Hypoxemia after Emergency Intubation

December 18, 2024

Bohringer C, Liu H. Hypoxemia after Emergency Intubation. PSNet [internet]. 2024.
https://psnet.ahrq.gov/web-mm/hypoxemia-after-emergency-intubation

The Case

A 19-month-old child was brought to the emergency department (ED) via ambulance after drowning in a private pool. Per emergency medical services (EMS) report, the patient went into cardiorespiratory arrest and cardiopulmonary resuscitation (CPR) was provided by the child's mother. The patient arrived at the ED with seizures, tachypneic with a respiratory rate of 30, blood pressure of 95/62, and SpO2 89% on a bag-mask device delivering 100% oxygen. Rapid sequence intubation was induced for airway protection. The team (nurses, physician, pharmacist, respiratory therapist) huddled before the procedure to ensure that they were ready. Emergency equipment, suction, bag-valve mask, and medications were all prepared. The entire team consented that everyone was ready for the intubation procedure. After intubation, endotracheal tube (ETT) placement was confirmed by auscultation of breath sounds and observation of chest rise and fall. Imaging was called to confirm ETT placement, and the ETT was connected to the mechanical ventilator. The patient's SpO2 did not improve and dropped to 15% after 10 minutes. The team decided to re-intubate the patient. The ETT was removed and another cycle of rapid sequence intubation induction was called. The second intubation was completed and another respiratory therapist came to assist and found that the mechanical ventilator was never connected to any oxygen source.

The Commentary

By Christian Bohringer, MBBS and Hong Liu, MD

Background

Drowning is a significant ongoing health problem and about 20% of survivors suffer permanent hypoxemic brain damage.[1] Forty percent of drowning victims are children under 5 years of age.[2] Inhaling water into the lungs leads to hypoxemia, which may provoke seizures as in this case.[3]

After a near-drowning in freshwater, as in the present case, water is usually absorbed rapidly from the lungs into the pulmonary circulation. As a result, intubation can frequently be avoided by oxygenating the patient with continuous positive airway pressure (CPAP) or with a high flow nasal cannula (HFNC). These non-invasive treatments are now used regularly to provide respiratory support for patients after near-drowning.[4,5] In a recent case series, 81% of patients could be treated successfully with these modalities and only 21% required endotracheal intubation.[6] After a near-drowning in the ocean, hypoxemia may persist longer because seawater has higher osmolality than freshwater, reducing the rate of diffusion from alveoli into pulmonary capillaries. However, oxygenation via HFNC has also been reported to maintain oxygenation in patients after near-drowning in seawater.[7]

In managing patients after near-drowning, the most important therapeutic goal is to maintain adequate oxygenation. A trial of CPAP or HFNC oxygenation should generally be considered to improve oxygenation rapidly while avoiding the risks of endotracheal intubation. These risks include apnea induced by neuromuscular blocking drugs, failed mask ventilation after an unsuccessful intubation attempt, misplacing the endotracheal tube into the esophagus or the right main bronchus, and failure to establish adequate ventilation after intubation, as in this case. HFNC oxygenation is usually better tolerated than CPAP when patients have never been connected to one of these devices before,[8] but CPAP has been shown to be more effective at preventing intubation.[9,10] Seizures should be terminated with anticonvulsant medications rather than masked with neuromuscular blocking agents to prevent exacerbating any hypoxic/ischemic brain damage.

Emergency intubation in the ED can be stressful for staff because they frequently have insufficient time to prepare for this intervention. The patient may arrive in the ED without prior notification and is already hypoxic, requiring urgent oxygenation. In the pediatric ED in particular, intubation is a low frequency, high risk procedure.[11] Clinicians performing endotracheal intubations must be proficient with preoxygenation, laryngoscopy, intubation, post-intubation ventilation, and managing failed intubation scenarios.[12,13] They must also be able to recognize ventilator malfunction. When the ventilator alarms and oxygen saturations drop, staff should maintain oxygenation with a bag-valve resuscitator connected to an oxygen source and a positive end expiratory pressure (PEEP) valve to prevent hypoxemia while staff troubleshoot the ventilator and the breathing circuit.

When clinicians infrequently perform intubation, they should practice on a mannikin in a simulation environment to increase their proficiency with all relevant tasks.[14] Simulation has also been shown to be effective for teaching new intubation skills with a video-laryngoscope.[15] Mask ventilation must also be practiced regularly; only staff who are skilled with mask ventilation should administer neuromuscular blocking agents because intubation may fail. When this happens, patients are entirely dependent for their oxygenation on the team’s competence with bag-valve resuscitation.

The intubating team must also be familiar with placing oral, nasal and laryngeal mask airways. If everything else fails, the team must also be competent to perform an emergency cricothyrostomy with an intravenous cannula in a small child or a cricothyrotomy with a scalpel in an older child. Clinicians who have never been trained in these procedures should not administer neuromuscular blocking agents to patients. When the intubation is not required immediately, it is prudent to wait for more experienced staff to arrive before administering neuromuscular blocking drugs, in case a “difficult to oxygenate” scenario arises. Simulation for emergent cricothyrotomy is now available. Repeated simulation is helpful because cricothyrotomy is a potentially life-saving procedure but is performed rarely in clinical care.[16]

Confirming intubation with a carbon dioxide monitor is recommended in the guidelines for all areas of clinical medicine.[17] A recent study found that the documented use of capnography after intubation and cardiopulmonary resuscitation did not increase in the years following the publication of these guidelines.[18] Capnography is also underused in critical care units.[19] A continuous capnograph trace provides a numerical measurement derived from an infrared gas analyzer, which is preferred over a chemical colorimeter device. Significant information about cardiac output and bronchial smooth muscle tone can be derived from the numerical readout and the continuous waveform of the end tidal carbon dioxide (ETCO2) tracing. There is a direct correlation between ETCO2 and cardiac output when the minute ventilation remains constant. The capnograph trace hence not only confirms endotracheal intubation and monitors ventilation but also provides an early warning signal of reduced cardiac output and hemodynamic shock.[20]

When hypoxia is severe and intubation is potentially difficult, HFNC oxygenation can be used as an accessory tool to increase the time from the beginning of apnea to the onset of desaturation.[21,22] This intervention prolongs the time available for the intubating team to place the ETT and reestablish ventilation after neuromuscular blockade, so patients are less likely to suffer hypoxemia during intubation. In addition, a bag valve resuscitation device with a positive end expiratory pressure (PEEP) valve should always be on standby next to the ventilator to serve as a backup tool in case of ventilator malfunction.

Approaches to Improving Patient Safety

Avoid emergency intubation when possible

In cases of pulmonary edema or near-drowning, non-invasive treatment modalities such as CPAP or HFNC oxygenation be considered. However, these options were not desirable in this case because the child suffered seizures, and the clinicians were worried about further aspiration of stomach contents. In other situations, non-invasive oxygenation eliminates the risk of misplacing the ETT and avoids the cardiovascular depression associated with sedative medications that are required for the patient to tolerate the ETT.

ETT placement should be confirmed with capnography

Capnography should be used even when intubation takes place in the ED or the critical care unit.[23] The view of the vocal cords is obscured by the ETT after it is inserted. Unintended esophageal placement of the ETT is not uncommon even when the clinician reports seeing the tip of the ETT pass through the vocal cords. Inadvertent esophageal intubation occurs more often when it was necessary to apply pressure to the front the neck to improve the view of the vocal cords during laryngoscopy. This pressure typically needs to be released so that the ETT can be advanced into the trachea; the larynx may then ricochet in the anterior direction causing the tip of the ETT to flick back out of the trachea into the esophagus. The introduction of capnography into clinical anesthesia practice has led to a significant reduction in the number of unrecognized esophageal intubations and cases of hypoxic brain injury, contributing to reduced malpractice premiums for anesthesiologists.[24]

If a capnograph had been used in this case, the team would have recognized that the ETT was placed correctly in the trachea, and they would not have removed it in error. Persistent hypoxemia after emergency intubation may also occur because of atelectasis, ventilation/perfusion mismatch, or the presence of a foreign body in the airway. In this clinical situation the capnograph is especially helpful because it can rule out esophageal intubation as a cause for the ongoing hypoxemia.

Intubated patients should be monitored continuously with capnography

After the patient is intubated, the capnograph trace should be monitored continuously. When the minute ventilation is not changed, a reduction in cardiac output can be easily diagnosed by a drop in the ETCO2 value. An upslope during the plateau phase of the capnography trace is suggestive of bronchospasm. When patients are transported to radiology, the intensive care unit or the operating room, the ETT may be accidentally dislodged. Continuous monitoring of ventilation with a capnograph can diagnose this complication early, before the patient suffers hypoxemia. Capnography has therefore been recommended for safe intrahospital transport of intubated patients.[25,26] Many anesthesia and intensive care ventilators now include a capnography trace on their home screen because the industry has recognized this monitor as a key safety component for delivering positive pressure ventilation. Transport monitors and defibrillators now also have the capability to monitor ETCO2.[27]

Attempt oxygenation with a backup bag-valve resuscitator with a PEEP Valve

Whenever clinicians encounter a problem with the ventilator, they should switch over to oxygenating the patient with a bag-valve resuscitator that incorporates a PEEP valve. This maneuver frequently corrects hypoxemia very quickly. This action would have improved oxygen saturation in this case, confirming that the hypoxemia was due to ventilator malfunction rather than ETT misplacement.

Staff should use trouble shooting algorithms for post-intubation hypoxemia and be familiar with ventilators

Before removing an ETT, clinicians should systematically review an algorithm for post-intubation hypoxia. The *DOPE* mnemonic can be used for this purpose.

- *D* stands for displaced ETT, such as inadvertent esophageal or right main stem intubation.
- *O* stands for obstruction, perhaps due to aspiration of a foreign body, a turbinate bone avulsed by a nasal ETT, or a kinked ETT.
- *P* stands for pneumothorax, which typically occurs in trauma patients with rib fractures or patients with severe chronic obstructive pulmonary disease. A small preexisting pneumothorax is often exacerbated by positive pressure ventilation, leading to tension pneumothorax with obstructive shock and cardiac arrest.
- *E* stands for equipment failure, such as a leak or stuck valve in the breathing circuit or ventilator malfunction. Lack of gas supply, as happened in this case, is a major cause of ventilator malfunction.

Finally, beyond the DOPE mnemonic, postintubation hypoxia may be due to atelectasis, which can often be corrected with a simple recruitment maneuver such as application of PEEP (40 cm H_2O) for 30 seconds.[28]

Practice intubation in a simulation environment

Clinicians who intubate patients infrequently should practice their skills with other team members in a simulation environment to improve their likelihood of success. Practicing on a simulator familiarizes them with the equipment and reduces stress when they need to perform intubation and ventilation. Experienced anesthesiologists can also benefit from simulation because they can practice a variety of "difficult airway" scenarios that are encountered only rarely in clinical practice. Practicing intubation with a flexible scope in a simulator has been particularly helpful.[29]

Take-Home Points

- Endotracheal intubation should always be confirmed with a capnograph.
- Intubated patients should be monitored with continuous capnography.
- Whenever the ventilator fails to oxygenate the patient, clinicians should try to improve oxygenation with a bag-valve resuscitation device that incorporates a PEEP valve.
- Clinicians should be familiar with troubleshooting algorithms for post-intubation hypoxemia.
- When staff perform intubation infrequently, they should practice regularly on a simulator.
- Clinicians who intubate patients should be familiar with the ventilators in their institution so that they can quickly detect a malfunction of this equipment.
- Non-invasive oxygenation devices, such as CPAP and HFNC, are often effective and may avoid some of the risks associated with intubation.

Christian Bohringer
Consulting Editor, AHRQ, Patient Safety Network (PSNet)
Professor of Anesthesiology
Department of Anesthesiology and Pain Medicine
UC Davis Health
chbohringer@ucdavis.edu

Hong Liu
Professor of Anesthesiology
Department of Anesthesiology and Pain Medicine
UC Davis Health
hualiu@ucdavis.edu

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This project was funded under contract number 75Q80119C00004 from the Agency for Healthcare Research and Quality (AHRQ), U.S. Department of Health and Human Services. The authors are solely responsible for this report's contents, findings, and conclusions, which do not necessarily represent the views of AHRQ. Readers should not interpret any statement in this report as an official position of AHRQ or of the U.S. Department of Health and Human Services. None of the authors has any affiliation or financial involvement that conflicts with the material presented in this report. View AHRQ Disclaimers