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Comparison of Blood Gases during Transport Using Two Methods of Ventilatory Support

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Transportation of critically ill patients requiring ventilatory support represents a common, yet difficult, problem faced by clinicians. We examined 28 patients requiring transport in a prospective, randomized fashion, comparing manual ventilation with ventilation provided by a transport ventilator. Patients were ventilated to their destination with one method and returned with the alternate method. After manual ventilation, all patients showed a marked respiratory alkalosis (pH increased from 7.39 to 7.51 and $PaCO_2$ decreased from 39 to 30 torr). After ventilation with the transport ventilator, no appreciable changes in pH or $PaCO_2$ were seen. Oxygenation remained stable with both methods. No patient suffered hemodynamic instability, although two patients in the manual ventilation group developed cardiac arrhythmias. We conclude that when ventilatory support is required during transport, a transport ventilator produces reliable control of ventilation.

The transportation of critically ill patients for diag- ic studies has become imperative for optimization of treatment. When mechanical ventilation is necessary in these situations, it is usually provided with a manual resuscitator. We have previously shown that all members of the health care team (physicians, respiratory therapists, and nurses) tended to ventilate patients at a more rapid rate and lower tidal volume during manual ventilation than on ventilatory support (1). This investigation was carried out to determine the effects of manual ventilation compared to ventilatory support with a transport ventilator on hemodynamics and gas exchange during intrahospital transport.

METHODS

All patients admitted to the emergency department requiring ventilatory support, except those requiring intentional hyperventilation for suspected head injury, were eligible for the study. Twenty-eight patients were admitted to the study in a 6-month period. Mean age was 27 ± 12 years and there were 19 males and nine females. The mean Trauma Score for the group was 10 ± 3.

In the emergency department, all patients were placed on a ime-cycled ventilator (IMV Bird, Palm Springs, CA) at a tidal olume of 10 to 12 cc/kg, respiratory rate sufficient to maintain ormocarbia ($PaCO_2$, 35 to 45 torr), and FIO_2 was adjusted to provide a PaO_2 of greater than 70 torr. After initial workup and stabilization, a set of arterial blood gases were drawn. Blood gas measurements were run immediately and corrected for patient body temperatures. Heart rate, systolic blood pressure, and diastolic blood pressure, measured by cuff, were also recorded. Patients were then randomized either to be ventilated by manual resuscitator or transport ventilator, using the last number in their medical record number (even = transport ventilator, odd = manual ventilation).

Method I. Fourteen patients were manually ventilated with a self-inflating resuscitation bag [Puritan Manual Resuscitator (PMR-II)] by either an experienced respiratory therapist or registered nurse assigned to the transport team. No special instructions were given. The PMR-II was equipped with a reservoir hose and an oxygen flow of 10 L/min was provided from an E-cylinder placed under the stretcher. This provided an FIO_2 of approximately 0.70, depending on respiratory rate, tidal volume, and bag refill time. Spontaneous ventilation through the system was allowed through the inspiratory port and leaf valve.

Method II. Fourteen patients were placed on a transport ventilator at the same respiratory rate and tidal volume as the original ventilator. The ventilator is a pneumatically powered and pneumatically controlled time-cycled controller which allows spontaneous breathing of room air between ventilator breaths. Inspiratory time, expiratory time, and inspiratory flow are set to deliver the desired V_T and respiratory frequency. The ventilator weighs 1.4 kg, and its dimensions are length, 16.5 cm, width, 8.0 cm, in a cylindrical shape. Oxygen at 50 psi g from an E-cylinder powers the ventilator. Delivered FIO_2 is a consequence of set tidal volume and lung compliance. At the airway, a Venturi mechanism entrains room air during inspiration. This helps to prolong the life of the oxygen tank, as a portion of the delivered tidal volume is from ambient air. As pulmonary compliance and resistance worsen, entrainment is decreased, resulting in a higher delivered FIO_2. In clinical use and in the laboratory, we have found the FIO_2 to vary from

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0.45 to 0.61% (3). A pressure manometer on one end of the ventilator monitors airway pressure, but no alarms are provided.

After patients reached their destination, another set of arterial blood gas measurements was made and blood pressure recorded. ECG was monitored continuously for the presence of arrhythmias. Patients were then placed on a ventilator identical to the one used in the emergency department, at the same ventilator settings. After the procedure, patients were either returned to the emergency department, taken to the operating room, or taken to the Surgical Intensive Care Unit, using the opposite ventilatory method than was used initially. Upon arrival, arterial blood gases were measured and blood pressure recorded. Figure 1 depicts the study method.

Patients served as their own controls and a paired t-test was used for comparisons. A p-value < 0.05 was considered statistically significant.

RESULTS

Table I summarizes the results of the study. In the emergency department and at the initial destination during conventional ventilatory support, arterial blood gases and pH were normal. Heart rate and blood pressure was also stable. During manual ventilation, patients were hyperventilated and demonstrated a marked respiratory alkalosis, pH increased from 7.39 ± 0.03 to 7.51 ± 0.2, and $PaCO_2$ fell from 39 ± 4 to 30 ± 3 torr ($p < 0.05$). Oxygenation remained stable. Two patients in this group demonstrated arrhythmias during transport (supraventricular tachycardia), but no abrupt changes in blood pressure were noted. Average transport time was 9 ± 3 minutes.

After ventilation with the transport ventilator, patients showed no change in either blood gases or blood pressure. No arrhythmias were seen in this group. Average transport time was 8 ± 3 minutes.

Figures 2 and 3 show the changes in pH and $PaCO_2$ from baseline during the two methods of ventilatory support.

DISCUSSION

This study has shown that unintentional hyperventilation and acute respiratory alkalosis is a common problem during manual ventilation, even in the hands of skilled operators. In every case, after manual ventilation pH rose and $PaCO_2$ fell.

There are myriad complications associated with sudden hypocarbia and respiratory alkalosis. The oxyhemoglobin curve shifts to the left, increasing the affinity of hemoglobin for oxygen, resulting in impaired oxygen delivery at the tissue level.

Hyperventilation also reduces cerebral and coronary blood flow. Patients with myocardial irritability may be susceptible to arrhythmias and hypotension during acute respiratory alkalosis. Experimentally, the rapid onset of alkalosis has been shown to precipitate coronary vasospasm (5). In chronic respiratory alkalosis, this does not occur because of adequate renal compensation (4). This may have been the cause of arrhythmias seen in two of

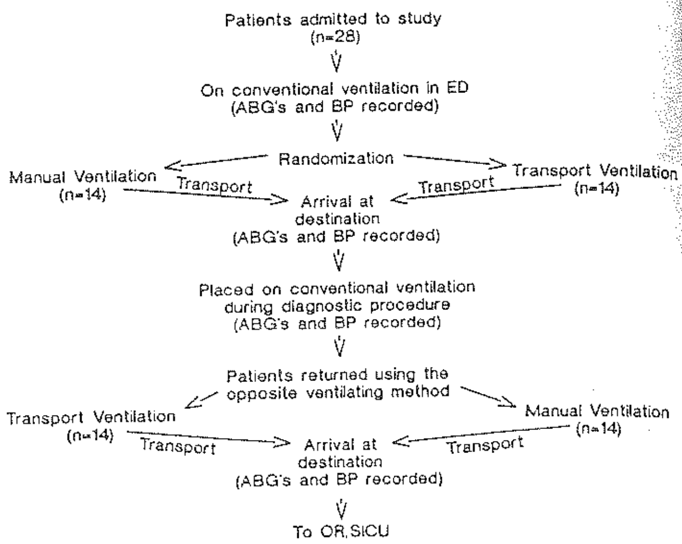

FIG. 1. Schematic diagram of the study protocol.

our patients who were manually ventilated, although hypotension was not observed.

Head-injured patients requiring hyperventilation for intentional reduction in cerebral blood flow and control of intracranial pressure may also be adversely effected by overzealous hyperventilation. When $PaCO_2$ falls below 25 torr, additional ischemia at injury sites may occur (7). This group is particularly at risk, since they tend to require multiple transfers to the radiology suite for diagnostic studies.

Successful transport of critically ill patients requires skilled team members with designated job responsibilities. We currently require a nurse, respiratory therapist, and physician to attend critically ill, mechanically ventilated patients during transport for diagnostic studies. Reliable, durable, and portable monitoring equipment should be available. Our experience suggests that minimum monitoring equipment is an ECG monitor (equipped with pressure monitoring capabilities when applicable), blood pressure cuff, and stethoscope. A pulse oximeter is a welcome addition to the transport team, as it may detect hypoxemia before the usual clinical signs.

Another advantage of using a transport ventilator is that it frees a member of the team from being entirely responsible for ventilation. Also, during transfer, manual ventilation can become difficult as a patient travels through the hospital corridors in and out of doors and elevators.

In a similar study, Braman and colleagues (2) studied 20 patients transported from a Medical Intensive Care Unit requiring ventilatory support. They found that, in 14 of 20 transports (70%), a change in $PaCO_2$ of greater than 10 torr or a change in pH of greater than 0.05 occurred during manual ventilation. In this group, $PaCO_2$ change ranged from −18 to +28 torr and pH from −0.17 to +0.18. It is unclear why this study demonstrated extremes of both hypoventilation and hyperventilation. They also reported that six of 20 patients developed

TABLE I
Summary of results

	Conventional Ventilation	After Manual Ventilation	Conventional Ventilation	After Transport Ventilation
pH	7.39 ± 0.03	7.51 ± 0.02*	7.41 ± 0.02	7.40 ± 0.03
$PaCO_2$ (torr)	39 ± 4	30 ± 3*	38 ± 2	39 ± 3
PaO_2 (torr)	116 ± 17	109 ± 24	120 ± 12	117 ± 20
Heart rate/min	106 ± 23	115 ± 19	104 ± 26	109 ± 25
Systolic BP (mm Hg)	130 ± 36	112 ± 24	128 ± 22	136 ± 31
Diastolic BP (mm Hg)	86 ± 12	73 ± 10	80 ± 16	81 ± 20

Average transport time = 9 ± 3 minutes during manual ventilation and 8 ± 3 minutes during transport ventilation.
* $p < 0.05$ compared to conventional ventilation.

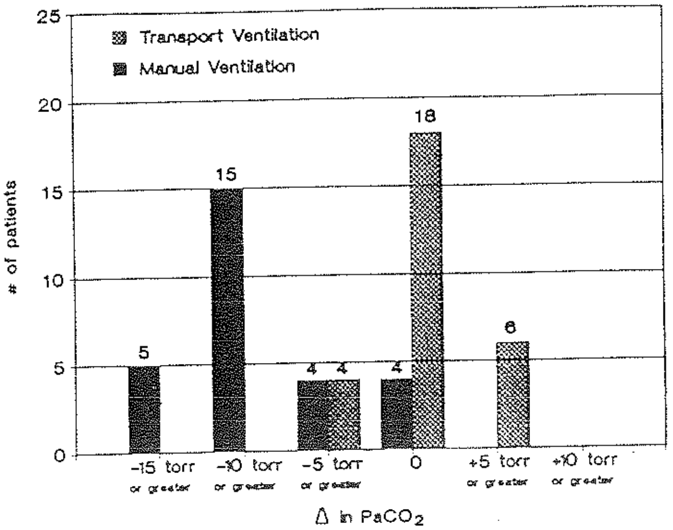

FIG. 2. Changes in $PaCO_2$ from baseline during the two methods of ventilatory support.

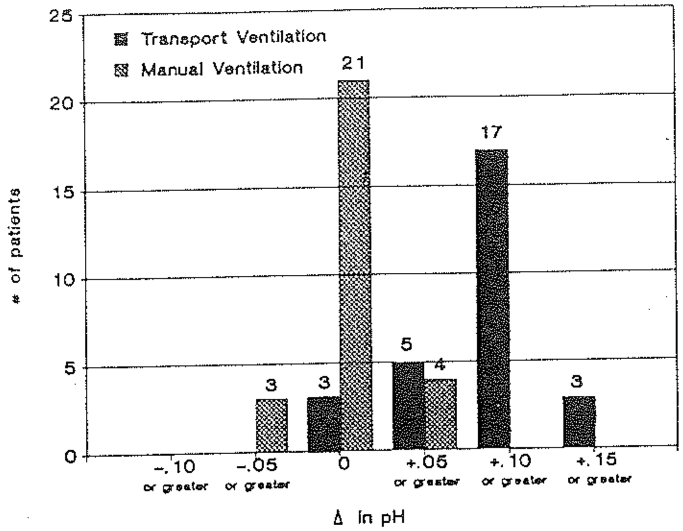

FIG. 3. Changes in pH from baseline during the two methods of ventilatory support.

hypotension and/or cardiac arrhythmias. There was a significant relationship between arterial blood gas de- ements and the presence of cardiac arrhythmias. These authors observed in a group of 16 patients transferred using a transport ventilator, that no patient had a change in $PaCO_2$ of greater than 10 torr. However, three did show signs of hypotension. The transport ventilator used in this study was actually a ventilator designed for home care. It is volume cycled, provides a variety of modes, and allows control of FIO_2, tidal volume, inspiratory flow, and respiratory rate. The disadvantage of this system is that the ventilator weighs approximately 25 pounds.

Gervais et al. compared blood gases in three groups of patients requiring ventilatory support during transport (6). The first group received manual ventilation with a self-inflating resuscitation bag, the second was ventilated with a transport ventilator, and the third group with a manual resuscitator combined with a respirometer to allow visual assessment of delivered tidal volume. They, too, showed a persistent respiratory alkalosis in patients manually ventilated. However, when the respirometer was added to the manual ventilation system, the incidence of respiratory alkalosis drastically declined. They suggested that this simple, relatively inexpensive ($300 per spirometer) addition to manual ventilation would reduce complications and improve patient care.

CONCLUSIONS

Transportation of patients requiring diagnostic studies continues to represent a challenge to health care teams. Patients requiring ventilatory support pose a particular problem. Our data and those of others suggest that use of a transport ventilator or a system which allows visual assessment of delivered tidal volumes is the preferred method of ventilatory support.

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