmHg (p = 0.013). The difference between operating room and ICU ETCO2 from each cohort was 1.31 mmHg (p = 0.067). The difference in PAmean measured at origin and destination was 0.783 mmHg (p = 0.622). All other hemodynamic variables were not different during transport.

Conclusions: Hand ventilation during transport was associated with greater change from baseline of ETCO2 compared to machine ventilation during transport after cardiac surgery, but this did not translate into any difference in hemodynamic changes upon arrival in ICU. A hemodynamic benefit of machine transport ventilation to cardiac patients was not demonstrated.

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Key Words: portable ventilator; transport ventilator; hand ventilation; end-tidal CO2; ICU transport
reliably deliver tidal volumes (Vt) at safe pressures, especially when lung mechanics are changing;²³ and studies of manual ventilation have reported significant changes in PaCO₂ and pH when compared to machine-ventilated patients.⁴⁻⁶ In contrast, the ability of transport ventilators to consistently deliver the expected Vt, their FIO₂ stability, and their battery duration have been questioned.⁷⁻⁸ Because no study has examined the hemodynamic consequences of either transport mode of ventilation, the authors randomized 36 intubated patients immediately after cardiac surgery to receive either manual or machine ventilation during transport from the operating room (OR) to the intensive care unit (ICU). The authors recorded hemodynamic variables, end-tidal carbon dioxide (ETCO₂) and PA pressures before and during transport and upon arrival in the ICU. They hypothesized that manual ventilation after cardiac surgery would result in greater changes in measured ETCO₂ and pulmonary artery pressure when compared to machine ventilation.

**Methods**

This study was approved by the University of California, San Diego Human Research Protections Program (IRB # 150836). All patients scheduled for cardiac surgery were screened. Patients were included if they underwent surgery on the heart with planned intubation during transport to the ICU. Screened patients were excluded if they had known pulmonary hypertension, hypoxic respiratory failure requiring an FIO₂ > 60% prior to transport, were not eligible for either mode of ventilation, or were expected to be extubated at the end of surgery. Immediately after cardiac surgery, 36 patients were randomized using a simple coin flip to 2 cohorts during transportation from the OR to the ICU. The first received manual ventilation with a self-inflating bag-valve resuscitator, and the second was attached to a portable transport ventilator (Viasys Healthcare LTV 1200, CareFusion, Yorba Linda, CA). Investigators recorded each patient’s vital signs including mean arterial pressure, heart rate, respiratory rate, SpO₂, exhaled Vt, and ETCO₂. These parameters were measured in the OR just prior to disconnection from an OR ventilator and then every 2 minutes until the patient was connected to an ICU ventilator. Then, the initial values were recorded in the ICU. In addition, each patient’s pulmonary artery pressure was recorded in the OR just prior to transport and again in the ICU immediately after transport. Manual ventilation was performed by the anesthesiologists who had provided anesthesia for the surgery. Machine ventilation was programed by respiratory therapists who set the ventilator to deliver a Vt and respiratory rate equal to the values that had been used in the operating room at the end of each case.

For both hand and machine cohorts, transport vital signs were displayed on a portable monitor. ETCO₂ also was measured but was not visible to the attending physicians or respiratory therapists during transport. No monitoring of airway pressure was performed during transport. Baseline values for both cohorts are listed in Table 1.

**Statistical Analysis**

The sample size of 36 patients was predetermined using a 2-sided significance level of 0.05, to detect a minimal difference from baseline ETCO₂ of 15% at a power of 0.8. In addition to the vital sign data, the total change in ETCO₂ (total ETCO₂ excursion) and actual change during transport (transport ETCO₂ excursion) were recorded. Total ETCO₂ excursion was the maximum difference in values obtained from the last value recorded in the OR until the first value obtained in the ICU. Transport ETCO₂ excursion was the maximum difference in values obtained at 2 minutes until the first value obtained in the ICU. Transport ETCO₂ excursion excluded the first value obtained in the OR and included only values recorded while the patient was being physically moved from the OR to the ICU. Changes in mean pulmonary artery pressure (PAm) before and after transport were calculated. A 2-sided, unpaired t-test was used to determine differences between mean values. Equal variance between samples was not assumed (Welch’s t-test). A threshold p value of < 0.05 was considered significant.

**Results**

Thirty-six patients were included in the study. The baseline characteristics demonstrated no significant difference between the 2 groups (Table 1). There was no difference in transport time between hand-ventilated (mean = 5 ± 1.41 min) and machine-ventilated (mean = 5.47 ± 1.74 min) patients. The transport ETCO₂ excursion was significantly different between patients (p = 0.0126) (Table 2). In contrast, total ETCO₂ excursion was not statistically significant between the manual- and machine-ventilator cohorts. No differences were found in mean arterial pressure, heart rate, or SpO₂ (ICU v OR). This transport difference was not associated with a difference in PAm (Table 2). In addition, at each successive time interval, the magnitude of CO₂ change from baseline increased in both cohorts, but increased more rapidly for patients who were ventilated by hand (Fig 1).

**Table 1**

Baseline Values in the Operating Room

<table>
<thead>
<tr>
<th></th>
<th>Hand Ventilation</th>
<th>Machine Ventilation</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>62.17</td>
<td>62</td>
<td>0.97011</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>81.31</td>
<td>83.67</td>
<td>0.76111</td>
</tr>
<tr>
<td>Height (in)</td>
<td>65.65</td>
<td>67.39</td>
<td>0.170512</td>
</tr>
<tr>
<td>BMI</td>
<td>30.06</td>
<td>29.17</td>
<td>0.70019</td>
</tr>
<tr>
<td>Last OR temp (°F)</td>
<td>97.76</td>
<td>97.35</td>
<td>0.431247</td>
</tr>
<tr>
<td>Last OR PAm&lt;sub&gt;mean&lt;/sub&gt; (mmHg)</td>
<td>23.44</td>
<td>19.00</td>
<td>0.144663</td>
</tr>
<tr>
<td>Mean duration of transport (min)</td>
<td>5</td>
<td>5.47</td>
<td>0.3693702</td>
</tr>
<tr>
<td>CABG</td>
<td>10</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Non-CABG</td>
<td>8</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>% with pulm disease preop</td>
<td>52%</td>
<td>44%</td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: BMI, body mass index; CABG, coronary artery bypass graft; OR, operating room.
In the ICU (by CO2 criteria). Only 3 of 18 patients manually ventilated patients were hyperventilated upon arrival in the ICU after cardiac surgery. Unlike Gervais and colleagues, the authors did not find that the majority of manually ventilated patients were hyperventilated upon arrival in the ICU (by CO2 criteria). Only 3 of 18 patients manually ventilated had lower ETCO2 values upon arrival in the ICU. This suggests that manual ventilation did not uniformly result in hyperventilation. Whereas ventilation can affect pulmonary pressures, many other variables also contribute to changes in pulmonary pressures immediately after cardiac surgery. Postoperative pain, depressed LV or RV function, and circulating volume may have a more immediate impact on pulmonary pressures than variations in ETCO2. For relatively brief transport durations (most were fewer than 8 minutes, and all were fewer than 10 minutes), the impact of variation in ventilation may not have been enough to achieve pulmonary vasoconstriction associated with elevated partial pressure of CO2 in the arterial blood (PaCO2) during that time frame. Indeed, Balanos and colleagues reported that hypercapnia induced pulmonary vasoconstriction in humans, but did not reach steady state until 1.5-to-2 hours of elapsed time.8 Institutional architecture can have a significant impact on transport duration. Patients in this study were transported up 1 flight via an elevator and down a hallway. Much longer transports may demonstrate greater excursions of ETCO2 and may demonstrate a greater impact on systemic and pulmonary hemodynamics.

The magnitude of the vasoconstrictive effect of hypercapnia has been reported differently and may depend on the method of measurement. Kiely and colleagues reported a significant but modest increase in PAm when they used transthoracic Doppler to measure PA pressures in 8 healthy volunteers.10 In contrast, Viitanen and colleagues studied 18 patients immediately post-coronary artery bypass graft (CABG) and cardiopulmonary bypass using a pulmonary artery catheter and reported a 34% increase in PAm when subjects were ventilated to achieve a PaCO2 between 46 and 50.11 Despite this, no change in stroke volume was observed. The authors’ findings did not demonstrate even a modest effect of hypercapnia in patients during transport. One difference was that their patients were measured during transport while Viitanen et al measured PA pressures while on the OR table after the case was completed. In that study, the authors were deliberately ventilating subjects to PaCO2 values between 32 and 50, with a 10-minute steady state between hypocapnia and hypercapnia. Although changes in ETCO2 were significantly different during hand ventilation in the authors’ cohort, absolute ETCO2 values did not vary by the wide margins reported by Viitanen.

The authors observed no safety issues in either cohort, and no transport ventilator malfunctions were observed. In the ventilator cohort, airway pressures were measured, and preset limitations of peak airway and plateau pressures were not exceeded. This was likely attributable to the relatively brief duration of transport of the patients in this study. Transports of substantially longer duration may confront greater safety problems including operator fatigue or battery failure, which might have a greater effect on systemic and pulmonary hemodynamics than the authors observed.

The authors’ study had limitations. Their sample size of 36 patients was relatively small, which increased the risk of type 2 error. Both cohorts were comprised of patients immediately following cardiac surgery, all of whom had been anesthetized primarily with volatile inhaled agents. A primary opioid technique was not used in any patient, which may be different in other settings. This is also different for most ICU patients undergoing intrahospital transport, many of whom will receive less sedation or will receive intravenous agents. None of the patients in the authors’ study had known elevation in intracranial pressure or brain injury at the time of investigation, which may have altered their hemodynamic response to hypercapnia. Many ICU patients are likely to have poorer baseline lung function and may be more susceptible to alterations in ETCO2 than cardiac surgery patients. In addition, although clinicians did not have information about ETCO2, delivered Vt, or airway pressures, they may have been more cautious.

### Table 2

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hand</th>
<th>Ventilator</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean PA difference</td>
<td>4.63</td>
<td>3.84</td>
<td>0.622459</td>
</tr>
<tr>
<td>ETCO2 difference (total)</td>
<td>3.56</td>
<td>2.63</td>
<td>0.066352</td>
</tr>
<tr>
<td>ETCO2 difference (transport)</td>
<td>5.44</td>
<td>2.32</td>
<td>0.012636</td>
</tr>
<tr>
<td>Mean MAP difference</td>
<td>4.80</td>
<td>2.95</td>
<td>0.781496</td>
</tr>
<tr>
<td>Mean HR difference</td>
<td>3.50</td>
<td>3.05</td>
<td>0.771504</td>
</tr>
</tbody>
</table>

NOTE: Differences in hemodynamic variables recorded before and after transport. ETCO2 difference (transport) only included values recorded during transport.

Abbreviations: ETCO2, end-tidal carbon dioxide; HR, heart rate; MAP, mean arterial pressure; PA, pulmonary artery pressure.

**Discussion**

The authors’ results were consistent with other investigators4 who have reported that, during transport, manual ventilation caused a greater excursion in ETCO2 when compared to machine ventilation. The authors also have found, however, that this difference was not associated with any significant changes in mean arterial pressure, heart rate, or PAm upon arrival in the ICU after cardiac surgery. Unlike Gervais and colleagues, the authors did not find that the majority of manually ventilated patients were hyperventilated upon arrival in the ICU (by CO2 criteria). Only 3 of 18 patients manually ventilated had lower ETCO2 values upon arrival in the ICU. This suggests that manual ventilation did not uniformly result in hyperventilation. Whereas ventilation can affect pulmonary pressures, many other variables also contribute to changes in pulmonary pressures immediately after cardiac surgery. Postoperative pain, depressed LV or RV function, and circulating volume may have a more immediate impact on pulmonary pressures than variations in ETCO2. For relatively brief transport durations (most were fewer than 8 minutes, and all were fewer than 10 minutes), the impact of variation in ventilation may not have been enough to achieve pulmonary vasoconstriction associated with elevated partial pressure of CO2 in the arterial blood (PaCO2) during that time frame. Indeed, Balanos and colleagues reported that hypercapnia induced pulmonary vasoconstriction in humans, but did not reach steady state until 1.5-to-2 hours of elapsed time.8 Institutional architecture can have a significant impact on transport duration. Patients in this study were transported up 1 flight via an elevator and down a hallway. Much longer transports may demonstrate greater excursions of ETCO2 and may demonstrate a greater impact on systemic and pulmonary hemodynamics.

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![Fig 1. Change of ETCO2 by 2 minute intervals.](image-url)
during manual ventilation in the presence of investigators. This may limit the applicability of the authors’ findings.

In conclusion, manual ventilation was associated with greater changes in ETCO₂ than machine ventilation, but these differences were not associated with changes in PA₉a pressure at the end of transport. These changes also were not associated with changes in vital signs, oxygen saturation, or heart rhythm. In addition, manual ventilation did not uniformly result in hyperventilation. For patients after cardiac surgery, hand ventilation, although associated with a significantly greater excursion of CO₂ from baseline than machine ventilation, made no measurable differences in hemodynamic variables, heart rhythm, or pulmonary artery pressure. These data did not support the routine use of a transport ventilator in patients transported after cardiac surgery.

References

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