TITLE: Ventilation During Patient Transport: A Review of Clinical Effectiveness and Guidelines

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CONTEXT AND POLICY ISSUES:

Assisted ventilation plays a key role in pre-hospital emergency care and transport of patients who require ventilatory support from one hospital to another for specialized diagnostic or treatment services.[1,2] Bag valve devices have been traditionally used for this purpose.[3] However, transport ventilators are also being used increasingly in patient transport, as they are shown to provide more consistent minute ventilation and oxygen concentrations.[4]

In current practice, for practical reasons, manual ventilation devices are commonly used for resuscitation and in intra- and inter-hospital transport of patients.[3] The ventilation provided by this kind of device may be insufficient to support patients' metabolic needs, e.g. in terms of oxygen concentration.[5] Another disadvantage of manual ventilation is that one member of the transport team is completely occupied and unavailable for providing assistance to the remaining members of the team.[6] Furthermore, operator-induced higher airway pressures or high respiratory rates can result in a higher risk of barotraumas, pulmonary hyperinflation, and hemodynamic instability.[7] Operator fatigue may also lead to ineffective minute ventilation.[8-10]

Transport ventilators could potentially be a better choice for transport of critically ill patients as they provide more stable respiratory and hemodynamic parameters than manual ventilation.[2] Due to the advances in transport ventilator technology, a wide variety of transport ventilators with various options (ventilation modes, alarms and monitoring capabilities) are now available.[11] The ventilator options should match the level of care that a patient may need during transport.

Transport ventilators are battery powered, pneumatic, or a combination of both. Pneumatic ventilators use gas (oxygen) as a power source.[12] Pneumatic ventilators are sensitive to changes in source gas pressure, and hence might be less precise than battery-powered ventilators.[12] Overall, transport ventilators can be classified into three categories: automatic resuscitators, simple transport ventilators, and sophisticated transport ventilators.[3] An automatic resuscitator is a pneumatic time and volume cycled ventilatory device, with no alarms (except

for a high pressure alarm) and monitoring capabilities. A simple transport ventilator uses the control mode to provide a specified rate and volume and includes a high-pressure relief valve with ban alarm. A sophisticated transport ventilator is a device with various ventilation modes that provides mechanical ventilation at a specified rate and volume. This kind of ventilator includes alarms and high pressure relief valves and monitors gas delivery.[3]

The purpose of this report is to review the evidence of the clinical effectiveness of transport ventilators compared with manual ventilatory support and to identify practice guidelines for the use of transport ventilators in out-of-hospital settings. The results of this review will be used to inform decision makers on whether transport ventilators can be used by paramedics in regular ambulances.

RESEARCH QUESTIONS:

1. What is the comparative effectiveness of transport ventilators versus manual ventilatory support during patient transport?

2. What are the evidence-based guidelines for use of transport ventilators in the pre-hospital or inter-hospital transport settings?

METHODS:

A limited literature search was conducted on key health technology assessment resources, including: Ovid MEDLINE, MEDLINE In-Process & Other Non-Indexed Citations; Ovid EMBASE; PubMed (for non-Medline records); Wiley's The Cochrane Library (Issue 7, 2010); EBSCOhost CINAHL; University of York Centre for Reviews and Dissemination (CRD) databases; EuroScan; international health technology agencies; and a focused Internet search. The search was limited to English language articles published between January 01, 2000 and July 28, 2010. Filters were applied to limit the retrieval to randomized controlled trials (RCTs) and non-randomized studies (controlled clinical trials and observational studies), meta-analyses, systematic reviews or health technology assessments, and guidelines.

To address research question 1, health technology assessments, systematic reviews and meta-analyses, RCTs, and non-randomized studies were eligible for inclusion. Studies were required to compare clinical effectiveness and safety of using transport ventilators to that of manual ventilator support (bag-valve mask) in adults or children requiring ventilatory support during transport to hospital or between hospitals/clinics. No restrictions on study outcomes, baseline characteristics of study participant or duration of follow-up were applied. To address question 2, practice guidelines that provided recommendations on the use of transport ventilators were included.

HTIS reports are organized so that the higher quality evidence is presented first. Therefore, randomized controlled trials are presented first. These are followed by non-randomized studies and evidence-based guidelines.

SUMMARY OF FINDINGS:

The literature search identified 727 potential articles and 56 articles underwent full text screening. No relevant health technology assessments, systematic reviews or meta-analyses were identified. Two RCTs[6,8] and one non-randomized study[13] were identified to answer question 1. Fifteen potentially relevant practice guidelines were identified in the full text screening phase.[4,14-27] However, three guidelines[21-23] were excluded due to absence of any recommendations on transport ventilators. Three additional guidelines[24-26] were excluded as their recommendations were focused on the use of transport ventilators in intra-hospital transport settings (Appendix 1). One guideline[27] pertaining to air transport of the critically ill patients was also excluded (Appendix 1). Eight practice guidelines[4,14-20] remained in the review to answer question 2.

Randomized controlled trials

Two RCTs comparing the effectiveness of transport ventilators with manual ventilation were identified;[6,8] one of which was conducted in an out-of-hospital setting.[6] The other RCT evaluated the effectiveness of transport ventilators during intra-hospital transports.[8]

Weiss et al.[6] compared emergency medical service (EMS) crew's perceptions of the usefulness of an automatic transport ventilator (ATV) compared with bag valve (BV) ventilation for adult patients (age ≥ 18 years) intubated for either cardio-pulmonary resuscitation (CPR) or assisted ventilation, in a pre-hospital setting. Twenty eight patients were randomly assigned to the ATV (n=14) or BV (n=14) arms. An automatic resuscitator (VAR™; VORTRAN Medical Technology1 Inc.; Sacramento, CA) was used in the ATV arm. The VAR™ is a single-patient, disposable, gas powered resuscitator which provides constant-flow, pressure-cycled ventilation. Data were collected through a questionnaire of successful management completed by paramedics after transport. Some physiological data including pulse rate, respiratory rate, oxygen saturation, and end-tidal CO_2 was collected in 15 of 28 (54%) of patients. The questionnaire included a number of questions on paramedics' perceptions of ease of use of the device, ability to accomplish additional tasks, ability to complete additional monitoring, ability to provide documentation, and overall assessment of the performance of the device. The results of the study showed statistically significant differences in favor of the transport ventilator in ability to accomplish additional tasks (p= 0.01), ability to document (p= 0.04), and ability to provide patient care (p= 0.03). There were no statistically significant differences between the two study arms in terms of perceived ease of use (p=0.08), time of set up (p=0.014), expedition of transport (p=0.27), or overall patient care (p=0.59). Adverse events were not significantly different between the two study groups. The authors concluded that the ATV could be successfully used in the EMS setting, as this type of ventilation allows paramedics to perform more tasks, to document more effectively and to provide a better patient care during transport. They also concluded that collection of physiological data was feasible during transport of intubated patients.

Nakamura et al.[8] conducted an RCT to compare the effectiveness and safety of manual ventilation to a transport ventilator with patient-triggering function. Adult patients who were spontaneously breathing and needed respiratory assistance during intra-hospital transport were included and randomized to receive manual ventilation using a Jackson-Rees circuit (n=11) or mechanical ventilation through a transport ventilator [LTV1000 transport ventilator; Pulmonetic Systems; Colton, CA] (n=11). Manual ventilation was provided by physicians who were blind to

the purpose of study. Hemodynamic and respiratory variables (systolic blood pressure, heart rate, airway pressure, flow, and end-tidal CO_2) were measured 30 minutes before transport from the intensive care unit (ICU), on arrival at the site of procedure, on return to the ICU and 30 minutes after return to the ICU. After transport, the PaO_2/fraction of inspired oxygen ratio deteriorated (>20%) in 5/11 of the patients in the manual ventilation group and 1/11 of the ones in the ventilator group (p=0.056). After return to the ICU, the respiratory rates were higher in the manual ventilation group (32±9 breaths/min) than the ventilator group (19±6 breaths/min; p<0.01). The patients in the manual ventilation arm also had a greater variation in inspiratory tidal volume (p<0.05) and end–expiratory pressure (p<0.001) than the ventilator group (p<0.001). The authors concluded that transport ventilator with patient-triggering ventilation could provide more stable ventilatory support for intra-hospital transport of critically ill patients than manual ventilation.

Non-randomized Studies

Davey et al.[13] performed a retrospective observational study to evaluate the effectiveness of transport ventilators during air medical transport in infants and children with sustained head injury. The hospital charts and transport records for 29 children, aged 0.6 to 16 years, who were intubated and ventilated either mechanically (n=15) or manually (n=14) were reviewed. The outcomes data included the final pCO_2 before transport and the first pCO_2 on the arrival in the pediatrics ICU. The difference between the two groups in terms of pre-transport pCO2 was not statistically significant. After transport, 60% of patients in the ventilator group had a pCO_2 level within the target range (35-40 mmHg) compared to 0% of patients in the manual ventilation group (p<0.01). The authors concluded that the use of a mechanical ventilator during inter-hospital transport can provide a better control of pCO_2, as compared with manual ventilation.

Guidelines and recommendations

Eight relevant guideline documents were identified by the literature search[4,14-20], three of which were in the same consensus document.[17-19]

The American College of Critical Care Medicine and the Society of Critical Care Medicine (ACCCM/SCCM) provided practice guidelines for both intra- and inter-hospital transport of the critically ill patients.[4] They produced their recommendations based on a limited literature review and expert opinion. The guidelines of the American Heart Association (AHA)[17-19] were developed in a consensus conference based on the review and evaluation of evidence by the International Liaison Committee on Resuscitation (ILCOR). The remaining guidelines did not contain any information on the source of information or the manner in which evidence was used to develop recommendations. The 2006 guidelines[14] of the Association of Anaesthetists of Great Britain and Ireland (AAGBI) focused on the transport of patients with brain injury, whereas the guidelines issued by this organization in 2009 addressed the issues related to inter-hospital transfer of critically ill patients.[15]

Guideline recommendations are listed in Table 1. As the table shows, transport ventilator is listed as the equipment that is necessary for the transport of critically ill patients in four guidelines.[4,14,16,20] Two of the guidelines[4,15] further recommend that back up ventilation devices should also be available in case of ventilator malfunction. According to the AHA guidelines,[17-19] automatic transport ventilators can be used in the transport of adult patients who already have

an advanced airway, but there is not enough information to recommend transport ventilators for the resuscitation of patients in cardiac arrest. The AHA guidelines[17,19] recommend that children and newborns requiring ventilatory support be transported while receiving manual ventilation (bag-valve mask), due to lack of sufficient data to support tracheal intubation and transport ventilators in this age group.

All of the included guidelines provide guidance on essential equipment needed for patient transport, including transport ventilators, and their required specifications. Transport ventilators are advised to have alarms for high pressure, low volume and disconnection.[4,14-16,20]

It is recommended by all but one[16] of the included guidelines that a minimum of two people accompany the critically ill patients during the transport. Five guidance documents[4,14-16,20] recommend that a physician with training in airway management, advanced cardiac life support, and critical care accompany unstable patients.

Table 1: Summary of the recommendations included in the identified guidelines for the use of transport ventilators in out-of-hospital patient transport settings

Organization, Year	Country	Patient population	Recommendations
The American College of Critical Care Medicine / the Society of Critical Care Medicine, 2004[4]	USA	Critically ill patients	Intra-hospital transport: - Bag-valve ventilation is essential. - Use portable mechanical ventilator, if necessary. Inter-hospital transport: - Transport ventilator is considered as needed. - The airway must be evaluated and secured before transport and adequacy of oxygenation and ventilation should be reconfirmed. Ventilator specifications: - Disconnect alarm, high airway pressure alarm, backup battery power supply are needed. - Backup ventilation equipment should be available. Personnel : - Minimum of two people (critical care nurses) is needed. - Unstable patients should be accompanied by a physician with airway management or critical care experience.
American Heart Association, 2005[17-19]	USA	Adults/ pediatrics/ newborns with life threatening cardiovascular or respiratory events	- For the adult cardiac arrest, there is insufficient data to support the use of a manually triggered, flow-limited resuscitator or an automatic transport ventilator - Automatic transport ventilators can be used for ventilation of adult patients who have an advanced airway in place, for both in and out of hospital transports. - Bag-valve-mask ventilation is the method of choice for children who need ventilatory support. - In a newborn, a self-inflating bag, a flow-inflating bag, or a T-piece mechanical device, can be used to provide bag-mask ventilation.
The association of Anaesthetists of Great Britain and Ireland, 2006 [14]	UK	Patients with brain injury	- Portable mechanical ventilator is listed as an essential equipment to go with the patient in the ambulance. Ventilator specifications: - Disconnect alarm, airway pressure and minute volume monitor are required.

Table 1: Summary of the recommendations included in the identified guidelines for the use of transport ventilators in out-of-hospital patient transport settings

Organization, Year	Country	Patient population	Recommendations
			Personnel : - Patients with brain injuries should be accompanied by a doctor with appropriate training and experience in the transfer of patients with acute brain injury and one adequately trained assistant.
The association of Anaesthetists of Great Britain and Ireland, 2009 [15]	UK	Critically ill patients	- The patient requiring mechanical ventilation should be placed on the transport ventilator for a period of time before transport. - A standard ambulance trolley should be able to carry oxygen supply, a ventilator, syringe drivers, suction and backup batteries. Ventilator specifications: A transport ventilators should have the following features: - Disconnect and high pressure alarms, the ability to supply positive end expiratory pressure and variable inspired oxygen concentration, inspiratory:expiratory ratio, respiratory rate and tidal volume - The ability to provide pressure controlled ventilation, pressure support and continuous positive airway pressure is also desirable. - Additional equipment for maintaining and securing the airway should also be available. Personnel : - Minimum of two people are required for transport. - All patients requiring support for multi-organ failure or patients requiring post-operative care must be escorted by trained and experienced personnel (usually a doctor and a nurse or paramedic).
The Intensive Care Society, 2002[20]	UK	Critically ill adult patients	- Appropriate transport equipment including monitors, ventilators and syringe pumps must be available. - In mechanically ventilated patients, the oxygen supply, inspired oxygen concentration, ventilator settings and airway pressure should also be monitored. - Standard ambulance trolleys should be able to carry monitors, syringe pumps, ventilators and reserve oxygen cylinders. Ventilator specifications:

Table 1: Summary of the recommendations included in the identified guidelines for the use of transport ventilators in out-of-hospital patient transport settings

Organization, Year	Country	Patient population	Recommendations
			The following features are required : - Disconnection and high pressure alarms - The ability to supply positive end expiratory pressure (PEEP) and - Variable inspired oxygen concentration (FiO2), inspiratory/expiratory ratio, respiratory rate and tidal volume - The ability to provide pressure controlled ventilation, pressure support and continuous positive airway pressure (CPAP) is desirable. Personnel: - Minimum of two suitably experienced attendants, including one medical practitioner with appropriate training in intensive care medicine, anaesthesia or other acute specialty are required.
The College of Intensive Care Medicine of Australia and New Zealand / the Australian and New Zealand College of Anaesthetists / the Australasian College for Emergency Medicine, 2010[16]	Australia and New Zealand	Critically ill patients	- Portable mechanical ventilator is listed as equipment that should be considered in the transport of critical ill patients. Ventilator specifications: - Disconnect and high pressure alarms are needed. Personnel: - Minimum of one experienced medical practitioner are needed.

Limitations

Evidence that compared the relative effectiveness of transport ventilator versus manual ventilation was sparse. The literature search identified two relevant RCTs and one relevant non-randomized study, but the data were too limited to make definitive conclusions. In addition, small sample sizes of each of the included studies can limit the generalizability of the results.

Our preliminary literature search suggested that there was limited evidence published between 2005 and 2010, comparing the effectiveness of transport ventilators with manual ventilation devices. The literature search was expanded to further include the articles published between 2000 and 2004. Any articles published prior to January 2000 have been excluded from this review. However, investigation of the evidence used for development of the practice guidelines included in this review suggests that additional potentially relevant research evidence exist published in the 1980s and 1990s.

Evaluations of transport ventilators can also be performed in simulation studies and bench models. These studies did not meet the inclusion criteria for this review and were excluded as they do not provide direct evidence of effectiveness in practice settings.

CONCLUSIONS AND IMPLICATIONS FOR DECISION OR POLICY MAKING:

Two RCTs and one comparative non-randomized study were identified to evaluate the effectiveness of transport ventilators versus manual ventilatory support during patient transport. One RCT[6] employed an automatic resuscitator in a pre-hospital setting and assessed its effects on perceptions of paramedics of successful management parameters and on some physiological data. A transport ventilator was used in the second RCT[8] and changes in hemodynamic and respiratory variables were measured before, during and after intra-hospital transport. The one non-randomized study included in this review[13] retrospectively compared PCO2 levels before and after air-transport in children with a head injury who were ventilated using either a transport ventilator or manual ventilation.

The evidence included in this review suggests that transport ventilators can provide more reliable ventilatory support than bag-valve ventilation devices. Additionally, the use of an automatic transport ventilator may allow paramedics to perform more administrative and monitoring tasks than when using a bag-valve device. A majority of included practice guidelines recommend transport ventilators as necessary equipment in out-of-hospital transport settings. However, they place emphasis on planning, establishing policies and staff education.

Given the quantity and level of evidence, the results of this review do not provide sufficient evidence to support or refute the use of transport ventilators by paramedics. Future studies of high methodological quality, with more objective outcome measures are needed to explore the relative effectiveness of transport ventilators versus manual ventilation devices in pre- and inter-hospital settings.

Other considerations in policy making might include the issues related to the selection of transport ventilators, ease of use, monitoring requirements, and training of medical personnel.

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APPENDIX 1: Guidelines for Intra-Hospital Transport and Air Transport

Table A1: Summary of the recommendations included in the identified guidelines for the use of transport ventilators in intra-hospital patient transport settings

Organization, Year	Country	Patient population	Recommendations
American Association of Respiratory Care, 2002[24]	USA	Mechanically ventilated patients	- Transport ventilators have been shown to provide more constant ventilation than manual ventilation in some instances. Ventilator specifications: A transport ventilator should have the following features: - Sufficient portable power; independent control of tidal volume and respiratory frequency - The ability to provide full ventilator support as in assist-control or intermittent mechanical ventilation (not necessarily both), and to deliver a constant volume in the face of changing pulmonary impedance. - Airway pressure monitor, and disconnect alarm - Capability of providing positive end expiratory pressure (PEEP) and an fraction of inspired oxygen of 1.0. Personnel: - a registered nurse and a respiratory therapist
The Joint Faculty of the Australian and New Zealand College of Anaesthetists and the Royal Australasian College of Physicians/ the Australasian College of Emergency Medicine, 2003[25]	Australia and New Zealand	Critically ill patients	- A portable ventilator is required for ventilator-dependent patients. - It should be checked before transport if the ventilator (if used) functions properly; and if respiratory variables and alarms are set appropriately. - The patient must be assessed after being placed on transport ventilator, before transport. - On arrival, the patient must be assessed when the new ventilator (if used) are established. Ventilator specifications: - Disconnect alarm are needed. - Facilities to deliver PEEP and different modes of ventilation are necessary for some patients. - A manual resuscitator bag must always be available. Personnel:

Table A1: Summary of the recommendations included in the identified guidelines for the use of transport ventilators in intra-hospital patient transport settings

Organization, Year	Country	Patient population	Recommendations
			- Minimum of one qualified nurse, and one appropriately trained doctor (familiar with the equipment and be sufficiently experienced with securing airways, ventilation of the lungs, resuscitation, and other anticipated emergency procedures).
Department of Surgical Education, Orlando Regional Medical Center, 2003[26]	USA	Critically ill patients	- The following patients should be transported on an appropriate transport ventilator: o Patients \requiring stable oxygenation and ventilation (such as the head injured or acute lung injury patient) o Patient for whom adequate arterial oxygenation is dependent on maintenance of a specified level of PEEP o Patients with an anticipated transport time of greater than 10 minutes o Any patient at the attending physician's discretion. - All patients requiring PEEP of ≥15 cm H2O or those patients on inverse ratio ventilation should be transported using an appropriate transport ventilator.

Table A2: Summary of the recommendations included in the identified guideline for the use of transport ventilators in air transport settings

Organization, Year	Country	Patient population	Recommendations
The Royal Flying Doctors Service of Australia, 2008[27]	Australia	Air-transported patients	- Therapeutic equipment would include a defibrillator, intravenous infusion controlling device and simple transport ventilator in transfers of seriously ill patients. - There should be an adequate standard of equipment to ventilate and monitor the patient during transport. Ventilator specifications: - Disconnection alarm with appropriate visual and/or auditory signals are needed. - Adequate oxygen to meet the patient's ventilatory requirements as well as that consumed by gas-driven ventilators. Personnel: - Medical and nursing attendants with adequate skills to monitor the patient, adjust the ventilator settings as required and to re-intubate the patient at any stage.