Management of respiratory problems in children on home invasive mechanical ventilation

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Abstract

The management of respiratory problems in children on home invasive mechanical ventilation (HIMV) is a complex and challenging task. In recent years, with appropriate family education, these patients have been able to be discharged from the hospital and continue their treatment at home. The population of pediatric patients dependent on HIMV has been increasing worldwide, presenting unique and varying care needs. Management of these patients involves addressing ventilator settings, monitoring respiratory status, ensuring airway safety, and providing continuous support and education to patients and their caregivers. Despite the completion of home settings and family education, children on HIMV may encounter various respiratory problems during home follow-up. Prevention and timely management of these complications are crucial to improving patient outcomes. This article summarizes the most significant respiratory problems in children on HIMV and the management strategies for each problem are discussed, emphasizing the importance of appropriate aspiration techniques, regular monitoring, adequate training of caregivers, and a well-prepared emergency plan.

Introduction:

The inability of the respiratory system to keep blood gas concentrations within the normal range is called chronic respiratory failure. These patients need external respiratory support and mechanical ventilators are appropriate treatment option to improving the ventilatory capacity of the respiratory system. While in the past, these patients were followed up with conventional mechanical ventilators in intensive care units when they needed external respiratory support. In recent years, with the development of new technologies, airway is provided with tracheostomy in prolonged intubations to avoid of complications of intubation. After family education these patients can be discharged, and their treatment is continued at an earlier time with home invasive mechanical ventilators (HIMV). Because long-term invasive mechanical ventilation in a hospital can have negative effects on a child's maturation including social, psychological even emotional impacts. Being in a hospital for an extended period can disrupt a child's normal routines and interactions, potentially affecting their social skills and emotional well-being. Additionally, being in a hospital environment exposes the child to a higher risk of hospital-acquired infections, which can further complicate their medical condition. As a result, patients dependent on HIMV represent a growing population worldwide, which have specific and variable care needs. The management of HIMV patients involves addressing their ventilator settings, monitoring their respiratory status, ensuring airway safety, and providing ongoing support and education to both the patients and their families or caregivers [1]. Once all processes for home support are in place, if clinical conditions allow; such as stable cardiopulmonary status as demonstrated by heart rate, pulse oximetry recording, oxygen support (possibly <40%), absence of recurrent respiratory infections and adequate weight gain; the child is a candidate for discharge from home [2]. Even if the patients discharged with a HIMV are discharged after the completion of home settings and family education, they experience various respiratory problems in their home follow-up. In a retrospective observational cohort analysis of 228 children enrolled in a home mechanical ventilation program over a 22-year period in Southern California, found that 21%

mortality rate of 34% due to progression of underlying conditions and 49% due to unexpected events; 19% of these unexpected deaths were associated with airway problems, such as tracheal hemorrhage, acute airway obstruction and accidental decannulation [3]. They also found that pneumonia and tracheitis were the most common causes of non-elective hospital readmissions in 40% of patients receiving HIMV support during their first year at home after discharge; half of these admissions occurred in the first 3 months [4]. Edwards et al. examined severe emergencies in a group of ventilator-dependent children, they found that the majority of admissions were associated with respiratory problems such as increased secretions, infection, atelectasis, and complications from tracheostomy [5].

Below, the management of respiratory problems in patients dependent on home invasive mechanical ventilation will be addressed.

1. *Increased respiratory secretions and airway obstruction*

Airway obstruction is the most critical and life-threatening event that can occur in patients with a tracheostomy tube or on home mechanical ventilation. Immediate and effective action is crucial to clear the airway obstruction to prevent the development of hypoxemia, which is a condition characterized by low oxygen levels in the blood. Even a slight contamination of small cannulas used in children can cause a significant increase in airway resistance, as the smaller the inside diameter of the cannula, the greater the risk of airway obstruction by secretions.

A tracheostomy tube, while necessary for respiratory support, bypasses the natural protective mechanisms of the nose and oral cavity, such as ciliary clearance, filtration, humidification and warming of the inhaled air. Consequently, children with a tracheostomy may encounter an array of respiratory challenges, including an increased likelihood of cough, susceptibility to pulmonary infections, and dryness of pulmonary secretions. To safeguard the airways from irritation caused by dry air, dust, or harmful particles present in the environment, the use of appropriate filters becomes indispensable. Equally vital is the implementation of humidification and frequent suctioning, essential measures aimed at reducing the risk of crust formation, mucus plugs, and potential tube blockages. By adhering to these meticulous care practices, we can ensure optimal airway health and enhance the overall well-being of children reliant on tracheostomy tubes for long-term respiratory support [6]. This vulnerable population, emergencies related to the tracheostomy cannula occur more frequently compared to adults, with accidental removal of the cannula and aspiration being particularly prevalent. When encountering symptoms such as fever, increased secretions, persistent cough, dyspnea, and exhaustive forced breathing, close monitoring is essential to identify potential complications. In such cases, employing pulse oximetry during spontaneous inhalation of ambient air aids in timely intervention and ensures adequate oxygenation for these young patients[7]. In patients requiring HIMV with ineffective cough and/or neuromuscular disease with poor respiratory muscle strength can be used a mechanical insufflation–exsufflation device to help maintain airway clearance. Despite advanced home monitoring systems, almost 20% of the overall mortality rate are attributed to preventable deaths related to tracheostomy accidents that like accidental decannulation and mucous plugging of the tracheostomy tube [1]. In such situations, one of the caregivers must always be awake and promptly remove the obstruction using an aspiration device. Ensuring the patient receives adequate oxygenation is crucial during this critical time.

According to the latest Canadian research study at a tertiary care center that involved pediatric respiratory specialists and pediatricians with specialist in tracheostomy tube care and home ventilation; in patients experiencing excessive oral secretions, medical centers accept a range of effective strategies for management. Among the approaches; salivary gland botox injection, nutritional assessment, gastrostomy feeding, humidifier thorough tracheal masks, enteral glycopyrrolate administration, salivary gland duct ligation, and scopolamine patches[8].

2. *Tracheal trauma and subglottic stenosis*

Tracheal trauma, particularly erosion, results from unsupported ventilator tubing pulling on tracheostomy canula and improper tracheal aspiration [9]. Flexible endoscopy can be used to check that the location of the tracheostomy tube is centered in the trachea and that the trachea is healthy. The American Thoracic Society

(ATS) statement "Care of the Child with a Chronic Tracheostomy" recommends a control bronchoscopy every 6-12 months to evaluate the underlying airway pathology, detect and treat complications, assess tube size and position, and determine readiness for decannulation[10]. If complications are suspected, additional bronchoscopies can be carried out.

Subglottic stenosis may occur due to the placement of the tracheostomy tube above the airway. Other contributing factors include trauma from prolonged endotracheal intubation before tracheostomy opening and inflammation often associated with uncontrolled reflux. To avoid this, correct tracheostomy care and proper placement are essential. With appropriate endoscopic evaluation before decannulation, this complication can be predicted and surgically corrected with cartilage graft or segmental tracheal resection.

The aforementioned Canadian study evaluated several aspects, including tracheostomy tube care, caregiver qualification, home monitoring, speaking valves, medical management of tracheostomy complications, and decannulation assessment. The frequency of tracheostomy cannula replacement is most recommended on a monthly basis. Clinical indications for more frequent tracheostomy tube changes were respectively; mucous plugs (94.1%), upper respiratory tract infection with increased secretions (70.6%), pseudomonas colonization (23.5%), and younger age: age <3 years (17.6%), and <1 year (11.8%)[8].

3. *Granuloma formation*

Granuloma formation is a condition that occurs when there is inflammation in the area due to tracheal trauma resulting from not being attentive to aspiration techniques. During the healing process, the inflammation leads to the development of raised scar tissue on the surface, which can cause narrowing or complete blockage of the airway. Localized tracheomalacia may also develop due to inflammation at the stoma site.

Silver nitrate is the most recommended first-line agent for the treatment of granulomas, while other recommended agents include ciprofloxacin-dexamethasone otic suspension, topical steroid ointments, frequent dressing changes, or topical antibiotics [8]. One study noted the choice of cuffless cannulas to ensure the possibility of using speaking valves and to reduce tracheal trauma. In the presence of excessive leakage, a new larger cannula was used if the exhaled tidal volumes could not be controlled [2].

When granulation tissue is detected, patients should be referred to head and neck surgery. If there is no response to medical treatment, the granulation tissue can be removed with optical forceps or potassium titanyl phosphate or laser coagulation. To prevent the recurrence, intralesional steroid injection can be performed [6].

5. *Hemorrhage*

Hemorrhage is the presence of blood during tracheostomy aspiration. In some severe cases, bleeding may occur within the tracheostomy tube even without aspiration. Such bleeding should be considered a serious condition and requires appropriate medical intervention. These bleedings can be caused by tracheitis or vulnerable granulation tissue on the trachea. Tracheitis is a bacterial infection of the tracheal mucosa. Frequent aspiration may be required due to increased secretion after infection, which may irritate the tracheal mucosa and cause bleeding. Systemic antibiotics are used in the treatment, and it is recommended to increase hydration. It is also important to use an appropriately sized and correct length suction catheter to avoid tracheal trauma during aspiration [6]. There are three techniques for aspiration: "Shallow aspiration" is the superficial insertion of a catheter into the very core of the tracheostomy tube to remove secretions from the opening. The "pre-measured technique" is a method that is neither deep nor shallow, in which the farthest side holes are inserted to a certain depth where they emerge from the end of the tracheostomy tube. "Deep aspiration" is the insertion of the catheter until it meets resistance and then gently withdrawing it before aspiration is applied. Damage and inflammation of the tracheal epithelium are known to occur when deep aspiration is routinely performed, and there are many recommendations for its discontinuation. Pre-measured technique is recommended to minimize airway injury. Determining the exact depth of insertion in the pre-measured technique is crucial to prevent epithelial damage or insufficient aspiration. Marking can be made on a demonstrative catheter using a tracheostomy tube of the same size to measure insertion depth

[6].

6. *Tracheocutaneous fistula*

Long-term tracheostomies often lead to epithelialization of the stoma with mucocutaneous overgrowth in the artificial lumen at the stoma site and tracheocutaneous fistulas [11]. There is the direct relationship between tracheostomy dependence times and the probability of developing a tracheocutaneous fistula. This situation can be explained by the need for more time for mucocutaneous overgrowth and squamous epithelialization. In studies, the conclusion that this critical time point is 24 months has come to the fore. The percentage of children who develop tracheocutaneous fistula ranges from 13% to 57.3% in the literature. Despite the longstanding and widespread use of tracheostomies in medical practice, a standardized approach for decannulation still does not yet exist among different practitioners. Clinicians should develop a standard decannulation protocol to decannulate patients as soon as appropriate to reduce the risk of developing tracheocutaneous fistula [12].

7. *Tracheoesophageal fistula*

Tracheoesophageal fistulas develop when the trachea opens into the esophagus after tracheal lacerations. These rare but serious complications can occur with chest trauma, tracheal intubation or percutaneous dilatation tracheostomy. It can be seen after rigid tracheal intubation, respiratory failure emergencies or esophagectomy. Tracheal lacerations can also be caused by a variety of factors, including inexperienced physicians, improper stylet use, cuff overinflation, or coughing with a closed expiratory valve. Tracheal lesions caused by the cuff can be of two types, longitudinal and circular, due to cuff overinflation or cuff decubitus in the tracheal wall.

Diagnosis of tracheal lesions can be confirmed by radiological findings or bronchoscopy. Treatment approaches range from conservative non-surgical treatment to surgical interventions and carry a high mortality rate. The choice of treatment varies depending on the location of the tracheal injury and the patient's respiratory status. In cases of severe respiratory failure, mechanical ventilation may restrict recovery and alternative approaches such as bypass or multi-tube use may be necessary [13].

8. *Respiratory tract infections and ventilator associated pneumonia*

Respiratory tract infections (RTIs), including tracheobronchitis and pneumonia, are prevalent among children with tracheostomy tubes and often lead to frequent hospital admissions. In a study conducted in Taiwan, 139 children who received HIMV support for more than 3 months were followed and found that the most common reason (47.7%) for re-admissions after discharge was infections, the most common infection type was respiratory tract infection. They thought that the reason for this was the negative psychosocial effects of caregiver family members, limited home care resources and financial burden [14]. Borges et al. observed hospital readmissions and found that the most common cause was respiratory infection, which was the most common prolonging and aggravating factor for hospitalizations[15]. Kun et al. found that pneumonia and tracheitis were the most common causes of hospital readmissions in the year following the initiation of HIMV [4].

Ventilator-associated pneumonia (VAP) is a serious complication with high morbidity and mortality in intensive care units. In studies conducted on patients dependent to HIMV, the incidence of VAP was found to be lower than in intensive care, but the risk increases as the duration of ventilator support is prolonged. Although VAP performed in a home environment rarely causes death, it often requires hospitalization. Treatment of bacterial tracheobronchitis or pneumonia should be based on the clinical picture and recent cultures and sensitivities. Additionally, vaccinations should be up-to-date for children receiving chronic ventilator support. High-risk children are recommended the flu vaccine, and antiviral drugs may be considered for flu treatment or prophylaxis. Palivizumab is recommended for reducing serious respiratory infections caused by respiratory syncytial virus in high-risk infants. To prevent respiratory viral infections, families should be trained to reduce exposure through handwashing and to limit time in high-risk environments [16].

Appropriate aspiration techniques should be used to prevent respiratory tract infections. There are two

techniques for absorbing secretions from the airway. "Sterile technique" involves using a sterile catheter and sterile gloves for each aspiration procedure, ensuring that the catheter placed in the tracheostomy cannula does not encounter any contaminated area. This method is traditionally used in hospitals, with the "modified clean technique" (using non-sterile gloves and sterile catheters) being used in recent years. In contrast, the "clean technique" for aspiration in the home environment is more common and useful. In clean technique, all caregivers should wash their hands before and after each aspiration procedure to avoid contamination. Alcohol or disinfectant solution is an acceptable tool when water and soap are not available. After aspiration is complete, the main catheter should be flushed with clean water until secretions are cleared [10]. Exposure to tobacco smoke also causes RTIs through a variety of mechanisms and avoidance of tobacco smoke exposure is recommended [17].

Also, there is a high aspiration rate in early readmission and recurrent pneumonia. Improper care by nurses, such as inadequate feeding methods for example feeding in the supine position, may contribute to a higher aspiration rate. In addition, nasogastric tube feeding is thought to cause aspiration pneumonia because it facilitates bacterial colonization and reflux in the upper gastrointestinal tract. In one study, the prevalence of nasogastric tube feeding was found to be higher in the early readmission group compared with oral and gastrostomy feeding tubes, suggesting that this may increase the incidence of aspiration. Prior to discharge, caregivers should be provided with appropriate training, knowledge of aspiration techniques to prevent contamination of the aspiration catheter and to prevent food aspiration. Also, training in feeding methods such as proper head height and proper feed rate control is recommended. Providing adequate training may help reduce the risk of aspiration and related complications in long-term ventilator dependent patients [18].

In addition, local wound infection is usually a self-limiting but possible event. This is often associated with inadequate secretion management leading to premature failure of maturation sutures. If these sutures become infected and fail too soon, it can result in direct access from the wound site to the cervical neck and chest. Rapid detection allows for home wound care, preventing more serious complications.

9. *Barotrauma, pneumothorax and pneumediastinum*

Air leaking problems such as pneumothorax, pneumomediastinum, and subcutaneous emphysema are more often classified as early complications of tracheostomy. Because of the anatomical differences between children and adults, children have traditionally been thought to be at high risk for these complications. These complications can be detected on postoperative chest radiographies (x-ray), and many centers routinely perform chest x-ray after tracheostomy for this reason[19]. Pneumothorax is one of the most common results of barotrauma, often associated with mechanical ventilation. In pediatric intensive care units, studies have shown that barotrauma and pneumothorax are linked to the duration of mechanical ventilator support and hospital stay. However, patients who experience pneumothorax have a significantly higher mortality rate compared to those who do not. This highlights the importance of careful monitoring and management of mechanical ventilation to minimize the risk of barotrauma and its potentially severe consequences. There are some opinions that argue that the incidence of barotrauma in intensive care patients is related to the underlying condition rather than ventilator settings, but there are not enough studies with this [20].

For children needing HIMV, ATS recommends regular maintenance of home ventilators and related equipment as specified by the manufacturer. Care should be taken to ensure that the actual ventilator settings seen on the ventilator monitor are consistent with the prescribed settings before the hospital discharge. Twenty-four hours a day service and telephone support should be available for mechanical breakdowns or malfunctions [1].

10. *Accidental decannulation*

Decannulation refers to the unintentional or voluntary removal of the tracheostomy cannula from its proper position. In the context of patients on home mechanical ventilation, involuntary decannulation is a critical and life-threatening respiratory problem. Decannulation is the most frequent (6%) late complication of tracheostomy in a Canadian cohort with 30 years of follow-up [21]. The incidence of accidental decannulation, as a late complication of tracheostomy, was found in a Korean (2.7%) and a Brazilian study (5.7%)[22,23].

There are some studies about various methods for maturing an infant's tracheostomy stoma to prevent accidental decannulation and complications, such as creating a permanent fenestration in the trachea, using flaps to suture the tracheal opening, and employing the 'starplasty technique'. The 'starplasty technique' appears to be the most effective in reducing major complications but may result in a tracheocutaneous fistula after decannulation, necessitating reconstruction. These procedures are generally reserved for long-term tracheostomy cases or when there's a concern for accidental decannulation [6].

The latest ATS statement on caring for a child with a tracheostomy at home recommends that two adult caregivers be trained in the care and replacement of a tracheostomy tube [1]. A study by Tolomeo et al. examined caregivers of infants discharged from the hospital with a tracheostomy. Seventy percent of caregivers reported that the second caregiver attended the child's medical care frequently or very often, and 50% of those surveyed believed they could not take adequate care of the patient at home without another trained caregiver (24). In making this recommendation, ATS places high value on patient safety and caregiver quality of life, while placing low value on the increased use of resources required for training multiple caregivers. The following pieces of equipment must be available for home use when caring for a patient in home mechanical ventilation: ventilator, spare ventilator, batteries, aspiration equipment (portable), a self-inflating bag and mask, heated humidifier, supplemental oxygen for emergency use, pulse oximeter and nebulizer [1].

When a tracheostomy cannula becomes dislodged or removed accidentally at home, it can lead to immediate airway obstruction, compromising the patient's ability to breathe. This situation requires urgent intervention and can be life-threatening if not addressed promptly. Patients on home mechanical ventilation are at a higher risk of involuntary decannulation due to their need for prolonged respiratory support and the presence of a tracheostomy tube.

Hypoxemia can lead to serious complications and even death if not promptly addressed. Therefore, in cases of accidental decannulation or any other event that obstructs the airway, it is essential to act quickly and appropriately. Caregivers, family members, and anyone responsible for the patient's care at home should be trained to recognize the signs of airway obstruction and know how to respond appropriately. For patients with tracheostomy tubes, reinsertion of the cannula by trained individuals should be attempted, if possible. However, if unsure or unable to reinsert the cannula safely, it is essential not to force it, as this could worsen the situation. Instead, focus on maintaining a clear airway until professional medical help arrives.

Regular monitoring, education, and having a well-prepared emergency plan are essential components of managing patients on home mechanical ventilation to mitigate the risks of airway obstruction and ensure a prompt response to any respiratory emergencies [25].

Conclusion:

To optimize the care of pediatric patients on HIMV, a comprehensive approach encompassing preventive measures, continuous monitoring, and prompt intervention for respiratory problems is essential. Through the implementation of effective management strategies, healthcare professionals can enhance the quality of life and outcomes for this vulnerable population of children dependent on HIMV.

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