

Supraglottic jet oxygenation and ventilation - A novel ventilation technique

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ABSTRACT

Supraglottic jet oxygenation and ventilation (SJOV) is a novel minimally invasive supraglottic technique of jet ventilation which has shown superior results in maintaining oxygenation without any major complications. Theoretically, it could maintain PaO₂ and PaCO₂ within physiological limits for as long as required, the maximum duration reported till now is 45 min. The distinct advantage of SJOV over techniques of nasal oxygenation is its ability to record EtCO₂ during the periods of ventilation. In addition, it also provides reliable airway access by the blind passage of the endotracheal tube into the trachea with a high success rate even in Cormack-Lehane-III (CLIII) grading patients. Potential complications seen with SJOV include nasal bleed and sore throat. No studies have shown to cause severe barotrauma. In this article, we review the evidence regarding oxygenation, ventilation, indications, airway patency and complications of SJOV in comparison to other more commonly used supraglottic oxygenation and ventilation devices.

Key words: Apnoeic oxygenation, jet ventilation, Supraglottic jet oxygenation and ventilation, supraglottic oxygenation, WEI jet endotracheal tube, WEI nasal jet tube

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INTRODUCTION

Hypoxia remains a major cause of morbidity and mortality in anaesthesia.^[1,2] According to the National Audit Project 4 (NAP4) report, it accounts for up to 25% of anaesthesia-related deaths.^[1] Hypoxaemia may develop during attempts to secure a definitive airway or it may develop intraoperatively especially during procedures done under sedation. Although pre-oxygenation followed by bag-mask ventilation (BMV) is sufficient to maintain adequate oxygenation while one makes intubation attempts, the apnoeic time frame is still limited. Besides inefficient BMV, poor physiological oxygen reserves, emergent or difficult airway may further reduce this cushion of safe apnoea time. Furthermore, this limited time frame may adversely affect anaesthetist's efficiency at securing a definitive airway^[3] and the situation may spiral into a complete ventilation failure scenario^[4] leading to significant cardiorespiratory morbidity. While recent airway guidelines recommend the use of cricothyrotomy in such situations, these techniques might be either difficult to perform or associated with significant complications.^[1,4-7]

Supraglottic jet oxygenation and ventilation (SJOV) is a novel minimally invasive technique of jet ventilation above the level of vocal cords using a specialised nasal tube (WEI jet endotracheal tube [WEI JET], WEI nasal jet [WNJ] tube). Recent studies suggest that SJOV is a feasible ventilation technique in both spontaneously breathing and apnoeic patients. Additionally, SJOV has also been used as a rescue oxygenation/ventilation method in complete ventilation failure scenarios. Advantages of SJOV include ease of administration, lack of any major complications and the device used to deliver SJOV itself maintains a patent airway without any external support. Also in case of a difficult airway,

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the nasal tube can be guided blindly into the trachea to secure a definitive airway.

This review summarises the evidence regarding SJOV in terms of its assembly and technique, physiology, applications, and complications. The purpose of this narrative review was to examine existing evidence regarding SJOV and not to perform a meta-analysis or grade the evidence of the published literature.

LITERATURE SEARCH

We searched PubMed (MEDLINE), EMBASE and Cochrane. All published data from 2006 to 2019 pertaining to SJOV were collected using the following keywords: *SJOV, WEI JET, WNJ tube, jet ventilation, high-flow oxygen and apneic oxygenation*. Abstracts and case reports were included. Articles published in a language other than English were excluded. Searches were augmented by manually reviewing the reference lists of all original research and all review articles.

COMPONENTS OF SJOV

SJOV was first described using a jet endotracheal tube,^[8] a prototype of the WEI JET.^[9] Later, WEI JET was modified into a WNJ tube with a port for a jet catheter in the adjacent wall of the tube and an additional catheter placed inside the wall of the tube for end-tidal CO₂ (EtCO₂) monitoring [Figure 1].^[10] This allows it to be used as a supraglottic airway device (SAD). Recent studies have used Cook's airway exchange catheter and even a suction catheter to provide supraglottic jet ventilation via a nasal tube or a nasopharyngeal airway.^[11,12] WNJ tube can be used either as a source of continuous oxygen flow, connected externally to a standard oxygen delivery system, or it can be used as a source of jet ventilation connected to a manual or automated jet ventilator, which in turn is connected to the wall-mounted oxygen delivery port. The working parameters of the automated jet ventilator include

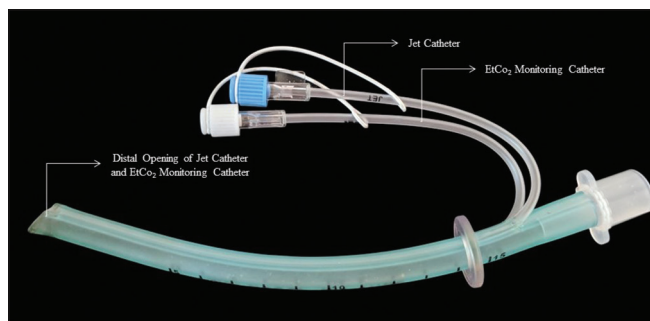


Figure 1: Components of WEI nasal jet tube (WNJ)

fraction of oxygen concentration to be delivered by the jet ventilator, driving pressure, respiratory rate (RR) and the inspiratory/expiratory (I:E) ratio.

PHYSIOLOGY OF SJOV

During SJOV, a jet of high flow high concentration oxygen is delivered using driving pressures between 10 and 30 psi. The jet passes through a narrow opening of a suction catheter pushed into the nasal airway or through a separate jet port within the lumen of a WNJ tube.^[9-13] The tip of the nasal airway/tube lies under the epiglottis pointing at the vocal cords along the axis of the airway. This ensures rapid delivery of oxygen in a pulsatile manner into the trachea leading to an exchange of gases. Additionally, it might also increase the functional residual capacity (FRC) of the lungs. The effect of SJOV on pulmonary physiology, shunt fraction, ventilation-perfusion (V/Q) mismatch has not been studied to date. But it should work on the principles similar to jet ventilation where the amount of delivered tidal volume should be a sum of delivered tidal volume and entrained volume (Venturi effect) if the jet pulses are directed towards the vocal cord. And the FiO₂ in the pharyngeal area may be high during SJOV, especially if ventilator settings for FiO₂ are kept at 100%.^[14]

In comparison, face-mask ventilation (FMV) or SAD ventilation is closer to physiological breathing allowing the anaesthesiologist to titrate the tidal volume, deliver positive-end expiratory pressure and regulate the rate of breathing while being used for both apnoeic and spontaneously breathing patients. On the other hand, conventional apnoeic oxygenation using nasal cannula with oxygen flows of 5–6 L min⁻¹, or nasal oxygenation with higher O₂ flows of up to 15 L min⁻¹ and more recently transnasal humidified rapid insufflation ventilatory exchange (THRIVE) with humidified O₂ flows of up to 80 L min⁻¹ are primarily oxygenation techniques that also allow for some degree of carbon-dioxide elimination. During the periods of apnoea, there is a continuous flux of oxygen from the alveoli into the capillaries, while carbon dioxide diffuses back into the alveoli. If there is a patent airway between the lung and the environment, this exchange of gases creates a negative pressure gradient of up to 20 cm H₂O, which drives oxygen into the alveoli from the environment.^[15] THRIVE generates a high flow of oxygen leading to flow-dependent flushing of dead space. As oxygen flushes at the rate of 70 L per min, it generates a continuous positive airway

pressure (CPAP) of 7 mmHg which splints the upper airway and prevents alveolar collapse allowing for continuous gaseous exchange.^[16] In addition, reduced oxygen dilution with nitrogen, humidification and heat-related improvement in airflow and pulmonary compliance and ability to avoid cold-air-related bronchoconstriction may further improve its efficacy.^[17] While THRIVE's oxygenation efficiency is much less if the patient's mouth is open,^[18] SJOV prolongs the apnoea period with both open and closed mouth. A summary of the differences between SJOV and THRIVE has been described in Table 1.

APPLICATIONS OF SJOV

SJOV has been described for spontaneously breathing and apnoeic adult patients in both emergency and elective clinical scenarios. It provides for both oxygenation and ventilation allowing for an active exchange of gases, and hence theoretically, we can use it for as long as is required, the maximum reported duration is 45 min.^[19]

Procedural sedation

SJOV has been used to avoid hypoxaemia in procedures done under sedation such as upper gastrointestinal (GI) endoscopy, colonoscopy, and hysteroscopy. In a large multicentre trial, SJOV decreased the incidence of hypoxaemia from 9% to 3% ($P < 0.0001$) in patients undergoing upper GI endoscopy using propofol sedation.^[10] They concluded that patients with additional risk factors for hypoxaemia, such as obesity, may benefit from SJOV especially during upper GI endoscopy procedures where bag-mask ventilation might not be possible due to the presence of endoscope. Levitt *et al.* successfully used SJOV to ventilate a 160 kg man with a history of obstructed sleep apnoea undergoing colonoscopy with propofol sedation.^[12] Also, in another case report, Hou *et al.* were able to maintain oxygenation with minimal haemodynamic changes in a spontaneously breathing obese (BMI-30.82 kg/m²) patient with the history of coronary artery disease, hypertension and diabetes who had presented for oesophageal foreign

Table 1: Summary of comparison between THRIVE and SJOV

	THRIVE	SJOV
Equipment	Optiflow with standard nasal cannula	WEI nasal jet tube (WEI nasal jet, WNJ*), WEI jet endotracheal tube (WEI JET*)
General characters		
Flows	High-oxygen flow (30-70 L/min)	High oxygen flow (>30 L/min at high frequency)
Driving pressure	Low pressure	High pressure
Humidification	Yes	Yes with modern jet ventilator
EtCO ₂ monitoring	Not possible	Available with built-in catheter
Suction	Done separately	Available port for suction
Invasiveness	Non-invasive	Minimally invasive
Efficacy with open mouth	Not as effective	Effective
Oxygenation		
FiO ₂ **	High, can be adjusted	High, adjusted with modern ventilator
Oxygenation	Improved	Improved
Apnoea period	Significantly longer (mean - 17-22 min, maximum - 65 min)	Theoretically as long as possible (maximum attempted - 45 min)
Role in airway obstruction	Patent airway required	Able to relieve airway obstruction
Ventilation		
PaCO ₂ rise	Slow (≈1.12 mmHg min ⁻¹) No plateau state	No rise seen.
Method to assess optimal ventilation	None	Chest rise, EtCO ₂ trace
Airway		
Patency	Requires jaw thrust	<5% of patients require jaw thrust.
Airway access	None	Passage of supraglottic nasal tube (WNJ) or infraglottic endotracheal tube (WEI JET)
Complications		
Barotrauma	No	Possible, not shown
Mucosal drying	No	Yes
Nasal bleeding	No	Yes

*WNJ – WEI nasal jet, WEI JET – WEI jet endotracheal tube, **FiO₂ – Fraction of inspired oxygen, THRIVE – Transnasal humidified rapid insufflation ventilatory exchange, SJOV – Supraglottic jet oxygenation and ventilation

body removal. They used WNJ tube as a source of continuous oxygen flow at 6 L/min.^[20]

SAD ventilation and FMV are more familiar methods for anaesthesiologists in maintaining oxygenation in sedated patients. Two separate studies have shown benefit of SJOV over both techniques. Liang *et al.* compared the efficiency of FMV, WNJ tube used as a source of continuous flow oxygen at 6 L/minute (WNJ-oxygen) and as a source of SJOV (WNJ-SJOV) in maintaining oxygenation in spontaneously breathing obese patients undergoing hysteroscopy. They found a significantly lower number of patients with SpO₂ below 95% in the SJOV group as compared to the other two groups. (WNJ-SJOV 6% vs WNJ-oxygen 27% vs FMV 33%).^[21] SJOV has also been compared to laryngeal mask airway (LMA) to assess the efficacy of maintaining oxygenation. Wu *et al.* compared SJOV and ventilation using LMA in paralysed patients undergoing fibre-optic bronchoscopy (FOB). They found the number of patients with SpO₂ lower than 94% were more in the LMA group at the time of intubation. (25% vs 0%, $P < 0.01$).^[13]

THRIVE, on the other hand, has been primarily described for pre-oxygenation and apnoeic oxygenation. Patel *et al.* first described THRIVE in patients with either known or expected difficult airway, patients with a high BMI or a cardiorespiratory disease where a rapid oxygen desaturation is expected. They took a series of 25 patients and provided oxygen at 70 L/min for pre-oxygenation and during the apnoeic period. None of their 25 patients desaturated below 90% with an average apnoea time of 17 min (5–65 min).^[16] In a similar study, Gustaffson *et al.* also found THRIVE to significantly prolong the apnoea time (mean apnoea time 22.5 min).^[22] However, THRIVE is not as efficient in maintaining PaO₂ during the apnoeic period as ventilating a patient using FMV. Also, THRIVE's benefits over FMV for pre-oxygenation have not been consistent.^[23-26] Currently, there are no studies that directly compare oxygenation using THRIVE and SJOV.

Facilitation of flexible fibre-optic intubation

FOB-guided intubation is considered as the gold standard for patients with a difficult airway. While performing an awake FOB might be difficult in uncooperative patients, sedating such patients may increase the risk of desaturation during the procedure. SJOV can be used to prevent hypoxaemia while fibre-optic intubation is performed in sedated patients

either apnoeic or spontaneously breathing. There are two ways in which SJOV can be used to facilitate FOB intubation. First, the nasal tube (WNJ/nasopharyngeal airway with *in situ* suction catheter for jet ventilation) is passed through one nostril to establish SJOV confirmed by adequate chest rise or EtCO₂ trace, this is followed by insertion of FOB through the other nostril or the oral cavity to allow for nasotracheal or oro-tracheal intubation, respectively. The other method is by the passage of an assembly of Aintree intubation catheter (AIC) mounted over 3.2 mm FOB through the WNJ tube up till the carina after WNJ tube has been used to establish SJOV. After this, FOB and WNJ tube are removed and the endotracheal tube (ETT) is guided over the AIC. This technique was described by Wu *et al.* They compared intubation using FOB-AIC assembly passed either through WNJ tube or SAD in 50 patients with difficult intubation. They found the total time for intubation (73.4 vs 99.5 s) and the first attempt success rate at intubation (100% vs 79.2%) were significantly better with the WNJ tube. Although, the overall success rate was similar in both the groups.^[13]

Intubation

SJOV uses a nasal tube with the distal tip directed towards the vocal cord which can be pushed into the trachea to secure a definitive airway if the need arises. Wei in simulated difficult airways in pigs was able to intubate in all cases using WEI JET.^[8] Peng *et al.* carried out a study to assess the success rate of intubation using WEI JET compared to the standard direct laryngoscopy (DLscopy) for all the Cormack-Lehane (CL) grading patients. They found that although the first attempt success rate was similar in patients with CLI and II, the success at intubation using WEI JET was 100% in patients with CLIII grading.^[9] Also, C-n *et al.* found a higher intubation success rate with WEI JET as compared to DLscopy in patients with unstable cervical spine.^[27] Dziewit *et al.* reported a case of Marfan's syndrome, where they used a jet catheter to deliver SJOV and maintain oxygenation while at the same time, they railroad an ETT over it into the trachea in the first attempt despite a CLIII view on DLscopy.^[28]

Rescue device

The inability to ventilate using the best attempts at all available means, which includes FMV, SAD, and tracheal tube, even if oxygenation is maintained is referred to as complete ventilation failure scenario.^[4] The American Society of Anesthesiologist (ASA) guidelines

recommend the use of surgical airway or transtracheal jet ventilation (TTJV)^[5] while All India Difficult Airway Association (AIDAA) and Difficult Airway Society (DAS) guidelines recommend emergency cricothyrotomy.^[4,29] TTJV is an invasive technique, associated with the risk of barotrauma, as high as 10% to 30% especially during emergent difficult airway management,^[1,2] and cricothyrotomy may be difficult to perform in emergency situations as most physicians tend to have limited hands-on experience with cricothyrotomy including identification of landmarks which might hamper their efficiency.^[6,7]

SJOV's ease of administration allows it to be used in emergency situations. Liang *et al.* reported a case in which they maintained oxygen saturation in a 176 kg patient using SJOV while they attempted fibre-optic intubation after failed attempts at FMV post muscle paralysis.^[30] Li *et al.* passed a small internal diameter jet catheter through a nasal airway up to the vocal cords to provide high-flow oxygen in a patient with an emergent cannot intubate cannot ventilate (CICV) situation after failed FMV and LMA insertion.^[19] They were able to ventilate the patient for 45 min without hypoxaemia.^[19] In another case report, Peng *et al.* described the use of SJOV using WEI JET for 20 min without desaturation.^[9]

MAINTAINING AIRWAY PATENCY

WNJ tube is shaped like a nasopharyngeal airway and hence can easily maintain a patent airway even in patients at risk of airway obstruction with FMV or nasal oxygenation techniques. Additionally, the jet can push the epiglottis away from the posterior wall of the pharynx further improving airway patency. In a large multicentre trial comparing WNJ and nasal cannula, only 3% of patients on the WNJ-SJOV technique required jaw thrust as compared to 18% of patients on nasal cannula ($P < 0.05$).^[10] In addition, SJOV-WNJ has a distinct advantage in patients with airway oedema and airway bleeding. The presence of a suction port allows removal of blood or secretions along the airway and improves airway patency. Sometimes, SJOV might also open up a narrow channel of an oedematous glottis. With nasal oxygenation techniques, one should always have a backup plan of securing the airway, especially in an anticipated difficult airway if PaO₂ or PaCO₂ reach unsafe levels whereas, in case of SJOV, anaesthesiologist can guide the WNJ tube into the trachea if the need arises.

CO₂ CLEARANCE

A limiting factor that determines the duration of apnoeic oxygenation is not oxygenation itself rather rapid rise in arterial carbon dioxide (PaCO₂) levels. Studies have found SJOV to be efficient in preventing an increase in the PaCO₂ levels and maintaining it within the physiological range.^[8,9] One of the main advantages in the built of WNJ tube is the inbuilt catheter to measure the EtCO₂ levels during the periods of apnoea and jet ventilation. During the process of SJOV, we adjust the nasal tube to optimise the EtCO₂ trace and chest rise to achieve the best ventilation. Although, whether chest rise is superior to ETCO₂ or vice-versa as a cue to optimal tube position is not very clear.^[9,11]

Classic apnoeic oxygenation technique is not efficient in CO₂ elimination leading to a rapid and potentially harmful rise in the CO₂ levels.^[17] The rate of rise of PaCO₂ with classic apnoeic oxygenation technique is around 2.6–3.4 mmHg min⁻¹, which is similar to the one measured by Stock *et al.* in patients with airway obstruction.^[16,31] On the other hand, THRIVE allows a faster CO₂ elimination as compared to apnoeic patients. While it flushes the dead space with high-flow oxygen, it also causes compression and expansion of small airways due to waves generated in the pulmonary blood as a result of constant heartbeats as the blood enters and leaves the thoracic cavity. These waves lead to gas flows within the airway which improve gaseous mixing and are known as cardiogenic oscillations.^[32] Patel *et al.* found the rate of rise in EtCO₂ in patients oxygenated using THRIVE to be 1.12 mmHg min⁻¹.^[16] A recent study by Hermez *et al.* found that for THRIVE with flows of 70 L min⁻¹ and cardiogenic oscillation volume of 20 mL beat⁻¹, the rate of CO₂ elimination from blood was 17.4 mL min⁻¹.^[32] Despite a faster CO₂ clearance, it is not as efficient as the traditional BMV.^[24] One of the major disadvantages of THRIVE or other nasal oxygenation techniques is that there is no way to measure CO₂ levels, and an obstructed airway may go unnoticed causing the CO₂ to rise to dangerous levels. Although no study has described hypercapnia-associated side effects with the use of THRIVE, even with transient hypercapnia to the range of 115 mmHg,^[22,33] it may still be deleterious in certain patient groups like the ones with raised ICP. It may be worthwhile to identify patients at risk of airway obstruction such as obstructive sleep apnoea which might limit the efficacy of THRIVE and where SJOV might be a better option for oxygenation.

COMPLICATIONS

There is a pertinent risk of aspiration in anaesthetised patients secondary to the unsecured airway with the use of SJOV. Gastric insufflation may happen with SJOV as high flow of oxygen enters the stomach especially if the nasal tube is not aligned with the airway, but currently, no study has reported it.^[10] Liang *et al.* did not find any change in the gastric antrum area and stomach volume after the use of SJOV through WNJ tube in 34 obese patients undergoing hysteroscopy despite the use of 30 psi pressure for jet ventilation.^[21] Theoretically, SJOV can also cause barotrauma, however, studies have not found any evidence of it.^[9-11,28]

Barotrauma develops due to rise in airway pressure as a jet of air enters a closed tissue compartment. There is a minimal chance of such a rise in the airway pressure during SJOV due to the presence of an open and patent airway which releases the excess pressure via the tube, mouth and nose. A similar absence of barotrauma has also been seen with THRIVE despite continuous flux of high-flow oxygen.^[25] On the contrary, both BMV and ventilation through LMA carry the risk of barotrauma and gastric insufflation in-case excess pressure is applied or due to improper positioning.

The risk of trauma to the airway is also higher with SJOV as WNJ tube is passed through the nose, it may cause nasal bleeding. The incidence varies from 2 to 16%,^[10,13] although the recent approach of using WNJ tube in the oral cavity may minimise this risk.

SJOV delivered using the traditional jet injector which does not have a provision to humidify dry gases could lead to side effects such as mucosal drying, headaches especially with flows above 15 L min⁻¹. Qin *et al.* found the risk of dry mouth to be 1.6% and 9% at 1 min and 5 min after starting SJOV.^[10] SJOV can also cause sore throat.^[11,19] However, the modern jet ventilators can warm and humidify the injected air, which may reduce the risk of these side effects associated with prolonged use of SJOV. In contrast to SJOV or conventional apnoeic oxygenation, humidification of supplied gases is possible with the use of THRIVE, FMV and SAD, thus obliterating the side effects of dry gases. In addition, this warm and humidified air also maintains body temperature intraoperatively.^[34]

LIMITATIONS

Unlike FMV, SAD or THRIVE, SJOV has been studied in limited clinical scenarios encompassing only adult patients. In addition, their role in patients with altered airway anatomy such as head and neck cancer patients is yet to be evaluated.

SUMMARY

SJOV is a novel minimally invasive supraglottic jet ventilation technique that can efficiently maintain oxygenation and ventilation in spontaneously breathing and apnoeic patients under anaesthesia. SJOV-WNJ can be used as a rescue airway device for both ventilation and for emergent airway access. Common side effects include dry mouth and nasal bleeding. However, larger studies in different clinical settings are required to further evaluate the efficacy and side effects of this novel oxygenation and ventilation technique.

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Conflicts of interest

There are no conflicts of interest.

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