Transtracheal jet ventilation

Shubhranshu Gupta
Rajib Ahmed

Abstract

Transtracheal jet ventilation (TTJV) is a method of lung ventilation via a narrow-bore catheter placed percutaneously into the trachea, bypassing the upper airway and glottis. A pressurized jet of oxygen that entrains air is delivered to the lungs. This technique can be utilized in both elective and emergency situations. It is no longer recommended by the Difficult Airway Society (DAS) in the 'Can't Intubate, Can't Oxygenate' (CICO) situation, as a surgical technique is now recommended in this scenario (unless the practitioner is familiar with TTJV). In the non-CICO emergency situation, TTJV may be utilized to preoxygenate the patient and allow time to secure a definitive airway. Humidified high-flow nasal oxygenation is a more recently described technique that may allow preoxygenation and time for a transtracheal catheter to be placed, and even replace the need for TTJV. However, a jet ventilator should be immediately available in the event of failure of the nasal high-flow system. This article will examine the indications for TTJV and physiology behind its mechanism of action. We will also describe the equipment required, technique and potential complications.

Keywords Difficult airway; failed intubation; jet ventilation; Ravussin needle; transtracheal

Royal College of Anaesthetists CPD Matrix: 1B02; 2A01; 3A01; 3A02

Learning objectives

After reading this article, you should be able to:

- explain the indications for transtracheal jet ventilation
- describe the methods for carrying out transtracheal jet ventilation
- discuss the potential complications of transtracheal jet ventilation

Transtracheal jet ventilation (TTJV) is a method of lung ventilation via a percutaneously placed narrow-bore (usually an internal diameter of ≤2 mm, or 14 gauge) catheter into the trachea, bypassing the upper airway and glottis. Jet ventilation involves the delivery of a pressurized jet of oxygen that entrains air. Jet ventilation can be low frequency or high frequency.

High pressure jet ventilators are able to generate an adequate inspiratory flow through a small bore catheter. Tidal volume is composed of the jet volume plus the volume of entrained gas. Adequacy of ventilation is assessed by chest expansion. Upper airway patency must be maintained in order to allow passive expiration from elastic recoil of the lungs and chest wall. Without this, a narrow diameter catheter would not allow adequate expiration due to the high resistance to flow. In 'Can't Intubate, Can't Oxygenate' (CICO) emergencies the upper airway may be partially or completely obstructed – this may be the underlying cause of the failure to intubate and oxygenate, or in addition to other factors.

Ventilation may be more effective when some degree of airway obstruction is present, as backflow of gas up a patent airway may occur in a completely open airway.[1] However, the priority is to maintain a patent airway in order to avoid barotrauma.

High frequency ventilation utilizes a rapid respiratory rate and low tidal volumes. Transtracheal high frequency jet ventilation (HFJV) with an automated ventilator may offer protection against pressure complications by means of pressure monitoring and alarms, and an automatic cut-off triggered by high peak or pause airway pressures. Reduction in airway driving pressure and ventilation frequency and are used to lower airway pressures.[2]

History

Reed et al. and Jacoby et al. published studies on transtracheal catheterization in the 1950s. Sanders described jet ventilation via a rigid bronchoscope in 1967. Spoerel was the first to combine percutaneous access to the trachea via the cricothyroid membrane with jet ventilation – this allowed not only adequate oxygenation but also CO_2 excretion.

The early use of transtracheal catheters focused on their use in resuscitation and in unanticipated difficult airways. From the 1980s onwards publications also described the technique for use in elective ENT surgery. In 2003, transtracheal catheterization was included in the American Society of Anaesthesiologists guidelines for management of the difficult airway.

Physiology

Gas exchange in low frequency TTJV occurs mainly via convective ventilation or bulk flow i.e. mass flow of gas into and out of the lung. The alveolar ventilation is calculated using the formula:

$$V_A = f \times (V_T - V_D)$$

where V_A is alveolar ventilation, f is rate of ventilation, V_T is tidal volume and V_D is dead space volume.

The delivered FiO_2 depends on the volume of the main jet flow (FiO_2 of 1.0) and the volume of entrained air in the side flow due to the Venturi effect (FiO_2 of 0.21).

Inspired flow may be lost to the upper airway in the presence of upper airway patency, resulting in insufficient tidal volume.[3] Increasing upper airway obstruction may divert more flow down to the lungs and result in increased tidal volume (TV) but a longer expiratory time, whereas a lesser degree of upper airway

Shubhranshu Gupta MBBS FRCA *is a Consultant Anaesthetist at the Queen Elizabeth University Hospital, Glasgow, UK. Conflicts of interest: none declared.*

Rajib Ahmed MBChB FRCA *is an ST7 in Anaesthetics at the Queen Elizabeth University Hospital, Glasgow, UK. Conflicts of interest: none declared.*

obstruction may result in lower TV, but preserved minute volume (MV) due to a shorter expiratory time.

HFJV delivers tidal volumes that are lower than the combined anatomical plus equipment dead space. Some bulk flow may be possible in the alveoli close to the conducting airways but this does not account for adequate ventilation. The above equation does not therefore explain gas exchange in this situation as other mechanisms are involved.[4]

Laminar flow occurs in the smaller airways where Reynolds number is low, which results in a parabolic airflow: the centre of the airflow has a higher velocity than that around it. Jet ventilation amplifies the difference in velocities of gas such that gas at the centre of the airflow moves into, and that at the margins tends to move out of the lung.

Taylor-type dispersion describes the interaction between axial parabolic velocity and the radial concentration gradient and explains further mixing of gases in smaller airways. In larger airways, turbulent flow eddy currents in combination with bulk flow result in a similar radial mixing effect.[4]

Pendelluft or collateral ventilation results from variable time constants of alveoli and leads to flow of gas from one alveolus to another. This is more pronounced in high frequency breaths and facilitated by higher mean airway pressures seen in HFJV leading to extensive recirculation of gas between regions. Smaller volumes of gases reach more respiratory units as compared to the tidal volumes used in conventional ventilation.[4]

Jet ventilation is effectively a time-cycled, pressure-limited ventilation. A decrease in compliance of the system results in a reduction in minute ventilation and it is the driving pressure rather than the frequency of ventilation that determines CO_2 elimination.

Indications

TTJV is used in both the elective and emergency settings. It may be used in elective ENT and thoracic surgery. It is routinely used for airway management for surgery on the larynx or trachea, including laser surgery, where it provides an unobstructed view of the larynx.

In emergencies, it can be used in CICO scenarios and the non-CICO situation. It is recommended by numerous airway guidelines for CICO emergencies and was previously advocated in the Difficult Airway Society (DAS) Guidelines on Unanticipated Difficult Airway, until the most recent edition of the guidelines in 2015.[5] DAS now recommends a surgical cricothyroidotomy using a scalpel/bougie/endotracheal tube technique, with TTJV reserved for use only by those clinicians experienced with the technique in their routine practice. This is due to the number of adverse events noted with TTJV in the emergency, and in particular, CICO situation. A systematic review of 428 procedures by Duggan et al. in the *British Journal of Anaesthesia* in 2016[6] found a statistically significantly higher risk of adverse events with the use of TTJV in CICO emergencies in comparison with non-CICO emergencies and elective use. Device failure occurred in 42% of CICO emergencies versus 0% of non-CICO emergencies and 0.3% of elective procedures. Barotrauma occurred in 32% of CICO emergencies versus 7% non-CICO emergencies and 8% elective procedures. The occurrence of more than one complication was also higher in CICO emergencies.

The National Audit Project 4 (NAP4)[7] reported a high failure rate with emergency cannula cricothyroidotomy of approximately 60%, whereas a surgical technique was almost always successful.

In the urgent non-CICO situation, lung ventilation via a prophylactically inserted transtracheal catheter maintains oxygenation and allows time to secure a definitive airway. General anaesthesia can safely be provided prior to securing the airway with an endotracheal tube or tracheostomy. The need for laryngoscopy to secure the airway may also be eliminated. However, TTJV can also be a useful aid for intubation where the larynx is obscured by swelling or tumour; intubation is guided by visualization of expiratory gas bubbles in the pharynx. It is an alternative to primary tracheostomy, which places a considerable stress on the awake patient.[8]

THRIVE (Transnasal Humidified Rapid Insufflation Ventilatory Exchange) is a method of apnoeic oxygenation, delivered by systems such as Optiflow™ Nasal High Flow by Fisher and Paykel Healthcare. It offers the ability to preoxygenate the patient and affords time to prepare equipment prior to commencing jet ventilation. It may also allow maintenance of oxygenation and ventilation throughout surgery without the need for transtracheal jet ventilation. Its mechanism of action is via the triad of apnoeic oxygenation, apnoeic ventilation and continuous positive airway pressure (CPAP), which prevents atelectasis. However, it relies on the presence of a patent airway and will not work in airway obstruction. A jet ventilator should be available in case of failure of the nasal high-flow system.

Equipment

There are numerous different cannula types and sizes for use in jet ventilation. A kink-resistant cannula should be used, such as the Ravussin cannula (VBM Medizintechnik, Germany) or the emergency transtracheal airway catheter (Cook Medical, Bloomington, USA).

The Teflon-made VBM cannula (Figure 1) has a curved shaft and angled connector that sits flush with the skin and is secured with the Velcro strap provided. It is produced in three sizes: 13G for use in adult patients and, 14G and 18G for paediatric patients. It has two connectors: a 15 mm diameter ISO (International Organisation for Standardisation) male connector that allows connection with a standard anaesthetic system for oxygenation insufflation, and a Luer lock connector for high pressure jet ventilation.

There are several methods for oxygenation via the catheter:

Anaesthetic circuit, which will enable apnoeic oxygenation. Other methods of connection to a low-pressure oxygenation outlet have been described. Cook produces oxygen tubing designed for connection to a transtracheal catheter and which

Figure 1 VBM transtracheal catheter.

