

# Intrahospital Transport of Critically Ill Patients Using Ventilator With Patient-Triggering Function\*

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**Objective:** To compare a new transport ventilator to manual ventilation in terms of maintaining the respiratory and hemodynamic levels of critically ill patients.

**Design:** Prospective, randomized, single-center study.

**Setting:** ICU in a university hospital.

**Patients:** A total of 16 patients (22 transports) who were spontaneously breathing and required ventilatory assistance on excursions from the ICU.

**Methods:** For each transport, the patient was randomly assigned to receive either manual ventilation (group M) or mechanical ventilation (group V). For transports in group V, the ventilators were set the same as in the ICU. Respiratory and hemodynamic variables were measured 30 min before transport ( $T_0$ ), on arrival at the site of procedure ( $T_1$ ), on return to the ICU ( $T_2$ ), and 30 min after return the ICU ( $T_3$ ).

**Results:** After transport, five patients in group M showed a significant deterioration in  $PaO_2$ /fraction of inspired oxygen ratio, while one patient in group V showed deterioration ( $p = 0.056$ ). The mean ( $\pm$  SD) respiratory rate in group M at  $T_2$  ( $32 \pm 9$  breaths/min) was significantly higher ( $p < 0.001$ ) than at  $T_0$  ( $19 \pm 6$  breaths/min) and also was higher ( $p < 0.01$ ) than in group V at  $T_2$  ( $19 \pm 6$  breaths/min). The mean tidal volume and positive end-expiratory pressure in group M at  $T_2$  showed significantly larger variation ( $p < 0.05$  and  $p < 0.001$ , respectively) than in group V.

**Conclusions:** The transport ventilator that was recently approved by the US Food and Drug Administration reliably provides more stable ventilatory support than does manual ventilation. Generally, the use of this transport ventilator for intrahospital transport is preferable to manual ventilation. (CHEST 2003; 123:159–164)

**Key words:** intrahospital transport; manual ventilation; patient-triggered ventilation; respiratory failure

**Abbreviations:** ABC = arterial blood gas; A/C = assist/control; APACHE = acute physiology and chronic health evaluation; Cst = quasi-static compliance;  $ETCO_2$  = end-tidal  $CO_2$  tension; FDA = Food and Drug Administration; HR = heart rate; PEEP = positive end-expiratory pressure; PPLAT = end-inspiratory plateau pressure; PS = pressure support; RR = respiratory rate; SBP = systolic BP;  $V_T$  = tidal volume

During the past 2 decades, the ventilators that have been available for use in the ICU have achieved sophisticated performance, acquiring features such as the ability to detect changes in airway pressure or flow that enable the triggering of the patient's inspiratory demand, which assist in reducing the work of breathing for spontaneously breathing critically ill patients.<sup>1</sup> Patients with severe respiratory failure are often heavily sedated and sometimes are paralyzed. Although these patients do

not require the triggering function, it is important to control airway pressure by titrating positive end-expiratory pressure (PEEP) to open the collapsed lung and by limiting peak alveolar pressure to avoid overstretching the lung.<sup>2,3</sup> Until several years ago, owing to the inadequate performance of transport ventilators, manual ventilation often has been the most practical means of ventilating these critically ill patients during transport. Even the most experienced practitioner, however, is unlikely to maintain consistent ventilation synchrony with spontaneously breathing patients. For patients with severe lung injury, controlling the airway pressure during manual ventilation is even more of a challenge.

Several years ago, transport ventilators with patient-triggering functions became commercially available. In a separate study<sup>4</sup> using a test lung to

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Manuscript received August 31, 2001; revision accepted May 21, 2002.

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simulate spontaneous breathing, we evaluated these transport ventilators and compared their performance with a standard ICU ventilator. We found that these newer US Food and Drug Administration (FDA)-approved transport ventilators performed as well as the standard ICU ventilators. Several studies<sup>5-8</sup> also had reported comparisons of manual ventilation with mechanical ventilation using transport ventilators. The transport ventilators used in these studies, however, lacked the patient-triggering functions. In this study, we compared the effectiveness of manual ventilation with the assistance provided by a newer FDA-approved transport ventilator. We wanted to test whether the newer transport ventilator was actually safe during transport and whether it provided more effective ventilation than did manual ventilation.

## MATERIALS AND METHODS

### Patients

The protocol of this study was approved by Osaka University Hospital Ethical Committee, and written informed consent was obtained from the next of kin of each patient.

The subjects included in this investigation were adult patients who were spontaneously breathing and required respiratory assistance due to respiratory failure during transport from the ICU for procedures elsewhere in the hospital. Patients who were paralyzed or lacked spontaneous breathing, or who were hemodynamically unstable were excluded. Prior to each trip, the transport was randomly assigned either to receive manual ventilation (group M; n = 11) or to receive mechanical ventilation (group V; n = 11) [LTV1000 transport ventilator; Pulmonetic Systems; Colton, CA].

### Protocol and Measurements

During the period under study, each patient in either group received 100% oxygen ventilation. ICU physicians, who were blind to the purpose of the study, provided manual ventilation using a Jackson-Rees circuit at an oxygen flow of 10 L/min. Transport ventilator settings were the same as those used in the ICU before transport. Table 1 shows the measurements taken during the protocol. Systolic BP (SBP) and heart rate (HR) were monitored with a transport monitor (Life Scope L; Nihon Koden;

**Table 1—Measurements**

Variables	T <sub>0</sub>	T <sub>1</sub>	T <sub>2</sub>	T <sub>3</sub>
ABG	*		*	
ETCO <sub>2</sub>	*	*	*	*
RR	*		*	
VT	*		*	
Cst	*		*	
PEEP	*		*	
SBP	*	*	*	*
HR	*	*	*	*

\*A measurement of variable was made at that time point.

Tokyo, Japan). Airway pressure, flow, and end-tidal CO<sub>2</sub> tension (ETCO<sub>2</sub>) were measured at a sampling rate of 100 Hz (CO<sub>2</sub>SMO+; Novamatrix Medical Systems; Wallingford, CT), and the measurements were stored in a personal computer for later analysis. Physicians providing manual ventilation during transport were also blind to this data. Inspiratory tidal volume (VT) was calculated by integrating the flow signals. Measurements were performed 30 min before transport (T<sub>0</sub>), on arrival at the site of the procedure (T<sub>1</sub>), on return to the ICU (T<sub>2</sub>), and 30 min after return to the ICU (T<sub>3</sub>). Arterial blood gas (ABG) analysis was performed (ABL505; Radiometer Corp; Copenhagen, Denmark) at T<sub>0</sub>, T<sub>2</sub>, and T<sub>3</sub>. VT, end-inspiratory plateau pressure (PPLAT), quasi-static compliance (Cst), PEEP, and respiratory rate (RR) were evaluated at T<sub>0</sub> and T<sub>2</sub>. In both groups, PPLAT and Cst were measured after connection to the ICU ventilator at T<sub>2</sub>. At T<sub>0</sub> and T<sub>3</sub>, the parameters in either group were measured under the same settings with the same ventilators before transport from the ICU. PPLAT and Cst at T<sub>0</sub> and T<sub>2</sub> were measured under assist/control mode (A/C) ventilation or synchronized intermittent mandatory ventilation, which were set with an inspiratory time that was long enough or with a plateau time to ensure zero flow at end-inspiration. When patients received ventilation with pressure support (PS) before transport, the A/C mode with the same peak airway pressure for PEEP for PS was used for the measurement of PPLAT. APACHE (acute physiology and chronic health evaluation) II score data were obtained at T<sub>0</sub>.

### Data Analysis

Stored data were analyzed with a program supplied by the manufacturer (respiratory profile analysis software with CO<sub>2</sub>SMO+ for Windows; Novamatrix Medical Systems). Five successive breaths were analyzed to determine VT and PEEP, which was defined as airway pressure at end expiration. The RR in both groups and the number of assisted breaths in group M were calculated from the number of breaths in 1 min.

**Statistics:** The data, after analysis using statistical software (StatView J-4.5; Hulinks; Tokyo, Japan; Statistica, version 5.1; Statsoft; Tulsa, OK), were expressed as the mean ± SD. The Student *t* test for unpaired data were used for the statistical analysis of differences between the two groups. Differences among repeated measures were evaluated by analysis of variance

**Table 2—Patient Group Characteristics\***

Variables	Group M (n = 11)	Group V (n = 11)
Sex, No.		
Male	5	7
Female	6	4
Age, yr	59 ± 14	62 ± 9
Weight kg	53 ± 14	56 ± 12
APACHE II score	18 ± 4	19 ± 5
Transport time, min	44 ± 24	42 ± 26
Examination time, min	16 ± 22	12 ± 20
Ventilation mode before transport, No.		
A/C	6	6
SIMV + PS	4	2
PS	1	3
PEEP, cm H <sub>2</sub> O	5.5 ± 1.7	5.7 ± 2.0
PaO <sub>2</sub> /FIO <sub>2</sub> , mm Hg	312 ± 113	319 ± 127

\*Values given as mean ± SD unless otherwise indicated. SIMV = synchronized intermittent mandatory ventilation.

Table 3—Respiratory and Hemodynamic Parameters\*

Parameters	Group	T <sub>0</sub>	T <sub>1</sub>	T <sub>2</sub>	T <sub>3</sub>
pH	M	7.44 ± 0.05		7.41 ± 0.07	7.45 ± 0.06
	V	7.46 ± 0.04		7.48 ± 0.06	7.46 ± 0.04
PaCO <sub>2</sub> , mm Hg	M	41 ± 7		44 ± 10	40 ± 9
	V	40 ± 7		37 ± 7	39 ± 6
PaO <sub>2</sub> , mm Hg	M	312 ± 113		269 ± 132	273 ± 121
	V	319 ± 127		300 ± 116	318 ± 131
Cst, mL/cm H <sub>2</sub> O	M	23 ± 8		23 ± 7	
	V	27 ± 13		28 ± 16	
SBP, mm Hg	M	131 ± 20	144 ± 27	131 ± 32	126 ± 22
	V	117 ± 17	122 ± 27	112 ± 23	109 ± 16
HR, breaths/min	M	112 ± 18	112 ± 18	118 ± 22	112 ± 17
	V	101 ± 19	102 ± 18	105 ± 21	103 ± 21

\*Values given as mean ± SD.

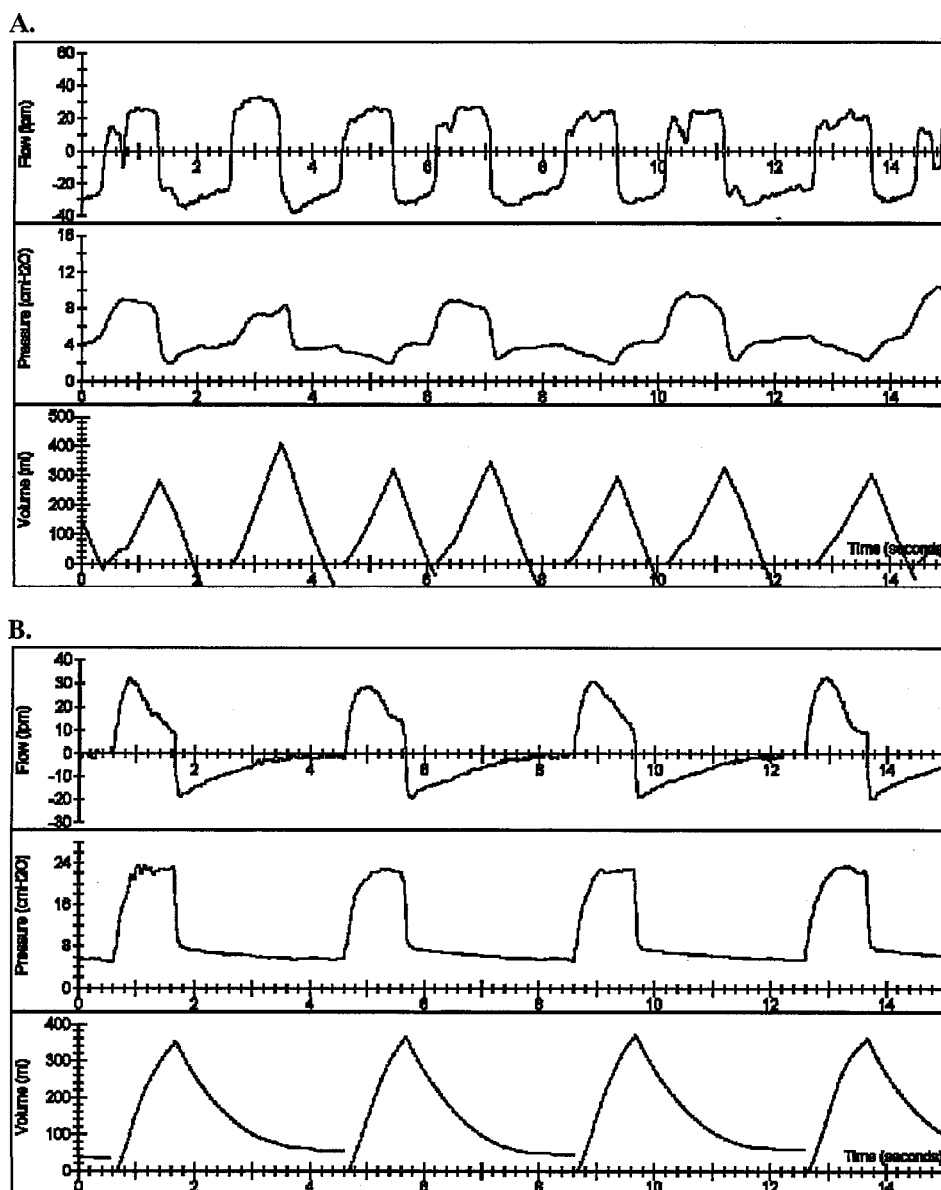


FIGURE 1. Representative waveforms of airway pressure, flow, volume in group M (top, A) and group V (bottom, B). The patient in group V was ventilated in the A/C mode.

using Scheffé F test as a *post hoc* test. Variations in each item of data between the groups were compared by Levene test. A p value of < 0.05 was considered to be significant.

## RESULTS

There was no significant difference in the demographic data between groups M and V (Table 2). One patient in group V required bolus IV administration of midazolam during transport. ETCO<sub>2</sub> waveforms during transport did not show any evidence of CO<sub>2</sub> rebreathing. There was no significant change in SBP or HR, and, as Table 3 shows, except for pH, at T<sub>2</sub> there were no significant differences in ABG data between the groups. After transport, five patients in group M, however, showed PaO<sub>2</sub>/fraction of inspired oxygen ratio deterioration (defined as a change of > 20%), while the condition of one patient in group V deteriorated (p = 0.056). At each measurement point for all patients, the pH values ranged between 7.27 and 7.56.

Representative waveforms of airway pressure, flow, and volume in each group are shown in Figure 1. In group M, 65.6% of the total number of breaths were assisted. The RRs at T<sub>0</sub> and T<sub>2</sub> in both groups are shown in Figure 2. In group M, the RRs at T<sub>2</sub> in group M showed a significantly larger value (mean RR, 32 ± 9 breaths/min) than at T<sub>0</sub> (mean RR, 19 ± 6 breaths/min; p < 0.001) and at T<sub>2</sub> in group V (mean RR, 19 ± 6 breaths/min; p < 0.01).

There was no significant difference in average VT between groups and between T<sub>0</sub> and T<sub>2</sub> (Fig 3, *top*, A). Figure 3, *bottom*, B, shows the SD of the VT calculated for each patient from five breaths at T<sub>2</sub>. In group M, there was a significantly greater variation in VT than in group V (p < 0.001).

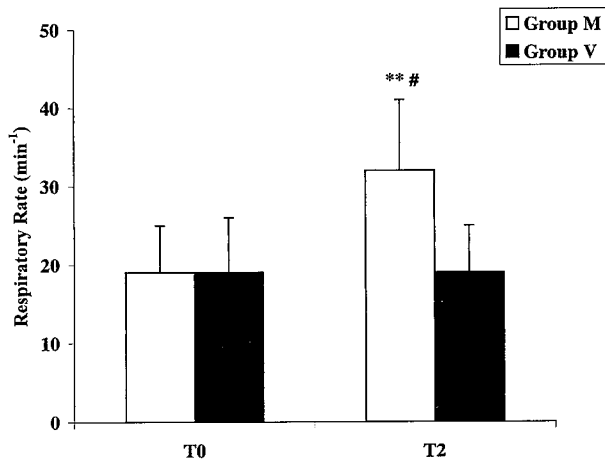


FIGURE 2. RRs at T<sub>0</sub> and T<sub>2</sub> in group M and group V. The data are expressed as the mean ± SD. \*\* = p < 0.001 vs T<sub>0</sub>; # = p < 0.01 vs group V (*post hoc* analysis).

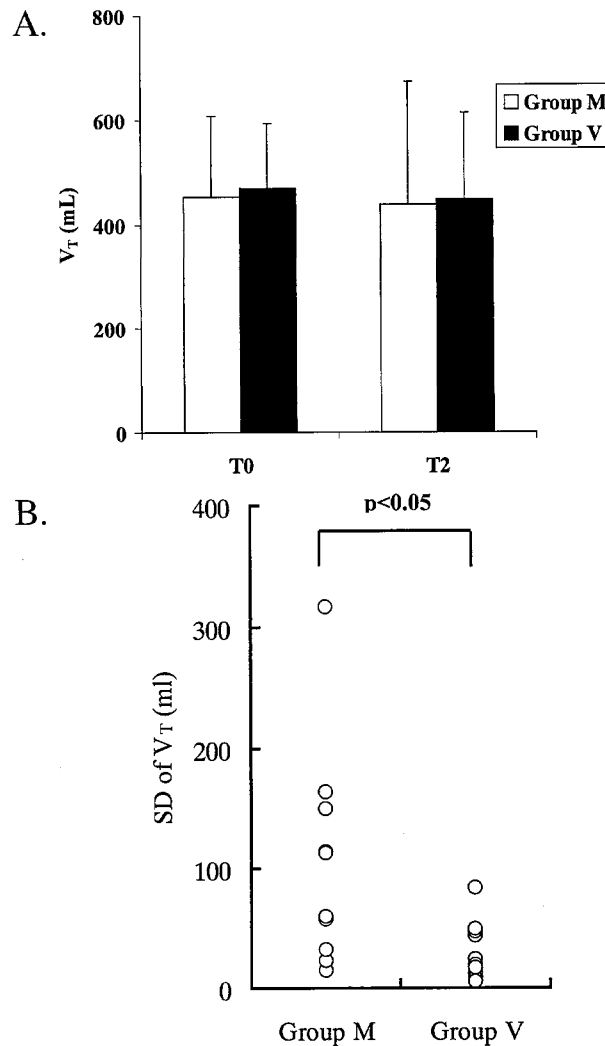


FIGURE 3. *Top*, A: VT at T<sub>0</sub> and T<sub>2</sub> in group M and group V. The data are expressed as the mean ± SD. There was no significant difference between groups and between T<sub>0</sub> and T<sub>2</sub>. *Bottom*, B: SD of the VT calculated from five successive breaths from each patient at T<sub>2</sub>. The SD of the VT in group M showed significantly greater variation than that in group V (p < 0.001).

There was no significant difference in average PEEP between groups and between T<sub>0</sub> and T<sub>2</sub> (Fig 4, *top*, A); however, the SD of the PEEP calculated for each patient from five breaths at T<sub>2</sub> in group M varied significantly more (p < 0.001) than in group V (Fig 4, *bottom*, B).

## DISCUSSION

In this study, we found that although intrahospital transport could be performed with adequate safety by means of either manual or mechanical ventilation, the use of a transport ventilator with a patient-triggering function was able to provide more consis-

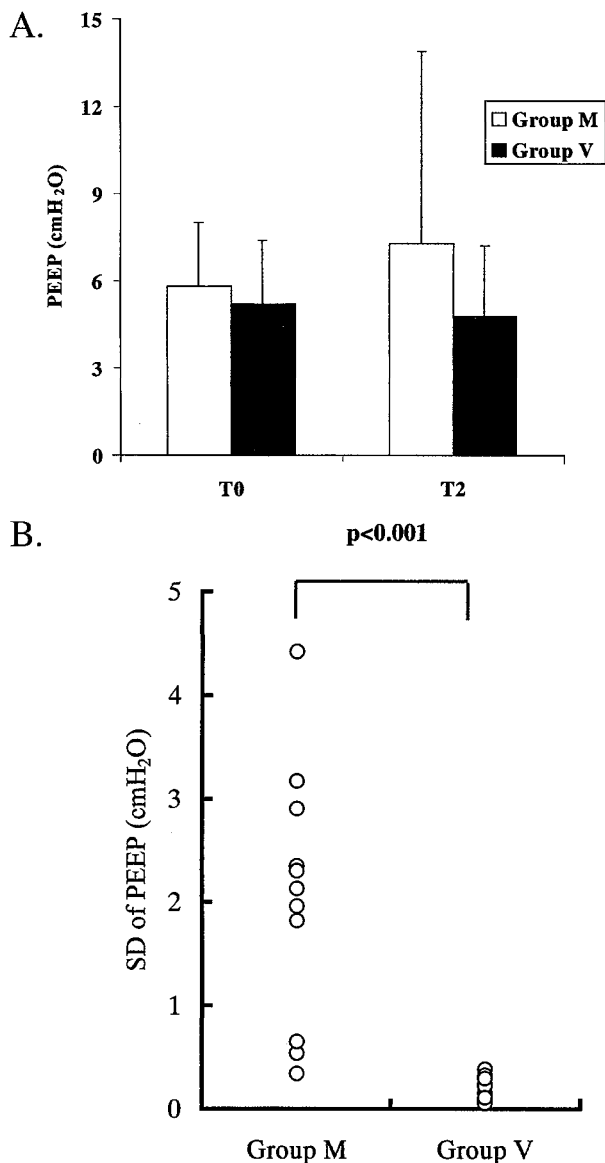


FIGURE 4. *Top, A:* PEEP at T<sub>0</sub> and T<sub>2</sub> in group M and group V. The data are expressed as the mean  $\pm$  SD. There was no significant difference between groups and between T<sub>0</sub> and T<sub>2</sub>. *Bottom, B:* The SD of PEEP calculated from five successive breaths from each patient at T<sub>2</sub>. The SD of PEEP in group M showed significantly greater variation than that in group V ( $p < 0.001$ ).

tent ventilation. The PaO<sub>2</sub>/fraction of inspired oxygen ratio deteriorated in some patients who received manual ventilation, while no patients receiving mechanical ventilation showed this change.

Braman et al<sup>5</sup> reported either hypotension or arrhythmia in 7 of 19 patients who showed ABG deterioration during transport. By contrast, other investigators reported<sup>6,8</sup> no similar complications associated with ABG deterioration during transport. These studies were published in the 1980s and were reports on volume-limited-type ventilators with no

patient-triggering functions. In other words, they compared manual ventilation with intermittent mandatory ventilation. The results of these studies made it difficult to decide which type of ventilation was better during the transport of spontaneously breathing patients. Recently, new, very compact, FDA-approved transport ventilators with patient-triggering functions have become commercially available. In a model lung study,<sup>4</sup> we confirmed that these ventilators are able to provide PS/control ventilation and have performance indexes that are comparable with the ventilators currently commonly used in ICUs. However, the new transport ventilators still had to be evaluated while being used with critically ill patients.

Our previous study led us to believe that the function of new transport ventilators would deliver more consistent ventilation and, due to stable PEEP, better oxygenation. The physicians who provided manual ventilation in our study, following clinical judgment, tried to maintain PEEP levels manually that were similar to those achieved before transport without being instructed to do so. Even so, the average PEEP and the delivered VT in group M were higher than in group V (Fig 3A, 4A). It would have been even more challenging to manually maintain PEEP levels of  $> 10$  cm H<sub>2</sub>O, but during the study period no patients had required this PEEP level before transport. Even though average oxygenation was maintained in group M, some patients receiving manual ventilation showed lower oxygenation levels after transport. This tendency would likely have been more pronounced if the patients had been in worse condition.

Although blind to the purpose of the study, the physicians providing manual ventilation decided from the observation of the patients' respiratory conditions in the ICU to titrate PEEP manually by adjusting the end-expiratory volume of the Jackson-Rees circuit. As a result, because airway pressure monitoring was not used with these patients, PEEP varied widely, with some patients receiving inadvertently high PEEP. In patients with severe ARDS, it is important to keep the lungs as open as possible by titrating the PEEP level<sup>9</sup> while controlling peak alveolar pressure,<sup>2,10</sup> which should be maintained at a consistent level even during transport. This kind of precise airway pressure control is an almost impossible challenge to even the most skilled provider of manual ventilation. Under the conditions of our study, the addition of a PEEP valve to the circuit may have enabled better control of PEEP, but it would still not prevent excess PEEP. Manual ventilation cannot match the consistency of mechanical ventilation.

On their return to the ICU, the patients receiving

manual ventilation showed greater tachypnea than those who had received mechanical ventilation. During manual ventilation, synchronization with patient breathing is normally incomplete, resulting in an increased work of breathing for the recipient. The RR increase in group M was also likely due to the variability in other ventilatory support items, such as VT and PEEP (Fig 3B, 4B). We evaluated these parameters only at the end of the transport. Because it is difficult for physicians providing manual ventilation to concentrate solely on ventilation during transport, it is possible that the variations in the ventilation factors were larger during transport. Gervais et al<sup>7</sup> have recommended that minute ventilation be monitored during transport to avoid ABG abnormalities. In addition to minute ventilation, VT and RR can be monitored with a transport ventilator without the need for any additional apparatus.

In our study, the majority of patients were post-operative esophageal cancer patients, so we did not measure the work of breathing with esophageal pressure. Even when it was possible to insert an esophageal balloon, we declined to do so to avoid complicating the transport because the study was intended to practically evaluate the performance of transport ventilators in a real clinical situation rather than to focus solely on physiologic parameters.

In our previous study,<sup>4</sup> with PEEP up to 5 cm H<sub>2</sub>O, the transport ventilator performed as well as an ICU ventilator, and so we chose to evaluate it because of its portability and acceptable performance. We have had experience, however, of ventilator asynchrony with a patient using a transport ventilator who required a PEEP of > 10 cm H<sub>2</sub>O. Since the patient-triggering function may be compromised by the attachment of a PEEP valve to the ventilator circuit with the transport ventilator that we

used (LTV1000), another type of ventilator may be a better option for transporting patients who are experiencing more severe respiratory failure.

In conclusion, the recently FDA-approved transport ventilator is able to provide more consistent ventilatory support than is manual ventilation and so would normally be a better choice for providing ventilation during intrahospital transport.

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