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Prehospital Mechanical Ventilation: An NAEMSP Position Statement and Resource Document

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Abstract

Airway emergencies and respiratory failure frequently occur in the prehospital setting. Patients undergoing advanced airway management customarily receive manual ventilations. However, manual ventilation is associated with hypo- and hyperventilation, variable tidal volumes, and barotrauma, among other potential complications. Portable mechanical ventilators offer an important strategy for optimizing ventilation and mitigating ventilatory complications.

- EMS clinicians, including those performing emergency response as well as interfacility transports, should consider using mechanical ventilation after advanced airway insertion.
- Prehospital mechanical ventilation techniques, strategies, and parameters should be disease-specific and should mirror in-hospital best practices.
- EMS clinicians must receive training in the general principles of mechanical ventilation as well as detailed training in the operation of the specific system(s) used by the EMS agency.
- Patients undergoing mechanical ventilation must receive appropriate sedation and analgesia.

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Introduction

Airway emergencies and respiratory failure are often complex yet frequent encounters in the practice of emergency medical services (EMS). Patients who receive out of hospital advanced airways are subsequently ventilated manually in most US EMS systems. Manual ventilation in this setting may lead to hyper- or hypoventilation, variable tidal volumes, and barotrauma, among other potential complications. Mechanical ventilation is a mainstay of in-hospital and air medical transport management of the intubated patient, yet outside of critical care interfacility transport, it is not widely used in ground EMS. There are portable devices marketed for this application and growing interest in this approach by EMS is anticipated. As EMS clinicians and agencies consider adoption of this technology, the National Association of EMS Physicians offers the following considerations:

Availability and Use of Mechanical Ventilation

EMS Clinicians, Including those Performing Emergency Response as well as Interfacility Transports, should Consider using Mechanical Ventilation after Advanced Airway Insertion.

NAEMSP recommends the use of invasive mechanical ventilation for hypoxic respiratory failure, hypercapnic respiratory failure, and airway protection. These may be on initial contact from an emergency ground ambulance response, or during interfacility transfers via critical care teams.

Invasive mechanical ventilation improves oxygenation in respiratory failure via precise delivery of a fraction of inspired oxygen (FiO_2) and effective positive end expiratory pressure (PEEP). It corrects hypercapnic respiratory failure via controlled delivery of a predicted minute ventilation, with a set tidal volume (Vt) and respiratory rate (RR). Table 1 demonstrates the four essential benefits of prehospital mechanical ventilation.

Successful ventilatory support is key during transport of the critically ill patient. Proper transport management includes integration of cardiac care with adequate oxygenation and ventilation. Maximizing ventilation using available methods and maintaining the best possible hemodynamic condition during interfacility transport is essential, meaning the difference between success and failure in transport.

Use of invasive mechanical ventilation by EMS clinicians may reduce barotrauma and atelectrauma, thereby decreasing complications such as pneumothorax and ventilator associated lung injury (1).

Prehospital mechanical ventilation is delivered during approximately 4% of annual EMS activations in the United States (2). Most of the data on prehospital care of critically ill patients are limited and include both interfacility transports and scene calls. Recent studies demonstrate that most prehospital transport patients undergoing mechanical ventilation (73-83%) receive ventilation with volume control, while a minority receives more advanced modes of ventilation (3,4). For the majority of intubated patients requiring prehospital ventilation, a transport ventilator is not available and a manual bag-valve-mask resuscitator (BVM) is used to provide ventilation, even for patients transported by air (5).

Traditional EMS education is focused on providing ventilation to achieve observable chest rise, yet bag-valve devices do not provide feedback on the delivered volumes, minute ventilation, and other important patient parameters. The use of BVMs can result in variable delivered volumes, with research suggesting that injurious ventilation can occur (6–9). A small study showed that simple educational interventions can aid in improving paramedic knowledge and attitudes toward mechanical ventilation (5). Another added benefit of using dedicated ventilators (as opposed to BVMs) is that invasive mechanical ventilation may also allow the paramedic or prehospital nurse to perform other needed patient care interventions (5).

Disease-Specific Considerations in Prehospital Mechanical Ventilation

Prehospital Mechanical Ventilation Techniques, Strategies, and Parameters should be Disease-specific and should Mirror in-Hospital Best Practices.

Numerous studies of critically ill patients in the intensive care unit, emergency department, and operating room have highlight best practices for mechanical ventilation in order to prevent ventilator-induced lung injury (10–12). These goal parameters include tidal volumes of 6 mL/kg of predicted body weight (range 4 to 8 mL/kg), a plateau pressure (Pplat) of less than 30 $cmH2_O$, and a driving pressure (Pplat - PEEP) of less than 15 $cmH2_O$ (13). While there are no prehospital data formally validating these standards, extrapolation of these parameters to the EMS setting are reasonable. A mechanical ventilator, allowing quantification of pressures and volumes, is preferred to manual bag ventilation to maintain these precise parameters.

Studies have shown that use of bag ventilation is associated with high tidal volumes and pressures. An adult-sized bag provides a mean tidal volume of approximately 800 mL, exceeding the upper limit tidal volume of 560 mL for a 70 kg man. Almost all participants (93%) in a manikin ventilation study exceeded this threshold when using an adult bag (14). A study of EMS clinicians found tidal volumes were more likely to be in the desired ranges when administered with a pediatric bag, but still, only 17.5% of breaths were in that range, with a median tidal volume of 663 mL (6). Similarly, the respiratory rate may be higher than intended when the patient is manually ventilated, causing hypocapnia.

The large tidal volumes and lack of regulation of ventilation have demonstrated clinical effects. Lung injury from large tidal volumes can develop in as little as 20 minutes (16). Hyperventilation in the prehospital setting has been shown to be deleterious in patients with cardiac arrest and traumatic brain injury (16). Given the lung injury and worse clinical outcomes shown by non lung-protective ventilation in numerous clinical environments, it is reasonable to apply these concepts to the prehospital environment, though direct data are lacking.

A recent review by Stephens et al. showed that mechanical ventilation in the prehospital and emergency department settings influence the ventilator management through intensive care unit admission and can affect patient outcomes. These findings suggest that prehospital clinicians should strive for lung-protective ventilator settings as the effects may last far longer than the duration of the transport (17).

Hypercapnic Respiratory Failure/COPD

Because of severe bronchospasm, exhalation is prolonged in patients with COPD. Mechanical ventilation in these patients should involve low tidal volumes, low respiratory rates (development of autoPEEP). FiO_2 should be titrated to target saturations of 88–92%. PEEP can be used but should never be higher than intrinsic PEEP (if able to be

TABLE 1. Benefits of mechanical transport ventilation methods.

1.	Provide the intubated patient with consistency in ventilation parameters including respiratory rate and tidal volume.
2.	Maximizing ventilation, improving oxygenation and the elimination of carbon dioxide.
3.	Limiting airway pressures and potential complications including barotrauma, gastric distention, and hypotension.
4.	Allow the transport team to focus on other aspects of patient care.

measured) to minimize the risk of dynamic hyperinflation. Inspiratory flow rate should be set to at least 60 L/min but can be increased if the patient is double-triggering. Other treatments including bronchodilators and steroids should be continued (18,19).

Other Etiologies of Respiratory Failure with Hypercapnia

The differential diagnosis includes sedative use/toxicology (including narcotics), central nervous system disorders (including infection and stroke), and respiratory muscular/thoracic problems (including neuromuscular disorders). As opposed to COPD, there is usually no primary lung process that needs to be managed. The hypercapnia is typically secondary to hypoventilation.

Management should be aimed at identifying and reversing the inciting pathology primarily. Mechanical ventilatory support should be initiated in the setting of continued respiratory failure and/or CNS depression. Minute ventilation (respiratory rate x tidal volume) should be selected to correct the hypercapnia. This may require a higher respiratory rate. Tidal volumes should be maintained at 6–8 ml/kg, and oxygen saturations at 94–98%.

Cardiac Arrest

If an advanced airway has been placed during ongoing cardiac arrest management, maximal inspired oxygen should be supplied in order to improve tissue hypoxia in the setting of a low-flow state from reduced cardiac output. Current ACLS recommendations state that once an advanced airway is in place, continuous uninterrupted chest compressions should occur while providing a ventilation rate of about 10 breaths/minute (20–23). The use of impedance threshold devices can be considered, as this may augment blood flow to vital organs. However, the evidence in humans is variable (24).

Once return of spontaneous circulation is achieved, strongly consider titrating inspired oxygen to maintain saturations of 94–98%. Evidence suggests hyperoxia may be detrimental to neurologically intact survival as a result of reperfusion free-radical injury (23,25). The prehospital clinician should be mindful that high minute ventilation or tidal volumes increase intrathoracic pressures, leading to a decrease in venous return to the heart.

Trauma

Traumatically injured patients do not necessarily require invasive mechanical ventilation. The decision to initiate mechanical ventilation should be made while weighing the severity, anatomy, and physiologic effects of the injury sustained; the hemodynamic stability of the patient; the logistics of transport; and the distance to definitive in-hospital care. It may be more advisable to support the airway and ventilation with basic techniques in a severely injured patient when transport times are short rather than increase scene time by proceeding with intubation and ventilation.

A common primary pathologic process in trauma is hemorrhage. This leads to progressive anaerobic metabolism, with associated metabolic acidosis and elevation in lactic acid levels. Mechanical ventilation may be indicated to support increased oxygen demand or to reduce work of breathing in severely injured patients.

When initiating mechanical ventilation in the traumatically injured patient, appropriate external hemorrhage control and volume resuscitation should have already occurred. This can offset the reduction in preload from positive pressure ventilation. Minute ventilation should be adjusted to account for the patient's metabolic acidosis. The ventilator should be set to meet or exceed the pre-intubation respiratory rate. Early adoption of a lung-protective strategy may affect outcomes. Severe traumatic injury is a risk factor for acute respiratory distress syndrome. Tidal volume should be titrated early to 6–8 cc/kg predicted body weight. Oxygen saturations of 94–98% will avoid hyperoxia (23,25–26).

Mechanical ventilation considerations for traumatic brain injured-patients are discussed in a separate section.

Airway and Chest Trauma. Rib fractures (and any associated pulmonary contusion) may compromise ventilation and oxygenation in trauma patients, especially in the elderly. Invasive mechanical ventilation solely for chest wall stabilization is not recommended. Appropriate analgesia (oral or parenteral) may allow improvement in respiratory capacity and negate the need for invasive mechanical ventilation during transport.

Low-impact mechanisms can actually lead to multiple rib fractures in the elderly, and multiple rib fractures should be considered in high-impact mechanisms in other age groups. Persistent increased work of breathing and/or hypoxemia despite appropriate analgesia and noninvasive oxygen therapy should prompt consideration of invasive mechanical ventilatory support, especially if scene or transport times are long. No single mode of ventilation has been proven to have an outcome benefit over another in this injury. Adopting a higher-PEEP strategy may allow recruitment of alveoli and reduction of shunting (27,28). Be cognizant of comorbid preexisting lung pathology.

Pneumothorax can be a complication in injured patients and should be actively monitored for. A small or moderate pneumothorax may become clinically significant on the initiation or continuation of invasive mechanical ventilation. This may occur during transport. Decompression of a pneumothorax should follow local guidelines. Note that recent evidence and guidelines report higher success from decompression in the fifth intercostal space, anterior axillary line as opposed to the second intercostal space, midclavicular line (29).

Tracheobronchial disruption is fairly uncommon but may be suspected in the setting of respiratory distress worsening with positive pressure ventilation, blood in the endotracheal tube, or severe subcutaneous emphysema. Injuries often lie within 2 cm of the carina. One method of overcoming the difficult ventilation in this situation is to advance the endotracheal tube carefully and deliberately into the right mainstem to get beyond the injury.

Neurologic Emergencies Affecting the Brain. A key consideration in neurologic emergencies is minimizing the risk of secondary brain injury (30). Intubation and mechanical ventilation in the setting of neurologic insult or injury (cerebrovascular accident, intracranial hemorrhage, traumatic brain injury) should be seen as a mechanism to prevent secondary brain injury (30,31). Both hypoxia and hyper- or hypocapnia can be detrimental to cerebral blood flow and intracranial pressure (ICP).

The decision to intubate a patient suffering a primary neurologic injury should not be therefore dictated strictly by a Glasgow Coma Scale score of <8. Rather it should be guided by the anticipated clinical course, duration and logistics of transport, signs/symptoms that may raise a concern for elevated ICP, and the presence/absence of airway reflexes.

Once intubated, specific considerations during prehospital transport include the maintenance of appropriate normal oxygen saturations, typically 94-98% (23,25). Minute ventilation should be adjusted to avoid hypo- and hypercapnia. If using end-tidal CO_2 monitoring, remember that due to alveolar dead space, the $PaCO_2$-$EtCO_2$ difference is 2-5 mmHg. Therefore, a low-normal CO_2 value should be targeted (35-40 mmHg). Hyperventilation is not advisable, except perhaps only as a temporary measure to manage uncontrolled elevated ICP.

Additionally, the prehospital clinician should consider the hemodynamic effects of mechanical ventilation. Hypotension can lead to secondary brain injury. Strategies to address this may include volume resuscitation, care with setting a tidal volume, and minimizing the PEEP level used. Appropriate sedation should be administered while mechanical ventilation is ongoing, as hypertension related to agitation will increase ICP. If transport mechanisms and logistics allow and no contraindications exist, the patient should be positioned with the head-of-bed raised to 30 degrees to assist in ICP management.

Training in Mechanical Ventilation Operation

EMS Clinicians must Receive Training in the General Principles of Mechanical Ventilation as Well as Detailed Training in the Operation of the Specific System(s) used by the EMS Agency.

All clinicians who use mechanical ventilators must receive appropriate training including knowledge of standard education regarding ventilator concepts, and a functional familiarization with ventilation systems in their EMS agencies is an essential element of mechanical ventilation implementation.

Understanding specificity of transport ventilators and prehospital mechanical ventilation is a needed training item. Transport ventilators are designed to be lightweight and portable; some are air-powered, while others are electrically powered. Some device models are designed for adult use while others more advanced can be used by both adults and children. Transport ventilators also allow the patient to breathe spontaneously through the breathing circuit, delivering a high flow rate and 100% oxygen. Transport ventilators are designed to take the place of manual ventilation during emergency or transport situations.

TABLE 2. General concepts of mechanical ventilation and key terminology.

Positive End Expiratory Pressure (PEEP)
Positive pressure applied during the expiratory phase following delivery of a mandatory or spontaneous breath.
Respiratory Frequency
Breathing cycles or breaths per minute delivered by the ventilator.
Tidal Volume (Vt)
Volume inspired or expired during a normal breath.
Control Variable
Which variable the ventilator will control. Ventilators normally control either tidal volume or peak pressure.
Fraction of Inspired Oxygen (FiO2)
Fraction oxygen delivered to the patient. Set between 21% (room air) to 100%; usually adjusted to maintain PaO2 level greater than 60 mmHg or SaO2 level greater than 90%.
Auto-PEEP
Intrinsic PEEP occurs when a positive-pressure breath is delivered before complete exhalation of the previous breath, air becomes trapped and pressure within the lungs becomes trapped, potentially leading to decreased cardiac output, hypotension and even pneumothorax.
Expiratory Time (Te)
The time from the start of expiratory flow to the start of inspiratory flow.
I:E Ratio
Ratio of inspiratory time to expiratory time. Normal I:E ratio is 1:3. During mechanical ventilation I:E should be 1:2 or greater to prevent air trapping.
Inspiratory Flow (Vi)
Glow of gas measured at the airway opening during inspiration. Normal inspiratory flow during mechanical ventilation is 60–100 L/minute.
Inspiratory Time (Ti)
Time from the beginning of inspiratory flow until the beginning of expiratory flow.
Peak Inspiratory Pressure (PIP)
Highest proximal airway pressure produced in the patient circuit during the inspiratory phase. The stiffer the lungs, the greater the PIP.

Initiating and transporting a mechanical ventilation patient requires the EMS clinician to understand the management of complex patients in challenging environments. Current training programs and the scientific literature are limited in terms of the most effective method to educate EMS clinicians in the management of mechanical ventilation. Some professional organizations have addressed this within their critical care transport competencies; however, there is no current unified scope.

Often EMS organizations define their own educational standards and clinician orientation, leading to great variability and training inconsistencies. Since personnel and transportation equipment qualifications are not defined in law or regulation, this leaves the field open to interpretation and variation. Ultimately EMS organizations and medical directors are responsible for ensuring adequacy of equipment choices and training of clinicians (32).

Training and familiarization with ventilation systems and platforms is an essential element of prehospital care programs. Standard settings and modes for mechanical ventilation with disease-specific considerations are basic concepts to understand when providing critical care transport services. Ventilation applications and platforms will vary depending on the primary transport reason. With key differences in short prehospital/EMS indications versus critical care transport considerations, these differences are directly associated with transport times and underlying patient pathology needs.

Ventilator capabilities should be commensurate with training of clinicians and the level of care authorized for the transporting agency, basic ventilator technologies include the following:

- Resuscitators offer basic ventilation support during CPR and respiratory arrest. Most are fully pneumatic and oxygen powered, being able to provide controlled ventilation. Primarily intended for use with a face mask or rescue airway, they grant the rescuer effective control over tidal volume and respiratory rate delivered, and often control inspiratory pressures.
- Simple transport ventilators provide mechanical ventilation at a specified rate and volume with a pressure-relief valve and alarm systems. These ventilators are used primarily in prehospital settings by personnel with some training in mechanical ventilation and are typically intuitive and fast to deploy. EMS/transport ventilators offer simple tidal volume and rate controls, while some newer types also include noninvasive functions. Key mechanical ventilation terminology is included in Table 2.
- Advanced transport ventilators are designed to duplicate the advanced functions of acute care ventilators.

These devices have built-in compressors or turbines to generate positive pressure without compressed gas and contain an air–oxygen blender. Most offer extensive control of ventilator parameters and comprehensive alarms. Most of these are intended for interhospital or intrahospital transport of critically ill patients. The big difference between CCT ventilators and hospital transport ventilators is that CCT units are intended for use in mobile medical transport, and many are certified for air medical use.

Post-ventilation monitoring in the prehospital environment should include saturation percentage of oxygen (pulse-ox or SpO2) and continuous end tidal waveform capnography. If available arterial or venous blood gas can offer additional monitoring for trained providers.

Common Mechanical Ventilation Device-Related Concerns

Battery life is a key consideration when planning long EMS transports. The battery life among transport ventilators varies greatly, and ventilator battery exhaustion can lead to important complications. System planning for contingencies should include extra batteries or use of AC power if transport duration exceeds battery life.

Hypoxic episodes during transport can occur and potentially lead to increased morbidity and mortality in critically ill patients. Based on device specifics and $FI0_2$ rate it is critical to estimate expected oxygen consumption to plan for safe transports. Continuous assessment of oxygen consumption will allow early identification of consumption exceeding estimates, which should prompt a search for leaks, increase efforts to conserve oxygen, and take steps to terminate or divert the transport as needed.

Hypocapnia secondary to hyperventilation also occurs during prehospital ventilation. Hypocapnia is associated with poor outcomes, as it decreases cerebral blood flow and causes vasoconstriction that worsens ischemia in brain tissue. Use of prehospital quantitative end-tidal capnometry to avoid unintentional hypocapnia can decrease hyperventilation.

Sedation and Analgesia during Mechanical Ventilation

Patients undergoing Mechanical Ventilation must Receive Appropriate Sedation and Analgesia.

The care of mechanically ventilated patients involves understanding of prehospital science for appropriate sedation, pain control, and neuromuscular blockade.

Ventilator asynchrony, pulling at lines, and persistent tachycardia are all obvious signs of anxiety. Inadequate pain control and sedation in the prehospital mechanically ventilated patient can exacerbate problems already associated with general critical care patient transports such as disconnection of the breathing circuit and accidental extubation. Analgesics, sedatives, and neuromuscular blockers are commonly used medications for mechanically ventilated critical care transport patients. Providing comfort and reducing pain are important tasks for critical care transport professionals (33). However, reducing anxiety in a ventilated patient is challenging in optimal settings, but even more so in the out-of-hospital environment.

Post-intubation sedation scales such as the Richmond Agitation Sedation Scale (RASS) have been well validated in the in-hospital setting and lead to a decrease in sedation consumption, time of connection to ventilator, and hospital length of stay (34). Recently the use of the RASS on time to post-intubation sedation in the prehospital setting has been evaluated (35).

Common pitfalls associated with post-intubation care in the prehospital setting include confusion of indications for paralytics and adequate sedation. Among patients who are not chemically paralyzed, we advocate for an analgesia-first model in which analgesia is optimized before sedation. Recommendation against paralytics unless they are needed for patient/provider safety during transport, since adequate sedation is difficult to assess. In paralyzed patients, it is nearly impossible to gauge sedation without advanced monitoring devices. Support of blood pressure with vasopressors while providing adequate sedation is preferred over reduction of sedation to maintain blood pressure. Use of vasopressors as an adjunct to improve low blood pressure/hypotension is recommended instead of reducing sedation in order to ensure adequate sedation is maintained. For transport of mechanically ventilated patients, we recommend starting at protocolized minimum weight-based doses of sedatives and analgesics. This is recommended based on a two-step approach described to provide "initial stabilization that includes paralysis with deep sedation, followed by a non-sedation period" (36).

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