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CASE REPORT

Intraoperative Ventilation Failure Due to a Fenestrated Tracheostomy Tube in a Three-Month-Old Infant with a Laryngeal Mass: A Case Report and Literature Review

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Abstract: Pediatric tracheostomy is a common procedure, with a substantial proportion of cases performed on infants, often due to chronic respiratory failure or complex airway anomalies. This case report details a critical intraoperative event involving a three-month -old infant undergoing tracheostomy for a laryngeal mass. The patient experienced immediate and profound ventilation failure following the insertion of a fenestrated tracheostomy tube. Mechanical obstruction was ruled out by passing a suction catheter through the tube. Furthermore, switching ventilatory modes to pressure-controlled volume-guaranteed (PC-VG) or volume-controlled ventilation (VCV) was also ineffective in restoring adequate ventilation. This was managed using a completely unfenestrated tube. The tube was placed and the breathing circuit connected, a large portion of the air leak was successfully eliminated, and appropriate ventilation parameters were restored. Fenestrated tracheostomy tubes have established benefits in adults; however, this case highlights a cautionary observation in ventilated infants due to potential air leak and ventilatory failure, underscoring careful tube selection.

Keywords: ventilation, fenestrated tracheostomy, infant

Introduction

Airway management in the pediatric population, particularly in infants, presents a unique set of anatomical and physiological challenges that necessitate specialized expertise and careful planning.[1,2]

Congenital or acquired laryngeal and pharyngeal masses, such as the one described in this case, are a significant cause of upper airway obstruction in this age group, often requiring surgical intervention and temporary or long-term tracheostomy to secure a definitive airway.[3]

Pediatric tracheostomy is a common procedure, with a substantial proportion of cases performed on infants, often due to chronic respiratory failure or complex airway anomalies.[4] While life-saving, the procedure is associated with a high rate of complications, which can be broadly classified as early (eg, hemorrhage, accidental decannulation, tube occlusion) or late (eg, granulomas, tracheocutaneous fistula).[5–7] Given the narrow margin for error in an infant's airway, any complication, especially those leading to acute ventilatory compromise, can be life-threatening.[4]

Fenestrated tracheostomy tubes are designed with an opening in the posterior wall of the outer cannula, facilitate airflow through the upper airway to aid phonation, weaning, and decannulation.[8] However, their use is not without potential drawbacks. Issues such as malposition, granulation tissue formation, and air leakage leading to inadequate ventilation have been documented, particularly in the context of chronic respiratory support or decannulation trials.[9] Pandian et al systematically reviewed 13 studies, and found that while phonation was often achieved, complications occurred in 0.9–5% of patients and included oxygen desaturation, shortness of breath, malpositioning, and chest

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discomfort.[10] Despite these known issues, acute, intraoperative ventilation failure immediately following the placement of a fenestrated tracheostomy tube in an infant is a rare and poorly documented event. The unique anatomical constraints of the infant trachea, combined with the specific design of the fenestrated tube, can create a critical air leak pathway that severely compromises mechanical ventilation.[1]

This case report details a critical intraoperative event involving a three-month-old infant undergoing tracheostomy for a laryngeal mass. The patient experienced immediate and profound ventilation failure following the insertion of a fenestrated tracheostomy tube. The subsequent diagnostic and management process, which involved the recognition of the fenestration as the primary source of the massive air leak and the successful resolution through tube exchange, highlights a crucial, yet under-recognized, pitfall in pediatric airway management.

Fenestrated tracheostomy tubes have well-established advantages in adults. They permit upper airway passage of airflow to allow for phonation especially in patients who cannot tolerate a one-way speaking valve. However, there is an evident lack in literature regarding their use in non-phonating infants and whether they have any advantage in this specific patient population.[11]

Accordingly, this report aims to describe a case involving an intraoperative ventilatory complication associated with the use of a fenestrated tracheostomy tube in an infant, and to discuss potential contributing factors leading to this event.

Case Presentation

Patient Information and Preoperative Assessment

The patient was a three-month-old, full-term, 4.3 kg infant diagnosed with a multiseptated mass lesion (2.9 × 3.2×3.0 cm) in the right pharyngeal space. The mass was causing airway compression, and the patient was scheduled for a surgical tracheostomy under general anesthesia.

Upon arrival to the operating theatre, the patient was maintaining spontaneous ventilation on a simple oxygen mask, with an oxygen saturation of 95% and a heart rate of 140 bpm. The tracheostomy was indicated as the first stage of a planned mass excision.

Anesthetic and Initial Airway Management

Anesthesia was induced using sevoflurane, 4 mcg of fentanyl, and an initial dose of 2 mg of atracurium. A size 3.5 uncuffed endotracheal tube was inserted, and pressure-controlled ventilation (PCV) was initiated. The initial ventilation settings were an inspired pressure of 22 cm H_2O and a respiratory rate of 17 breaths per minute, which provided an acceptable minute ventilation of 1.0 L/min. Following the placement of arterial and femoral lines and connection of all monitoring and intravenous lines, the surgical procedure commenced.

Intraoperative Ventilatory Challenge

After the successful creation of the tracheostomy stoma, a size 3.5 fenestrated tracheostomy tube was inserted. A ventilation check was performed, and while end-tidal CO_2 ($EtCO_2$) initially confirmed ventilation (27 mmHg), the reading immediately dropped to 16 mmHg upon connection of the circuit to the tracheostomy tube.

Other ventilatory parameters showed a significant decline, with the minute ventilation dropping drastically to 0.2–0.3 L/min. Auscultation revealed markedly decreased air entry bilaterally compared with the prior endotracheal tube ventilation. Mechanical obstruction was ruled out by passing a suction catheter through the tube. Furthermore, switching ventilatory modes to pressure-controlled volume-guaranteed (PC-VG) or volume-controlled ventilation (VCV) was also ineffective in restoring adequate ventilation.

Intervention

The ventilatory insufficiency was temporarily managed by disconnecting the circuit from the tracheostomy and reconnecting it to the oral ETT, or by manual ventilation with large tidal volumes. An audible leak was detected through the patient's oral cavity. This led to the assumption that a large portion of the ventilated air was escaping through the single fenestration on the tracheostomy tube, causing inadequate ventilation at the set inspired pressure of 22 cm H_2O.

The issue was communicated to the otolaryngologist. Intraoperatively, initial troubleshooting focused on tube size and stoma fit, as the issue was thought to be mechanical rather than related to tube design. The first attempt at resolution involved replacing the tube with a shortened size 4 fenestrated tube, based on the initial assumption that the problem was due to partial blockage of the distal tube by the tracheal wall. This intervention did not resolve the ventilatory failure.

The final, successful intervention was the suggestion by the anesthesia team, who raised the possibility of a fenestration-related leak, to use a completely unfenestrated tube. The smallest available size in the facility was a size 4.5 uncuffed tracheostomy tube, which was subsequently shortened. Once this shortened, uncuffed, unfenestrated tube was placed and the breathing circuit connected, a large portion of the air leak was successfully eliminated, and appropriate ventilation parameters were restored.

Outcome

Following the final tube replacement, the patient achieved adequate ventilation with stable minute ventilation. The patient remained hemodynamically stable throughout the procedure, with no significant intraoperative complications. The immediate postoperative period was uneventful, and the patient was transferred for further monitoring and respiratory optimization.

Discussion

The management of the pediatric airway, particularly in infants, is fundamentally challenging due to distinct anatomical and physiological differences compared to adults.[2] The infant larynx is positioned more cephalad, the epiglottis is omega-shaped and floppy, and the narrowest point of the airway is the cricoid cartilage, rather than the glottis.[4,12] Furthermore, the infant trachea is short and highly compliant, making it susceptible to kinking, compression, and injury from tracheostomy tubes.[13] These factors contribute to the high-risk nature of both endotracheal intubation and surgical tracheostomy in this population.[6]

For infants requiring mechanical ventilation via tracheostomy, the standard of care often involves the use of uncuffed tracheostomy tubes.[14,15] This practice is primarily adopted to minimize the risk of pressure-induced tracheal mucosal injury, which can lead to long-term complications such as tracheomalacia or subglottic stenosis.[16]

The trade-off for using an uncuffed tube is the presence of a physiological air leak around the tube, which is generally tolerated and even desired, as it allows for some passage of air to the upper airway and reduces the risk of excessive pressure buildup.[17]

Fenestrated tracheostomy tubes feature an opening in the posterior wall of the outer cannula, designed to allow air to pass through the upper airway for phonation and to facilitate the weaning process.[8] While they serve a valuable purpose in stable, non-ventilator-dependent patients, their use in the context of mechanical ventilation, particularly in infants, is highly controversial and often discouraged.[9]

The primary concern is the potential for the fenestration to act as a direct, low-resistance vent for the delivered positive pressure.[18] When a fenestrated tube is used without a non-fenestrated inner cannula or an inflated cuff, the positive pressure from the ventilator is preferentially shunted through the fenestration, up the trachea, and out the upper airway. This mechanism results in a massive air leak, which can render the mechanical ventilation completely ineffective. Furthermore, the fenestration itself can be a nidus for granulation tissue formation, which may lead to tube obstruction or bleeding.[8,19]

The primary speech-related indication for fenestrated tracheostomy tubes is inaudible phonation or poor voice intelligibility in patients who cannot tolerate a one-way speaking valve. In a systematic review evaluating the safety and effectiveness of fenestrated tubes in mechanically ventilated patients, Pandian et al reported that the primary indications for tracheostomy in the included studies were chronic ventilator dependence (83%) and airway protection (17%), and that complications included granulation tissue formation (5%), malpositioning (0.9%), decreased oxygen saturation (2.6%), increased peak pressures (1.7%), and air leakage (0.9%), subcutaneous emphysema were also detected.[10] These safety concerns are particularly relevant in the pediatric population. The American Thoracic Society clinical practice guideline on the care of infants and children with tracheostomies has reported that children with tracheostomies are at high risk of significant morbidity and mortality, with rates of in-hospital mortality and

tracheostomy-related complications in the 2 years after tracheostomy placement of 9% and 38.8%, respectively.[20] Furthermore, the Global Tracheostomy Collaborative, reporting on outcomes from more than 6500 patients globally, has identified that tracheostomy-related adverse events account for half of all airway-related deaths and hypoxic brain damage in critical care units. The collaborative identified a previously unrecognized association between bleeding and mortality, and emphasized that successful implementation of quality improvement requires effective training for health professionals, multidisciplinary team collaboration, and engagement and involvement of patients and their families.[21] The case presented, acute intraoperative ventilation failure in a three-month-old infant immediately following the placement of a fenestrated tracheostomy tube, represents a critical, yet preventable, complication that underscores the importance of meticulous tube selection and a deep understanding of airway mechanics in the pediatric operating room.

Notably, this event occurred in the intraoperative setting, which distinguishes it from most similar reports that describe fenestrated tube complications in the intensive care unit. The intraoperative environment introduces additional risks, including the potential for hemorrhage at the tracheostomy site, which is an elevated concern in pediatric patients due to their limited pulmonary reserve and small airway caliber.

The patient's clinical presentation, a sudden and dramatic drop in end-tidal CO_2 (from 27 mmHg to 16 mmHg) and minute ventilation (from 1.0 L/min to 0.2–0.3 L/min), is the hallmark of a loss of circuit integrity.[22] In the differential diagnosis for intraoperative ventilation failure, possibilities include circuit disconnect, tube obstruction (eg, mucus plug, kinking), pneumothorax, or equipment malfunction.[7] However, the key findings in this case, the ability to pass a suction catheter (ruling out obstruction) and the audible, massive air leak through the oral cavity, conclusively pointed to the fenestration as the source of the problem.

The pathophysiology is directly related to the principles of pressure-controlled ventilation (PCV). The ventilator was set to deliver an inspiratory pressure of 22 cm H_2O. With the uncuffed, fenestrated tube in place, the fenestration created a direct, low-resistance pathway from the pressurized trachea to the pharynx and out the mouth.[23]

This shunt prevented the buildup of the necessary driving pressure within the lower airway and alveoli, leading to a profound failure to deliver an effective tidal volume. The initial, transient $EtCO_2$ reading likely occurred before the full effect of the air leak was established or during a momentary occlusion of the fenestration.[24] The failure of the intervention to resolve the issue with a shortened, fenestrated tube further confirmed that the fenestration design, not the tube length or a partial obstruction, was the primary etiological factor.

The successful resolution of the crisis, the replacement of the fenestrated tube with a shortened, unfenestrated size 4.5 tube, provides a clear, evidence-based lesson. By eliminating the fenestration, the low-resistance leak pathway was sealed, allowing the ventilator to effectively pressurize the airway and restore adequate minute ventilation.

It should be acknowledged that while the fenestration is the most probable cause of the ventilatory failure in this case, other factors may have contributed to the observed air leak and inadequate ventilation. These include the dynamics of using an uncuffed tube in an infant trachea, the inherent compliance and distensibility of the infant airway, and the sequential changes in tube size during troubleshooting (from a 3.5 fenestrated to a 4 fenestrated, and ultimately to a 4.5 unfenestrated tube). The resolution of ventilatory compromise upon switching to an unfenestrated tube strongly supports the fenestration as the primary contributor; however, the change in tube size from a fenestrated 3.5 to an unfenestrated 4.5 may have also improved the seal between the tube and tracheal wall, reducing the peri-tube leak. Therefore, the causal role of the fenestration, while highly plausible, should be interpreted as a probable rather than definitive mechanism.

This case emphasizes the need for a rapid, systematic approach to managing acute ventilation failure in a tracheostomized patient. The initial steps, ruling out obstruction and circuit issues, were appropriate. However, the immediate recognition of the fenestration as the likely cause, based on the massive air leak, was the key to the successful, life-saving intervention.

This study has several limitations. As a single case report, the findings cannot be generalized, and the conclusions drawn are inherently limited by the absence of a control group or comparative data. The direct relationship between the fenestration and ventilatory failure, although strongly supported by the clinical sequence, remains a probable rather than proven mechanism, as other variables such as tube size changes and uncuffed tube dynamics may have contributed.

Future prospective studies comparing fenestrated and unfenestrated tracheostomy tubes in the pediatric population are needed to establish more definitive evidence-based recommendations.

Conclusion

This case provides a cautionary observation regarding the use of fenestrated tracheostomy tubes in mechanically ventilated infants, highlighting a potential risk of significant air leak and ventilatory failure. While not sufficient to establish definitive practice recommendations, it underscores the need for careful tube selection and consideration of fenestration-related complications in similar clinical scenarios.

Data Sharing Statement

Data supporting the findings of this study are available from the corresponding author upon reasonable request.

Ethics Approval

Institutional review board is not required for this type of article.

Consent for Publication

Written informed consent was obtained from the patient's parents for the publication of this case report and accompanying images. We confirmed that the privacy of the participants was preserved and that the data were anonymized and kept confidential.

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Disclosure

The authors declare that they have no competing interests in this work.

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