Rescue ventilation using expiratory ventilation assistance : innovating while clutching at straws

Summary

The inability to maintain oxygenation in a patient by non-invasive airway maneuvers is one of the most pressing emergencies in anaesthesia and emergency care. To prevent hypoxic brain damage and death, emergency percutaneous airway access must be performed immediately. In the **prologue** a case of a ‘cannot intubate, cannot oxygenate’ (CICO) situation is described. In this case a narrow-bore catheter was successfully inserted in the airway and oxygen could be insufflated into the lungs. However, a new problem arose as it was impossible to provide an adequate outflow of the gas, which resulted in air trapping and haemodynamic instability.

The various techniques, strategies and equipment available for emergency oxygenation are described in **chapter 1**. Unfortunately all available techniques have their limitations and the ideal rescue technique for a CICO situation seems not yet to exist. Although a narrow-bore cricothyroidotomy catheter is easy to insert and anaesthetists generally feel comfortable placing it, reoxygenation and ventilation through a narrow-bore catheter poses new challenges. In order to overcome the resistance of a narrow cannula, a high-pressure oxygen source is necessary for achieve adequate flow through the narrow cannula.
Because an automated or hand-triggered jet injector may not be immediately available, various self-assembled devices consisting of a three-way stopcock and oxygen tubing have been proposed for emergency jet ventilation through a narrow-bore airway catheter. Combined with a high oxygen flow, these devices are generally supposed to provide adequate pressure and flow for emergency reoxygenation. However, as shown in the bench study described in **chapter 2**, a three-way stopcock based, self-assembled device acts as a ‘flow splitter’ and, when connected to an oxygen flow, even with the side port completely open, never ensures total flow and pressure release. In a completely obstructed upper airway, the oxygen flow will inevitably create high airway pressure during the expiratory phase that can lead to barotrauma and hemodynamic instability. Thus, the use of a three-way stopcock device to control oxygen flow during emergency jet ventilation, as described in current textbooks and recent literature, is potentially dangerous and should not be recommended.

When using an automated or hand-triggered jet injector it is mandatory to maintain a patent upper airway for the egress of gas. Obstruction of the outflow tract or insufficient expiratory time results in air trapping with subsequent barotrauma and haemodynamic instability as described in the prologue. In a CICO situation partial obstruction of the upper airway, resulting from oedema, laryngospasm or distorted anatomy occurs frequently and it is uncertain whether the upper airway will open at a higher airway pressure. Therefore, it is crucial that a device used in a CICO situation is not only

able to provide effective flow release and pressure control, but also allows bidirectional airflow. The self-assembled jet ventilation devices studied in Chapter 2 did not ensure total flow and pressure release during the expiratory phase. However, changing the connecting position of the transtracheal catheter on the three-way stopcock from the in-line port (as in chapter 2) to the side port (device B in **chapter 3**) resulted in a slightly negative pressure at the catheter's tip. This improved the safety of the emergency ventilation device as it allowed bidirectional airflow. So even in a fully obstructed upper airway gas could escape.

Passive outflow of gas through a small-bore catheter is limited because of the high internal resistance of the catheter and the low driving force for the egress of gas. The time needed for passive backflow of 1000 ml oxygen through a catheter with an internal diameter (ID) of 2 mm is 13.4 seconds. To facilitate the outflow external suction can be applied during the expiratory phase. In pediatric ventilation this has shown to be very useful. However, in emergency ventilation in adults none of the proposed techniques and devices found their way into clinical practice, because they were not effective or too complex to use. In **chapter 4** a small, modified industrial ejector is introduced for applying Expiratory Ventilation Assistance (EVA). An ejector is a multi-purpose device able to create subatmospheric pressure based on Bernoulli's principle. Comparable with a Venturi nozzle, the driving gas flowing through an ejector entrains gas (e.g. ambient air) through a side port. The modified ejector was able to shorten the expiration time significantly and achieved a calculated expiratory minute volume through a 2 mm ID transtracheal catheter in a simulated obstructed airway up to 6.6 $l \cdot min^{-1}$.

An industrial ejector is designed to create a maximum negative pressure to pick up and hold parts during manufacturing processes in industrial assembly lines. It cannot be expected to work perfectly as a ventilator. In **chapter 5** the technical features and abilities of the modified industrial ejector and an optimized ejector-based ventilation device (DE5) are described. The results illustrate that the amount of entrainment and consequently the degree of expiratory assistance depend on the velocity of the driving gas and the resistance of the outflow tract of the ejector. The optimized DE5 achieved a calculated minute volume up to 7.5 l·min–1 through a 2 mm ID transtracheal cannula in an artificial lung model with complete outflow obstruction

In severely hypoxic pigs with a completely obstructed airway EVA, applied by the DE5, restored oxygenation through a small-bore transtracheal catheter within 20 seconds and kept PCO_2 stable (**chapter 6**). EVA was found to be less efficient in a setting simulating a completely open airway. As airway patency increased re-oxygenation was delayed and severe hypercapnia developed.

Based on the optimized prototype for EVA (DE5, chapter 5), a portable, flow-regulated, manually operated, and ergonomically shaped ventilation device was developed: Ventrain® (Dolphys Medical BV, Eindhoven, The Netherlands).

The results of the bench study as described in **chapter 7** show that the degree of expiratory assistance is flow-dependent, with a maximum suction capacity of 12.4 $l \cdot min^{-1}$ at an oxygen flow of 15 $l \cdot min^{-1}$. At this flow rate Ventrain® can achieve through a 2 mm ID transtracheal catheter a minute volume of 7.1 litres. This minute volume would not only be enough for swift re-oxygenation, but it would also prevent hypercarbia in most adults. In a CICO situation use of EVA by Ventrain® would be the most efficient and safest technique currently available to reoxygenate the patient through a narrow-bore transtracheal catheter.

Expiratory Ventilation Assistance (EVA) is introduced as a new ventilation mode for ventilation through narrow-bore catheters in an obstructed airway. The full potential of EVA within modern airway management, including elective routine use, has yet to be explored. The general discussion (**chapter 8**) focuses on the possible role of EVA by Ventrain® in emergency ventilation and on potential future applications of EVA as a new ventilation mode for airway surgery, single lung ventilation and lung-protective ventilation strategies.