British Journal of Anaesthesia **110** (3): 456–62 (2013)
Advance Access publication 20 November 2012 · doi:10.1093/bja/aes417

BJA

RESPIRATION AND THE AIRWAY

Jet or intensive care unit ventilator during simulated percutaneous transtracheal ventilation: a lung model study

Y. H. Liu[1,2], A. L. Wang[4], A. D. Marchese[3], R. M. Kacmarek[2,3] and Y. Jiang[2*]

[1] Anaesthesia and Operation Centre, Chinese PLA General Hospital, Beijing, China
[2] Department of Anaesthesia, Critical Care and Pain Medicine and [3] Department of Respiratory Care, Massachusetts General Hospital, 55 Fruit Street, Jackson 422, Boston, MA 02114, USA
[4] Department of Surgery, Jining Medical College, Jining, China

* Corresponding author. E-mail: yjiang@partners.org

Editor's key points

- This study evaluates the tidal volume (V_T) generated by a conventional ventilator during simulated percutaneous transtracheal ventilation (PTV) compared with jet ventilation (PTJV) in an artificial lung model.
- A conventional ventilator can generate reasonable alveolar ventilation through the transtracheal catheter.
- Insertion of a second catheter as a vent reduces auto-PEEP and improves ventilation during PTJV.
- PTV is less dependent on the directions of catheter insertion and should be considered during transtracheal ventilation.

Background. Percutaneous transtracheal ventilation (PTV) via a jet ventilator (PTJV) is considered a rescue technique in difficult airway management. However, whether a conventional ventilator can generate adequate ventilation via PTV is not known. Our goal was to evaluate the tidal volume (V_T) generated by a conventional ventilator during simulated PTV compared with PTJV in a lung model.

Methods. A lung model simulating an adult lung was used. A catheter was inserted through the artificial trachea and connected to either a jet ventilator or a conventional ventilator. The direction of catheter insertion was perpendicular to the trachea, pointing towards the lung and away from the lung. The jet ventilator was operated at 344.7 kPa. The conventional ventilator was operated in the pressure mode at peak inspiratory pressures of 40–90 cm H_2O.

Results. The jet ventilator generated larger V_T [817 (336) ml] when the catheter was pointing towards the lung than when pointing away from the lung or perpendicular to the trachea [121 (41) and 69 (24) ml, respectively, $P<0.01$]. With the conventional ventilator, changes in V_T at different direction of catheter insertion were much less [222 (81) ml catheter pointing towards the lung, 229 (121) ml perpendicular to the trachea, and 187 (97) ml away from the lung].

Conclusions. Our result demonstrated that PTJV was effective only when the catheter was pointing towards the lung and requires high operating pressure. A conventional ventilator can generate reasonable minute ventilation through the transtracheal catheter less dependent on directions of catheter insertion and should be considered during emergent PTV.

Keywords: airway obstruction; equipment, ventilators; ventilation, transtracheal

Accepted for publication: 1 September 2012

Despite advances in airway management technology, difficult mask ventilation and tracheal intubation still challenge anaesthesia providers.[1] Even though these events do not occur frequently, an overall 5.8% incidence of difficult intubation during anaesthesia[2] and 0.15% of impossible mask ventilation,[3] 'cannot intubate and cannot ventilate' or CICV are nearly always catastrophic. The inability to provide life-sustaining gas exchange during CICV was the number one cause of major complications related to airway management in anaesthesia[4] and has been responsible for up to 30% of deaths attributed to anaesthesia.[5 6]

Percutaneous transtracheal jet ventilation (PTJV) has been recommended in the ASA and Difficult Airway Society guidelines for management of the difficult airway during CICV to provide emergent oxygenation.[7 8] However, there are still some circumstances that a jet ventilator may not be immediately available when an emergent airway happens, including the operating theatre in some rural and remote health institutions[9] and critical care units in the USA[10] and in Europe.[11] On the other hand, since PTJV is not routinely used, whether clinicians can correctly use it in a timely manner is not known and the high driving pressure used during PTJV has been shown to be associated with pneumothorax, emphysema, and other forms of complications.[4 12] Therefore, alternative approaches which are easy to use and immediately available as a rescue technique for CICV are still needed. A self-inflating resuscitation bag or oxygen flush from an anaesthesia machine via cannula cricothyroidotomy has been previously studied in lung models with its efficiency still not determined.[13–16]

A regular anaesthesia or intensive care unit (ICU) ventilator is commonly available to anaesthesia care providers. In addition, with its pressure alarm system and continuous monitoring of expiratory flow and end-tidal CO_2, a conventional ventilator allows clinicians to recognize in a timely manner if the catheter is inserted in the lumen of the trachea. We hypothesized that a conventional ventilator, *vs* a jet ventilator, can generate reasonable minute alveolar ventilation (MAV) and adequate oxygenation without exposing the patient to the high pressure required with jet ventilators. Because the need for emergent percutaneous transtracheal ventilation (PTV) is unpredictable, human studies to compare the efficacy of these two approaches are not feasible. Therefore, we tested this hypothesis in a lung model. Using this model, the lung compliance, airway pressure, and anatomic dead space can be precisely controlled to compare the efficacy of PTV with a jet and a conventional ventilator.

Methods

A lung model (Dual adult TTL training/test lung, Model 1600, Michigan Instruments Inc., MI, USA) with functional residual capacity of 1020 ml was connected to the distal end of an artificial trachea with anatomical dead space 150 ml. The respiratory system compliance was set at 20, 40, and 60 ml cm H_2O^{-1}. The proximal end of the trachea was connected to a Pneuflo™ resistor (5 cm H_2O litre^{-1} min^{-1}) and a PEEP valve with pressures of 7.5 and 15 cm H_2O simulating two levels of critical opening pressure of the upper airway or a sealing cap simulating complete upper airway obstruction. The PEEP valve was unidirectional allowing out flow of air only. A 14 G i.v. catheter of 1 in length was inserted through the wall of the artificial trachea ensuring 50% (75 ml) of the anatomic dead space was on each side of the catheter. This setting was intended to simulate the situation where a catheter is inserted through the cricothyroid membrane dividing the anatomical space ~50% on each side of the catheter insertion. The catheter was connected either directly to a jet ventilator or to an ICU ventilator via a 3 ml plastic syringe connected to an adaptor of a 7.0 mm inner diameter tracheal tube (Fig. 1).

Ventilators

The jet ventilator (Acutronic Monsoon Deluxe Jet Ventilator, Autronic Medical Systems AG, Hirzel, Switzerland) was operated at 50 pounds in^{-2} (344.7 kPa) using the hospital central air supply system. The distal end of the jet ventilator hose was connected to the 14 G i.v. catheter. The insertion direction of the catheter was perpendicular to the tracheal axis, pointing towards the lung at an angle of 45 (10)° to the tracheal axis and pointing away from the lung at an angle of 45 (10)° to the tracheal axis. Ventilation was performed at rates of 6, 8, and 10 bpm. *I:E* ratios of 1:1, 1:2, and 1:3 were achieved manually by the operator guided by a timer.

Jet ventilation with a second 14 G i.v. catheter inserted parallel and adjacent to the first catheter was evaluated to determine if jet ventilation generated air trapping and auto-PEEP with a single catheter. The second catheter was kept open to ambient pressure during the entire respiratory cycle and functioned as a venting catheter.

The ICU ventilator (Puritan Bennett™ 840 Ventilator, Mallinckrodt Inc., Carlsbad, CA, USA) was operated in the pressure-controlled mode. Exhaled tidal volumes were measured with the ICU ventilator at peak inspiratory pressures (PIP) of 40, 60, 75, and 90 cm H_2O, *I:E* ratios of 1:1, 1:2, and 1:3, and respiratory rates (RRs) of 6, 8, and 10 bpm with the catheter inserted perpendicularly to the trachea axis, pointing towards and away from the lung.

Flow/pressure sensor

A flow/pressure sensor (NICO Cardiopulmonary Management System, Model 7300, Respironics Corp., Murrysville, PA, USA) was placed between the distal end of the artificial trachea and the model lung (Fig. 1). Pressure and gas flow were continuously measured through the sensor at a sampling rate of 100 Hz. The expiratory tidal volumes (V_T) measured with the sensor were automatically recorded. The sensor was automatically calibrated before data collection.

Data collection and statistics

Data from each experimental setting were continuously collected using the NICO Analysis Plus data management system. However, data were analysed only after measurement reached a steady state at each setting. The steady state was generally achieved after two to three breaths. After reaching steady state, data from three consecutive breaths were analysed and data were then averaged at each setting. Data are expressed as mean (SD). The PASW statistics package (IBM Corporation, New York, NY, USA) was used for statistical analysis. For main effects, the general linear model for univariant analysis was used to identify the significance of different direction of catheter insertion, PEEP level, *I:E* ratio, RR, and compliance on expiratory tidal volume generated by the jet and ICU ventilators. A *P*-value of <0.05 was considered statistically significant.

Results

The mean V_T generated by the jet and ICU ventilators at three different directions of catheter insertion (towards the lung, away from the lung, and perpendicular to the tracheal axis), at critical opening pressure of 7.5 and 15 cm H_2O and *I:E* ratio of 1:1 are presented in Figure 2. When the catheter was directed towards the lung, jet ventilation resulted in an average V_T of 817 (336) ml and a maximal V_T of 1496 ml, which were significantly larger than those obtained when the catheter was directed away from the lung [121 (41) ml] or perpendicular to the tracheal axis [69 (24) ml] ($P<0.01$). With the ICU ventilator, V_T's were 187 (97), 229 (121), and 222 (81) ml when the catheter was pointing away from the lung, perpendicularly to the tracheal axis,