ISSN: 2755-9858

Journal of Otolaryngology Research & Reports

Case Report

Open Access

Application of Various High-Frequency Ventilation Techniques during Surgical Procedures on the Larynx and Trachea

Alexander Aloy

MD, Institute of Fluid Mechanics and Heat Transfer, TU Wien, Austria

***Corresponding author**
Alexander Aloy, Institute of Fluid Mechanics and Heat Transfer, TU Wien, Austria E-mail: alexander@aloy.at.

Received: April 17, 2024; **Accepted:** April 23, 2024; **Published:** April 30, 2024

Background

Surgical procedures on the larynx and in the trachea pose a special problem for the surgeon and the anaesthetist. Both require access to the larynx. Different ventilation techniques have therefore been developed for a long time to provide the surgeon with optimal working conditions and the anaesthetist with the possibility of safe ventilation. Techniques that could apply the ventilation gas via a nozzle have been established. Special catheters or jet needles were developed for this purpose.A new generation of ventilators was then developed that could simultaneously apply two gas flows with different frequencies. The transcricoid approach thus offers the surgeon optimum conditions with no movement of the vocal cords [1]. Ventilation using two jet nozzles built into the surgical endoscope (superimposed high-frequency jet ventilation) is also an advance. The range of applications for these techniques has expanded considerably. Nevertheless, the physical processes associated with these techniques are often still not clear [2]. The behaviour of the jet gas is often unclear, as it is not visible. However, its effects are recognisable and measurable [3]. These physical processes as well as the indications and contraindications for all these high-frequency ventilation techniques will be clearly described in this paper.

Basics of Jet Ventilation - Physical Mechanisms

In principle, there are some special terms for jet ventilation that apply to all jet techniques.

1. These are: Behaviour of the gas flow: When the gas jet exits a nozzle, a turbulent free jet with special properties is created

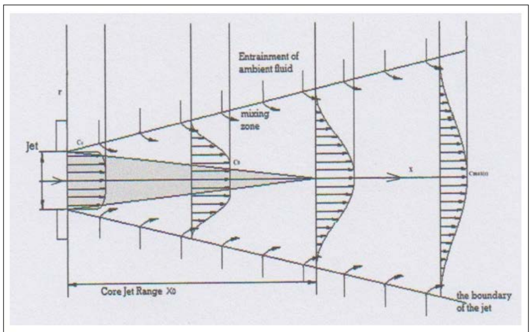

Figure 1: The Free Jet Character of the Jet Gas Creates an Entrainment of Room Air in the Edge Zone of the Jet Stream. Velocity Decreases Hyperbolically with Increasing Axial Distance from the Nozzle Opening

2. Venturi effect is a suction of the jet gas in the area of the nozzles. Venturi described this effect but Bernoulli mathematically formulated it (Formula 1.) [2]

(Formula 1.) $$p_1 + \varrho \cdot v^2{}_1/2 = p_2 + \varrho \cdot v^2{}_2/2$$

If the gas exits the nozzle at high pressure and the pressure decreases, the velocity increases according to the formula and if the pressure falls below atmospheric pressure, the surrounding air is sucked in.

3. **Joule Thomson Effect:** increase in volume of the gas after the nozzle leads to a cooling of the gas. Humidification and heating of the jet gas is necessary.
4. **Oscillations:** oscillations can superimpose each other. Oscillations of different frequencies can be superimposed.

Types of Jet-Ventilation

Low Frequency Jet-Ventilation

Gas is applied at a low frequency (12-20/min) with high pressure and a narrow nozzle. Low-frequency jet ventilation alone is hardly used any more.

High Frequency Jet-Ventilation

Gas is applied at a high frequency (60-100-800/min).Common technique for surgery. Problem: reduced CO_2 elimination at high frequencies.

Combined High Frequency Jet-Ventilation

Simultaneous application of low frequency and high frequency jet ventilation by separate nozzles. The simultaneous use of a larger tidal volume along with the high-frequency oscillations solves the problem of CO_2 elimination.

Superimposed High Frequency Jet Ventilation (SHFJV)

Combined high frequency jet ventilation was used for the first time in a patient population with lung failure [4]. Two ventilators with different ventilation frequencies were used. Superimposed high-frequency ventilation corresponds to combined high frequency jet ventilation. However, two jet gas ventilation frequencies are now applied by one ventilator. This technique has been termed superimposed high frequency jet ventilation (SHFJV). This technique was developed for laryngotracheal surgery. SHFJV was prospectively studied in 1515 consecutive patients (including 158 children requiring laryngotracheal surgery) [5,6]. There were no complications. It provided optimal working conditions for laryngotracheal surgery, including its use for laser surgery and stent implantation. Subsequently, it was also used for interventional bronchoscopy. Ongoing improvements were made to the jet tubes (jet laryngoscopes) and the respirator (Twinstream) used for this purpose.

Superimposed jet ventilation uses two jet gas streams which are administered via a special jet endoscope. A special respirator was developed for this purpose, which generates these jet gas streams simultaneously (Figure 2) [7-9]. A low-frequency and a high-frequency jet stream are used simultaneously (Figure 3). These jets are applied via an open system.

Jet Ventilator for Combined High Frequency Ventilation

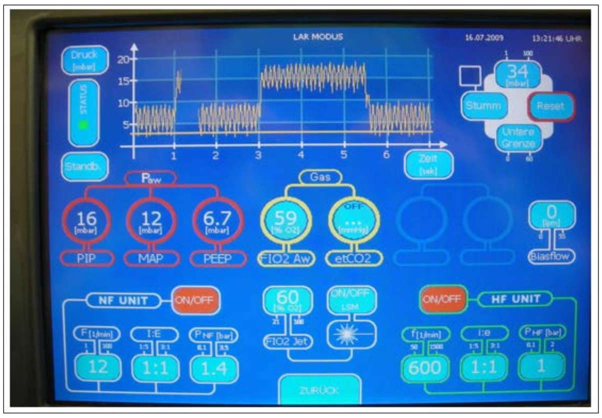

Figure 2: This image shows the screen of the respirator. At the top you can see the low and high frequency jet ventilation. An upper pressure plateau can be seen. Here, high-frequency jet pulsations are superimposed on the low-frequency jet ventilation. The lower pressure plateau is generated by the high-frequency pulsations alone. Below left you can see the measured ventilation pressures. At the bottom left you can see the setting parameters for the low frequency jet ventilation (NF unit) at the left and at the right for the high frequency jet ventilation. At the bottom centre you can see the automatic FIO_2 reduction when the laser is used.

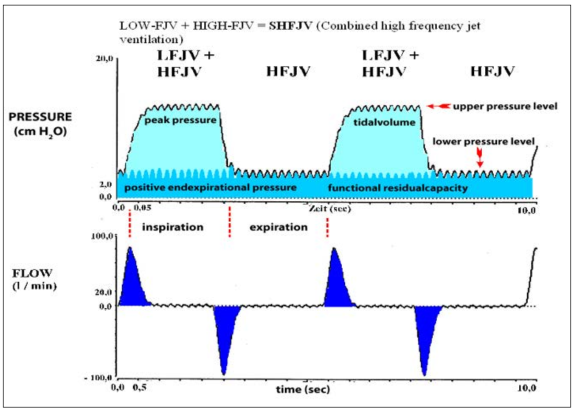

Figure 3: The illustration shows the pulsating pressure curves for low-Frequency and High-Frequency Ventilation

Low-frequency jet ventilation (LFJV) generates an upper pressure plateau and displays the superimposed high-frequency jet gas impulses. High-frequency jet ventilation (HFJV) alone generates a positive end-expiratory pressure.

Modified Jet Laryngoscope

This tube-free jet ventilation was and is carried out with these endoscopes [10,11]. A special jet endoscope (laryngoscope) with two integrated jet nozzles was developed (Figure 4) to administer the two jet gas jets and then extended by a necessary gas monitoring system.

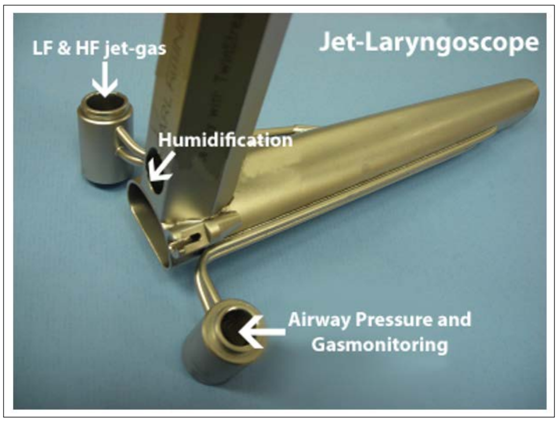

Figure 4: On the left side of the Jet laryngoscope is the connection for the simultaneous administration of low and High Frequency Jet Gas. In the centre of the handle there is a connection for the administration of heated and humidified gas. On the right is the connection for measuring the airway pressure at the tip of the endoscope and for measuring the end-expiratory pCO_2

Subsequently, the flow behaviour of the respiratory gas (Figure 5) during superimposed high frequency jet ventilation (SHFJV) via the jet laryngoscope was also investigated using computational fluid dynamics (CFD analysis) [12].

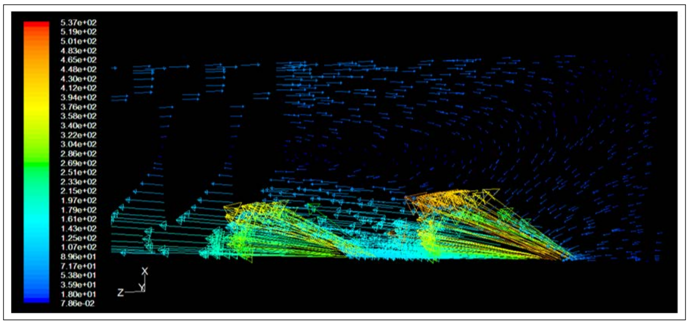

Figure 5: Vector field of the velocity in the region of the two nozzles (m s−1). The typical shape of the expansion of the high-frequency free jet (left) and low-frequency (right) free jet can be seen.

It can be seen that there is a simultaneous flow in both directions during inspiration to the left and expiration to the right.

Indication List for all Jet-Ventilation Techniques

The main indication for all Jet-Ventilation techniques is the optimization of the surgical conditions:

- Expected Difficult Airway
- Selected surgical procedures
  - On the Larynx-Glottis
  - Laryngo-Stenosis/ Subglottic-Stenosis
  - Trachea-Stenosis-Stenting
  - Tracheotomy

Surgeon's Wishes for Endoscopic Laryngeal and Intratracheal Procedures

- A lot of space
- No barotrauma
- Safe application of the laser
- No risk of fire
- No risk of explosion

These whishes can be fulfilled under the following conditions: No plastic material, no nitrous oxide, reduced oxygen concentration (40%).

Infraglottic Jet Ventilation with Catheter Techniques

There are numerous industrially manufactured jet catheters. However, the diameter of these catheters often becomes larger and larger due to the additional lines that are often installed for measurements. This reduces the space available for the surgeon and the advantages of a thin catheter are lost. Especially as the catheters are often not absolutely safe when using a laser. Transtracheal jet ventilation via puncture of the cricothyroid membrane is another common technique that provides optimal working conditions for the surgeon. The successful application of this technique was described in a review of an audit of 90 patients [13]. A total of 12 complications occurred in 12 patients, which were described as minor. However, it has been established for this method that the gas outflow must be guaranteed. Obstruction of the gas outflow can be disastrous. A study investigating different ventilation techniques for endoscopic laryngeal surgery over a 10-year period found that transglottic jet ventilation had the highest complication rate [14]. The cases of complications were: transtracheal jet ventilation 265, transglottic jet ventilation 469, apnoeic intermittent ventilation 159 and controlled mechanical ventilation with endotracheal tube or laser-safe tube 200. 1093 patients were analysed. The authors believe that the vigilance of anaesthetists to assess airway obstruction is the best prevention of complications from these ventilation techniques, such as barotrauma.

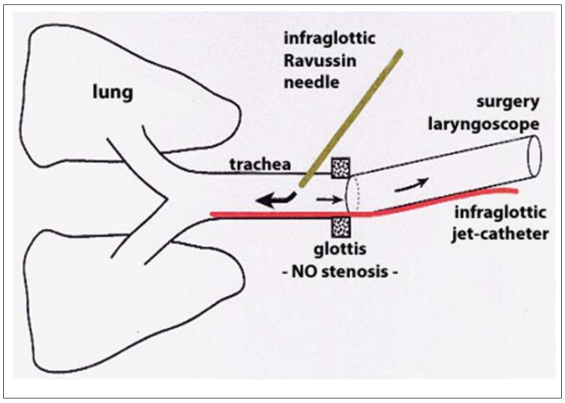

Figure 6: Infraglottic Jet-Ventilation - No Stenosis

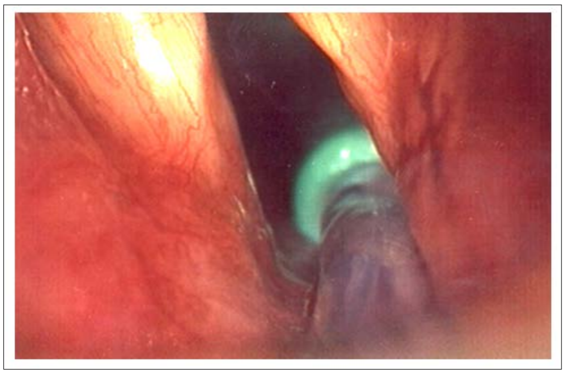

Figure 7: Transglottic Jet Catheter: Elective Surgical Procedure

Figure 8: Ravussin needle for emergency and elective surgical procedures (TTJV)

Infraglottic Jet-Ventilation with Stenosis

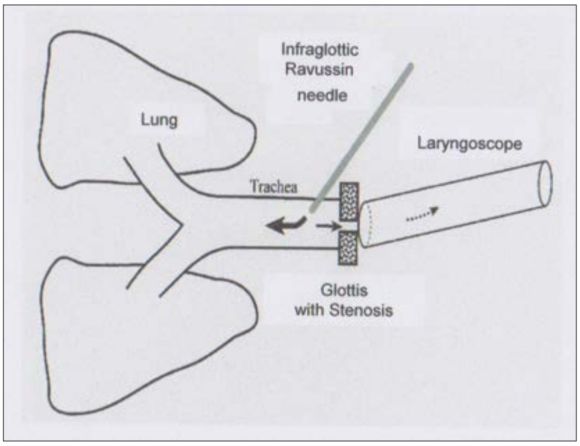

Figure 9: The gas should be able to flow through this stenosis during expiration, so that no barotrauma can occur

Ventilation Settings for Infraglottic Jet Ventilation with Stenosis

Frequency	high
Inspiration Time	short
Expiration Time	long
Driving Pressure	low

see if the chest rises (inspiration) and - which is most important - if it lowers during the expiration phase. If the chest doesn´ t lower, you must stop the ventilation immediately!

Possible Complications of the Transtracheal Catheter Jet Ventilation

General Complications

- Barotrauma
- Subcutane Emphysema
- Pneumomdiastinum
- Puncture of the Oesophagus with overexpansion of stomach
- Hematoma

Superimposed High-Frequency Jet Ventilation for Stenoses

The use of SHFJV in laryngotracheal stenoses is a frequently discussed question (Figure 10). We have experimentally proven that it is not possible to create barotrauma with SHFJV [15]. With SHFJV, the jet gas is applied above a stenosis (Figure 11). As our results of the CFD analyses show (Figure 12, Figure 13), the pressure behind a stenosis is always lower than in front of the stenosis when the SHFJV is used. It is also possible to ventilate difficult forms of stenosis. Our clinical results also show that the SHFJV is suitable and indicated for the surgical removal of stenoses [16-18].

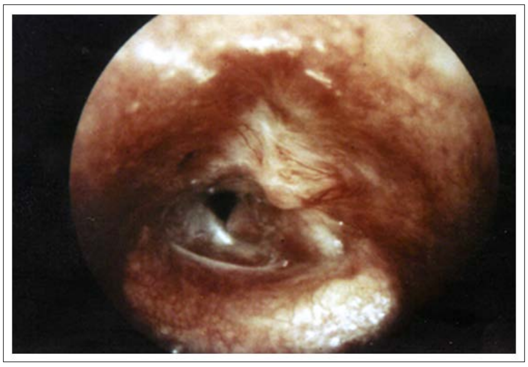

Figure 10: Difficult Airway: Subglottic Stenosis- Indication for SHFJV, The use of a jet catheter is not possible

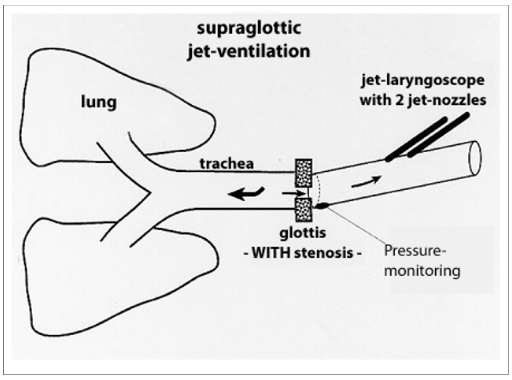

Figure 11: Supraglottic Jet-Ventilation with Stenosis

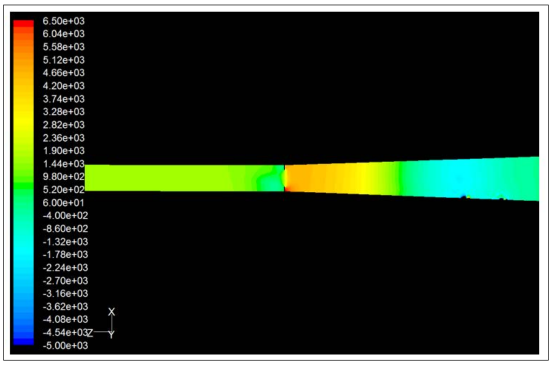

Figure 12: Pressure Distribution in the Jet laryngoscope in case of Stenosis- CFD-Analysis

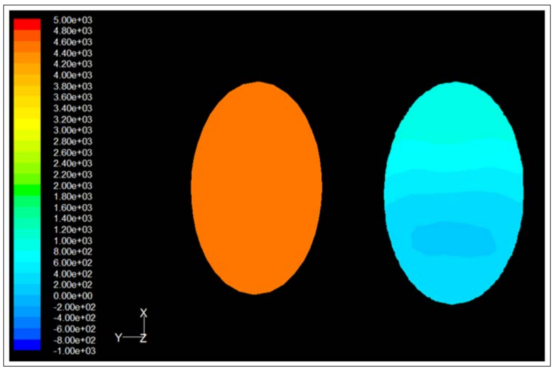

Figure 13: Pressure before and after a stenosis in the Jet-laryngoscope

Pressure distribution: note the backpressure in front of the stenosis – right

Comparison of the pressure before (left) and after (right) the stenosis

Ventilation Settings for Supraglottic Jet Ventilation with Stenosis

Frequency	high
Inspiration Time	long
Expiration Time	short
Driving Pressure	high

The aim is to achieve a sufficiently high pressure behind the stenosis

Transtracheal Jet Ventilation and Superimposed Jet Ventilation in Children

Transtracheal jet ventilation can also be performed successfully in children with severe laryngeal obstructions. Ravussin, for example, reported on the successful operation of a severe laryngeal obstruction in 2 children [19]. Depierraz reported on the successful treatment of 28 operations [20]. There were 3 complications: 1 x emphysema, 1 x pneumothorax - lack of pressure monitoring, 1 x vagal circulatory reaction; all complications were resolved. Over a period of 12 years, superimposed jet ventilation was performed on 198 children. Special paediatric jet laryngoscopes are available for children. The smallest child was 2 weeks old. Indications were: Inspections, surgical interventions, laser surgical interventions. There were no major complications. Minor complications - moderate hypercapnia. Tang et al. also describes in a case report the successful application of SHFJV in a 3-year-old child with congenital subglottic stenosis [21]. TIVA was performed with propofol and remifentanil.The advantages of the SHFJV for laryngotracheal procedures in infants and children are the optimal visibility of the larynx and trachea as well as the maximum space available. This means that the laser can be applied during FIO_2 reduction without risk and without a time limit and is particularly suitable for stenoses [22,23]. However, severe airway stenosis is not a contraindication for supraglottic SHFJV, but surgical and anaesthesiological teams must be prepared to switch to alternative ventilation techniques in these cases [24].

Rigid Bronchoscopy and Stent-Applikation

Rigid bronchoscopy is an established procedure for interventional procedures. The combination of superposed high-frequency jet ventilation with a special jet bronchoscope results in excellent visibility and room conditions. In addition to the connections for the jet gas, the bronchoscope developed for this purpose also has connections for airway pressure measurement (peak pressure and PEEP) and for gas analysis ($etCO_2$,FIO_2). Ventilation is continuous without a time limit as it is a system that is open to the outside. A window is not necessary. Already in the first applications of endoluminal stenting with SHFHV, we were able to show that this method offers advantages for both the surgeon and the anaesthetist [25,26]. All commercially available stents (Figure 14) can be applied trough the jet laryngoscope. Further studies have shown that ventilator-associated complications such as barotrauma, hypercapnia and hypoxaemia have not occurred. In a recent multicentre prospective randomised control trial of superimposed high-frequency jet ventilation (SHFJV) and conventional high jet ventilation (CHFJV) with catheters during interventional bronchoscopy, the authors concluded that SHFJV is effective and safe during interventional bronchoscopy. The SHFJV can provide more effective and stable ventilation than

CHFJV in cases with long procedure times [27].

Figure 14: Endoluminal Stenting with an Expandable Stent

Advantages of the Superimposed High Frequency Jet Ventilation (SHFJV)

- Use of the laser: none of the known laser complications can occur
- There is no age limit for ventilation. there is no time limit.
- Use for high-grade stenosis
- Optimal working conditions for the surgeon. No constriction of the operating area
- Safe oxygenation and CO_2 elimination
- The high-frequency respirator has the same modern control mechanisms as a normal respirator. Total intravenous anaesthesia (TIVA) is performed (Remifentanil, Propofol).
- No anaesthetic gases are used

KI: Impossibility to adjust the endoscope - In this case, the SHFJV cannot be used.

Complications associated especially with supraglottic jet ventilation
Insufficient Oxygenation
Hypercapnia

Conclusion

Our results show that each jet technique has weaknesses and strengths. The difficulties of tranlaryngeal techniques often lie in the user's experience with puncture techniques. When applying transglottic catheters, it should be borne in mind that they are not absolutely laser-safe for laser surgery. As the diameter of the catheter increases, the advantage of maximising the space available for the surgeon is lost.They cannot be used for endoluminal splinting - stent application. Similarly, catheters placed trans-laryngeally are not suitable for infants. In a recent retrospective study, 224 patients were analysed to determine the predictors of failure of supraglottic superposed high frequency jet ventilation [28]. The authors came to the following conclusions: No serious complications occurred during SHFJV. Barotrauma, subcutaneous emphysema, endotracheal burn and death did not occur. Ventilation is also possible with pulmonary pathology. The probability of conversion is higher in patients with obesity and a higher BMI. There was no statistical evidence of conversion in patients with high-grade stenoses. The use of the CO_2 laser makes it possible to use the SHFJV when the oxygen concentration is reduced to 40 % and it is not necessary to switch to an alternative ventilation technique. Upper airway surgery is feasible in the majority of patients. Nevertheless, a critical assessment of both the pathophysiology of the local situation and the planned ventilation technique must be carried out for each procedure.

References

1. Barnes Richard K, Au Jonathan (2021) Transtracheal jet ventilation in a general tertiary hospital: A 7-year audit. Anaesth Intensive Care 49: 316-321.
2. Sigloch H (2012) Technische Fluidmechanik. Springer Verlag, 8 Auflage https://link.springer.com/book/10.1007/978-3-642-22845-2.
3. Ihra G, Aloy (2000) A On the use of Venturi`s principle to describe entrainment during jet ventilation. J.Clin.Anesth 12: 417-419.
4. El-Baz N, Faber LP, Doolas A (1983) Combined high-frequency ventilation for management of terminal respiratory failure: a new technique. Anesth Analg 62: 39-49.
5. Lanzenberger-Schragl E, Donner A, Grasl MC, Zimpfer M, Aloy A (2000) Superimposed high-frequency jet ventilation for laryngeal and tracheal surgery. Arch Otolaryngol Head Neck Surg 126: 40-44.
6. Rezaie-Majd A, Bigenzahn W, Denk DM, Burian M, Kornfehl J, et al. (2006) Superimposed high-frequency jet ventilation (SHFJV) for endoscopic laryngotracheal surgery in more than 1500 patients. British Journal of Anaesthesia 96: 650-659.
7. Aloy A, Schachner M, Cancura W (1990) Tubuslose translaryngeale superponierte Jet-Ventilation. Der Anaesthesist Band 39: 493-498.
8. Aloy A, Schachner M, Cancura W (1991) Tubeless translaryngeal superimposed jet ventilation.Eur. Arch. Otorinolaryngol 248: 475-478.
9. Kraincuk P, Kepka A, Ihra G, Schabernig C, Aloy A (1999) A new prototype of an electronic jet-ventilator and its humidification system. Crit Care 3: 101-110.
10. Aloy A, Donner E, Lanzenberger E, Kashanipour (1996) A Low-Frequency and High-Frequency Jet Ventilation. Technical basics and special considerations for clinical application in various area Acta Anaesthesiol.Scand Supp l109: 147-149.
11. Bacher A, Pichler K, Aloy A (2000) Supraglottic combined frequency jet-ventilation versus subglottic monofrequent jet ventilation in patients undergoing microlaryngeal surgery. Anesth Analg 90: 460-465.
12. Aloy A, Schragl E, Neth H, Donner A, Kluwick A (1995) Strömungsverhalten des Atemgases bei superponierter Hochfrequenz-Jet-Ventilation (SHFJV) über das Jet-Laryngoskop. Anaesthesist 44: 558-565.
13. Russell WC, Maguire AM, Jones GW (2000) Cricothyroidotomie and Transtracheal High Frequency jet ventilation for Elective Laryngeal Surgery an Audit of 90 cases. Anaest. Intensive Care 28: 62-67.
14. Jaquet Y, Monnier Ph, Van Melle G, Ravussin P, Spahn DR, et al. (2006) Complications of Different Ventilation Strategies in Endoscopic Laryngeal Surgery. A 10-year Review. Anesthesiology 104: 52-59.
15. Hell Simon (2011) Analysis of the flow conditions in a laryngoscope using Fluent. Biofluid mechanics project work. Institute of Fluid Mechanics and Heat Transfer, Vienna University of Technology.
16. Schragl E, Donner A, Grasl MC, Kashanipour A, ALoy A (1995) Beatmung während einer Tracheotomie bei langstreckiger, 90%iger laryngealerStenose mettles superponierter Hochfrequenz Jet-Ventilation über das Jet-Laryngoskop. Laryngo-Rhino-Otol 74: 223-226.
17. Aloy A, Kimla T, Schragl E, Donner A, Grasl M (1994) Tubuslose superponierte Hochfrequenz-Jet-Ventilation (SHFJV) bei hochgradigenaryngeale Stenosen. Laryngo-Rhino-Otol 73: 405-411.
18. Schragl E, Donner A, Kashanipour A, Gradwohl I, Ullrich R, et al. (1994) Anaesthesie bei akuter Atemwegsobstruktionen

infolge hochgradiger laryngealer und tracheobronchialer Stenosen. Anaesthesiologie-Intensivmedizin-Notfallmedizin-Schmerztherapie 29: 269-277.
19. Ravussin P, Bayer-Berger M, Monnier P, Savary M, Freeman J (1987) Percutaneous transtracheal ventilation for laser endoscopic procedures in infants and small children with laryngeal obstruction: report of two cases. Can J Anaesth 34: 83-86.
20. Depierraz B, Ravussin P, Brossard E, Monnier P (1994) Percutaneous transtracheal jet ventilation for paediatricendoscopiclaser treatment of laryngeal and subglottic lesions. Can J Anaesth 41: 1200-1207.
21. Tang MM, Xu Z, Ren J, Zou J, Chen G (2022) Superimposed high-frequency jet ventilation used for endolaryngotracheal surgery in a child with congenital subglottic stenosis: a case report. Transl Pediatr 11: 2057-2062.
22. Grasl MC, Donner A, Schragl E, Aloy A (1997) Tubeless Laryngotracheal Surgery in Infants and Children via Jet Ventilation. The Laryngoscope 107: 277-281.
23. Ihra G, Hieber C, Adel S, Kashanipour A, Aloy A (2000) Tubeless combined high-frequency jet ventilation for laryngotracheal surgery in paediatric anaesthesia. Acta Anaesthesiol Scand 44: 475-479.
24. Plate CH MA, Krenz G, Molenbuur B, Dikkers FG, Eindhoven GB, et al. (2020) Predictors for failure of supraglottic superimposed high-frequency jet ventilation during endoscopic upper airway surgery in pediatric patients. Pediatric Anesthesia 30: 1041-1043.
25. Aloy A, Donner A, Strasser K, Klepetko W, Schragl E, et al. (1994) Jet ventilation superimposed on a special jet laryngoscope for endoluminalstent insertion in the tracheobronchial system (Article in German). Der Anaesthesist 43: 262-269.
26. Klepetko W, Müller MR, Grimm M, Aloy A, Kashanipour A, et al. (1991) Endoluminal Stenting of tracheobronchial system.Endoluminale Schienung (Stenting) bei Stenosen des Tracheobronchialsystems. Acta Chirurgica Austriaca, Heft 3/ 23 Jahrgang 124-129.
27. Wang T, Yinghua Pei, Xiaojian Qiu, Wang J, Wang Y, et al. (2022) multi-centre prospective random control study of superimposed high-frequency jet ventilation and conventional jet ventilation for interventional bronchoscopy. Ear Nose Throat J 11: 14556132210944441.
28. Halmos GB, Plate CH MA, Krenz G, Molenbuur B, Dikkers FG, et al. (2020) Predictors for failure of supraglottic superimposed high-frequency jet ventilation during upper airway surgery in adult patients; a retrospective cohort study of 224 cases. Clin Otolaryngol 45: 253-258.

Copyright: ©2024 Alexander Aloy. This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.