

C-01 Jet Ventilation During Laryngeal Surgery With Laser in Patients With Tracheal Stenosis

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Objective

After completion of this session, the participant will be able to:

- Categorize the steps in the management of complications of jet ventilation.

Case Stem Question

A 46 year old male with a history of asthma, obesity with a BMI of 34, hypoxic respiratory failure in the setting of COVID in 2021 resulting in a prolonged intubation with subsequent tracheostomy presents for direct microlaryngoscopy, tracheoscopy, balloon dilation of the trachea, and CO2 laser resection of granulation tissue. The patient was decannulated shortly after the tracheostomy and developed tracheomalacia with tracheal stenosis that has continued to recur requiring multiple interventions.

Guiding Questions for Discussion

What information would you like preoperatively to assess this patient's clinical picture?

How would you evaluate this patient's severity of tracheal stenosis?

Both subjective and objective information provided may aid in determining the severity of this patient's condition. Subjectively, the patient can determine whether or not they are able to lay flat without any difficulty breathing, or if they are limited in their positioning as well as exercise tolerance, particularly over a certain period of time without any other variables limiting their capacity. Objectively, the ENT team may provide any images or videos of a flexible scope exam of the airway, a CT or MRI that may have measurements of the degree of stenosis, and potentially PFTs to analyze the degree of obstruction. It is important to recognize that although the stenosis may be relatively fixed compared to a significant soft tissue obstruction, imaging such as a CT or MRI may exhibit dynamic changes that may not adequately reflect their true level of obstruction at present or may overestimate the severity.

Would this patient's body habitus preclude him from being a candidate for jet ventilation?

While obesity may increase the risk of airway obstruction preventing passive exhalation, egress, and an expected decreased chest wall expansion, it has been safely reported in many institutions doing jet ventilation in a controlled setting on morbidly obese patients⁶. Despite the increased challenges presented with jet ventilation, this patient's fixed subglottic stenosis would be the primary challenge. However, great attention needs to be given to maintaining patency of the airway and reducing obstruction of soft tissue if beginning to jet ventilate, possibly doing so while already in suspension laryngoscopy or with an oral airway, supraglottic devices, or other airway device.

What are contraindications to jet ventilation?

While there are no absolute contraindications to jet ventilation, some pathologies or

circumstances may make high frequency jet ventilation (HFJV) unsafe, not feasible, or quite challenging. These relative contraindications include complete upper airway obstruction, particularly if exhalation would be difficult or impossible, a foreign body in the airway, severe aspiration risk, severe obstructive lung disease, and morbid obesity, which as discussed above, has been safely documented although may be challenging^{3,6}.

What equipment would you use in airway management for this case?

Equipment related to jet ventilation is varied depending on institutional availability. In some cases, a manual handheld jet ventilator with a gas mixer for both oxygen and air would suffice, however, it lacks the automation and safety mechanisms such as gas supply failure, FiO₂ levels, and an automatic stop on elevated pressures that are present in other jet ventilators. See discussion at the end of the case regarding settings and parameters.

Other equipment that would be necessary for this procedure are laser-safe tubes of appropriate size, whether planning for intubation or as backup. Examples include the flexible laser tubes and laser tubes with wrapping or shield.

If planning for subglottic jet ventilation, a catheter to intubate with that connects to the primary delivery of the ventilator of use would be required. We previously used a catheter that had self-centering cage-like wings on the end. However due to supply constraints, we now use dual lumen jet catheters.

When using automated jet ventilators, it is important to have a backup manual jet ventilator in case of equipment failure.

Other anesthetic planning would benefit from a total intravenous anesthetic given the multitude of airway techniques with the possibility of no endotracheal tube in delivering a volatile anesthetic.

The patient is brought into the operating room and placed on standard ASA monitors. Room air saturation is 96%.

How would you proceed with induction?

There are many approaches to induction of general anesthesia in this patient with concern for the ability to ventilate and intubate. One study shows that despite more severe subglottic stenosis, there is not an association with greater difficulty in mask ventilation with the appropriate use of adjuncts/airway management techniques⁷. With the understanding that unless near complete stenosis, and the likelihood of being able to ventilate via the fixed stenosis as opposed to a mobile soft tissue mass (i.e. ball-valve effect), a standard induction of anesthesia with propofol, attempted mask ventilation, and subsequent neuromuscular blockade would be safe. Adjuncts to blunt laryngeal reflexes such as intravenous lidocaine or a short acting narcotic such as remifentanyl may provide better airway conditions.

Would it be possible to keep this patient spontaneously breathing for this procedure?

It is certainly feasible to maintain spontaneous respiration with a gentle induction of general anesthesia in order to confirm adequate air passage/ventilation prior to neuromuscular blockade or apnea for an attempted intubation. The patient is likely to hypoventilate while spontaneously breathing and may not tolerate subglottic jet catheter

placement or suspension laryngoscopy, at which point it is most optimal for the patient to be given neuromuscular blockade or an agent such as remifentanyl to optimize airway conditions.

The surgeon states that he would like to do the procedure without any endotracheal tube or catheter present in the airway for optimal visualization with dilation and laser. He states he routinely does so with high flow nasal cannula oxygen to maintain adequate oxygenation. How would you proceed?

Although controversial and there are documented cases of doing so, there are significantly elevated risks of doing this laser procedure on 100% FiO₂. At our institution, we have agreed that it is safest to avoid doing so and agree not to do laser cases with 100% FiO₂ via HFJV. The controversy is that despite not having any “flammable” device in the airway, specifically an endotracheal tube during supraglottic jet ventilation, the soft tissue that becomes charred from the laser can further be fuel for a catastrophic airway fire.

Further development of intraoperative use of high flow nasal cannula (HFNC), particularly for laryngeal surgery, has allowed for excellent “apneic oxygenation”. There is debate on the extent of effective gas exchange as ventilation, but likely some component of improved washout of CO₂ and improved O₂ reserves, similar to HFJV. However, physiologically similar conditions with HFNC are found compared to HFJV without the risks and complications associated with further airway management, which may be optimal for short direct microlaryngoscopy cases without laser. If this case proceeded otherwise with a plan for steroid injections as opposed to laser, HFNC would be a strong feasible option.

What are the required components for a fire intraoperatively?

In order to create a fire, the trifecta required is a fuel source, an ignition, and an oxidizer. Fuel can be anything that would remain ablaze or stimulate a fire, typically anything from surgical drapes, towels, endotracheal tubes, tape, alcohol-based prep solutions such as chlorhexidine and Iodine povacrylex with Isopropyl alcohol. An oxidizer would be oxygen, particularly at higher FiO₂, and nitrous. Ignition sources are typically monopolar cautery, laser, or fiber optic light sources. It is important to note that large chlorhexidine applicators should not be used on the head and neck due to pooling by the neck and soaking of the hair that can take up to an hour to dry, and soak into surgical drapes increasing the risk for a fire significantly with an electrocautery source present. This is why most ENT procedures are done with a non-alcohol based prep such as povidone-iodine.

The most common combination of circumstances for intraoperative fires based on closed claims analysis are MAC cases with an open oxygen source (nasal cannula, face mask), in procedures close to the head and neck, or above the xiphoid process, with an ignition source such as cautery or laser, present. As such, the greater use of high flow nasal cannula intraoperatively may present a higher risk of fire requiring greater vigilance^{4,5}.

What other considerations would you have to reduce the risk of airway fire during this laser procedure?

One could designate a specific team member to ensure safety of the laser equipment, as well as removal of electric ignition sources from the field when appropriate. Towels that are fuel could be moistened on the field. Eyes can be covered with moistened gauze, as well as using silk tape or copper foil that is less caustic compared to typical plastic tape used to protect the eyes or secure the endotracheal tube. A timeout may be done or close communication between the anesthesia provider and surgeon to clarify what the FiO₂ is when electrocautery is to be used. Saline or sterile water should be available on the field particularly for airway procedures^{4,5}.

How would you proceed if an airway fire was experienced intraoperatively in this procedure?

While it is debated on what step should be taken first, it is likely that multiple steps to ensure safety and minimizing damage are done simultaneously. However, we would recommend, as feasible, to simultaneously stop the flow of all gas and remove the endotracheal tube, which may present a blowtorch effect if still connected to high flow oxygen when removed. Doing so quickly may minimize the damage to the airway. This may be followed with pouring saline/water down the airway to extinguish any further fire, and reestablish control of the airway as feasible, assessing for the damage done⁴. All other fire safety protocols apply.

On completion of the procedure, a supraglottic device can be placed for emergence to avoid instrumentation of the airway below the glottis. Minimal tidal volumes are able to be delivered via the ventilator with no sustained end tidal CO₂ and minimal chest rise.

How would you proceed with managing this case?

Concern for laryngospasm, can potentially administer lidocaine 4% via the supraglottic device, or deepen the anesthetic with propofol. Furthermore, with a flexible scope/bronchoscope available in the room, one could look down the supraglottic device to see if there is any obstruction of the airway, soft tissue, vocal cords. It is unlikely to be an acute change in the area of the procedure given recent completion of visualization, but one could likely confirm while still in the operating room under anesthesia. Ultimately succinylcholine may be administered with the plan to secure an endotracheal tube, preferably one of a smaller diameter.

The supraglottic device is removed and mask ventilation is successful but requires high peak pressures with tidal volumes of approximately 200ml. The decision is made to intubate the patient in order to secure the airway for a repeat laryngoscopy by ENT to gain hemostasis and evaluate the lesion. Video laryngoscopy shows mild laryngeal and glottic edema with some blood in the airway. You are unable to successfully pass two different types of small diameter endotracheal tubes, but you are able to place the jet catheter with some mild resistance.

What further concerns do you have at this point?

There may be subglottic edema or a lesion preventing passage of an endotracheal tube that may have been exacerbated post procedure. Any reduction in airway diameter may decrease passive exhalation and increase airway pressures. There may be bleeding that may create difficulty with visualization for the surgical team, and the possibility for aspirating blood in the setting of a non-secure airway.

What other complications are known from jet ventilation?

Due to no secure endotracheal tube, aspiration is a possible complication, also potentially exacerbated by stomach insufflation from a possibly misdirected jet. Hypercarbia is likely in the setting of inadequate ventilation or dead space ventilation and passive exhalation. Laryngospasm given instrumentation of the airway without an endotracheal tube can be mitigated with topical lidocaine. Airway obstruction in the setting of relaxed soft tissue under anesthesia may increase risk for lack of exhalation/egress. This may lead to pneumothorax or pneumomediastinum due to barotrauma from stacked breaths and possibly leading to subcutaneous emphysema. Extensive jet ventilation for longer procedures greater than two hours without humidifying the delivery can lead to necrotizing tracheobronchitis due to drying of tissue^{3,6}.

The patient begins to desaturate slowly and you connect the patient to the jet ventilator. The ventilator alarms shortly after beginning and stops, signaling high PIP. You attempt to restart ventilation with subsequent alarms again. The saturation continues to slowly decrease to 75%. What steps would you take next?

It would be prudent to listen to the patient's breath sounds given the high risk for pneumothorax in this case of airway obstruction and restarting jet ventilation, especially which stopped given a high pressure alarm. In order to prepare for a worsening airway, it may be beneficial to prepare for an emergency tracheostomy given ENT surgeons present and the possibility of not being able to further intubate or ventilate. If there was a rigid bronchoscope present as well, that may also allow for intubation by the surgical team; however, given the time constraints and possibility for a worsening airway, such a technique may be difficult or unsuccessful. While an allergic reaction is unlikely, it may be comprehensive to examine for possible signs of anaphylaxis causing airway compromise or swelling, as well as treat accordingly, including dosing a steroid such as dexamethasone to aid in reducing inflammation.

You hear diminished breath sounds bilaterally on auscultation. Your monitors show a decrease in HR associated with the desaturation, as well as a decrease in end tidal CO₂ from 35 to 26. The blood pressure cuff is unable to cycle appropriately, and radial pulses are difficult to palpate, although a femoral pulse is palpable. You call for help. At this point, the patient has a palpable pulse but is likely hypotensive due to lung overinflation and the associated drop in cardiac output from decreased preload and with bradycardia. You suspect pneumothorax progressing into a tension pneumothorax due to the hemodynamic implications. A colleague of yours prepares for placement of an arterial line.

A team member requests an X-ray be performed stat due to your suspicion. However there is a delay in availability of resources and the X-ray technician does not present with the required equipment. What other resources would you mobilize?

Given the high clinical suspicion of a pneumothorax, a needle decompression would be appropriate, or a provider that is trained in placement of a chest tube would be required immediately. Another quick method of diagnosing a pneumothorax would be a lung scan using an ultrasound⁸. One may be able to quickly pick up lack of lung sliding on the ultrasound at superior lung fields. However, the presence of lung sliding does not rule out a pneumothorax, nor does it rule it in given the sensitivity of the exam. A lung

“point” would rule in a pneumothorax, which is the transition point of lung sliding to none. This would only be absent in the presence of complete pneumothorax, which is possible in this case given the extent of inflation and progression to severe tension pneumothorax.

A needle decompression can be performed with a large bore angiocath or needle. However, it is important to recognize an adequate length needle or catheter is required given this patient’s body habitus. The technique would be perpendicular placement at the midclavicular line of the 2nd intercostal space, making sure to enter above the bottom rib. The rib space may not be clearly palpable, so care should be taken not to puncture too close to the clavicle which could result in injury to the subclavian artery and vein, or below the rib that may injure the intercostal vessels. If pleura is punctured, it is possible to hear a classical “whoosh” of air, or an air leak, via the needle or angiocath.

Needle thoracostomy or decompression is only a temporary solution until a surgical team member is able to place a chest tube(s) as a more stable solution.

The patient’s saturation improves to 96% and is hemodynamically stable after completion of a tracheostomy and bilateral chest tubes. The surgical team states he may clinically benefit from a balloon dilation in hopes for early decannulation of the tracheostomy.

It warrants a further discussion whether or not this patient is stable and can tolerate further airway instrumentation given the events of this procedure. If the patient presents to be hemodynamically stable with control of the airway, it may be appropriate to proceed with a quick intervention if it may improve prognosis based on the surgical team’s expertise. There may be a concern for positive pressure ventilation in the setting of acute pneumothorax, however with chest tube placement there is reduced risk for expansion given appropriate decompression. One should clarify if the tracheostomy placed is below the level of the stenosis, as an intervention should not allow for manipulation or removal of a newly placed tracheostomy/airway. If it is above the level of the tracheostomy, a balloon dilation may be feasible. Of note, if balloon dilation were occurring without an airway or under HFJV, barotrauma may occur with continued positive pressure ventilation without apnea or negative pressure pulmonary edema may occur if spontaneously breathing.

On completion of this case, what is the patient's disposition? Would you take this patient to your PACU? Would you attempt to awaken this patient?

It is likely this patient requires ICU level of care postoperatively and an attempt to awaken the patient should be attempted to assess neurologic status.

Further Discussion

High frequency jet ventilation is a safe technique that may provide optimal surgical conditions such as minimizing patient movement or an unobstructed airway, and possible improvement of respiratory physiology during many procedures, as well as utility in rescue of an unanticipated difficult airway, allowing for a multitude of uses intraoperatively. There may be multiple approaches to these cases and pathologies that may require jet ventilation for airway management cases; however, fundamental knowledge of the equipment and alternative techniques provides for greater patient

safety. Close, effective communication with surgical providers is paramount to a safe and desirable outcome. If a HFJV technique has been attempted or does not seem feasible, it is important to plan for other backup techniques such as intermittent apnea, small endotracheal tubes, or possibly a tracheostomy allowing for similar outcomes. Understanding the possible complications of these techniques and how to manage them are crucial in avoiding poor outcomes.

It may be prudent to provide an in-service amongst anesthesiologists or orientation to your institution's high frequency jet ventilator setup. Settings that can be adjusted are frequency, FiO₂, %IT (inspiratory time), PP limit (pause pressure limit), and DP (driving pressure)².

Basic troubleshooting considerations include ensuring the catheter placed is not obstructed or up against a tracheal wall which may alarm as elevated pressure. Although one is setting the limit for the pause pressure, which reflects the airway pressure prior to the next breath, it does not set the actual pressure delivered. This is just the maximum pressure sensed before the ventilator would alarm and pause. If a patient is experiencing hypoxia with 100% FiO₂, one can improve ventilation to minimize atelectasis by increasing the driving pressure or inspiratory time. A decreased %IT may help decrease air trapping and improve gas exchange, which may also improve with increased driving pressure.²

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