Abstract:
Rapid-sequence intubation is the standard for definitive airway management in the emergency department and requires multiple stepwise tasks where the sequence and timing are important. Optimal performance of this critical procedure can be challenging, and common pitfalls exist that emergency providers may encounter when performing rapid-sequence intubation in children. Prolonged and/or failed endotracheal intubation attempts and adverse effects are not infrequent, especially in neonates and young children. Formal standardization of the approach and use of technological advances in intubation and monitoring equipment can decrease variation in the process, improve team-level situational awareness, and mitigate risk to the patient. This article reviews the required planning and preparatory steps, and offers specific strategies aimed at mitigating the associated risks and potential pitfalls to enhance the likelihood of success and safety during the performance of this high-risk procedure in children.

Keywords:
rapid-sequence intubation; desaturation; preoxygenation; laryngoscopy; airway management; pediatrics

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A Modern and Practical Review of Rapid-Sequence Intubation in Pediatric Emergencies

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Rapid-sequence intubation (RSI) is the standard for definitive airway management in the emergency department (ED).[1–3] *Rapid-sequence intubation* is defined as the combination of preoxygenation with the administration of sedative and neuromuscular blocking medications (NMBs) in rapid succession to optimize conditions for efficient endotracheal tube placement in critically ill or injured patients while limiting the risk of patient harm.[4] Although laryngoscopy and insertion of the endotracheal tube are central to RSI, these portions of the procedure may be overrepresented in the peer-review literature and trainee education programs. In practice, RSI requires multiple stepwise tasks where the sequence and timing of steps are vital. Optimal performance of RSI can be challenging because of the severity of a patient's illness, tremendous cognitive load associated with caring for a critically ill or injured patient, and the multiple co-occurring events of an active resuscitation.

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Figure 1 depicts the general approach to RSI in our pediatric ED. This approach has been developed based on standard descriptions of RSI, greater than 7 years' experience of performing and studying RSI, and formal ongoing quality improvement work to optimize the safe performance of RSI in our ED. Through these research and improvement efforts with data collected by video review, we have participated in or reviewed videos of nearly 500 cases of RSI. The current review is based on the approach described in Figure 1 and assumes some basic knowledge of RSI. We will focus on optimizing performance of the entire RSI process, not just laryngoscopy and endotracheal tube insertion, as well as the common pitfalls that emergency care providers may encounter when performing RSI in children. Rapid-sequence intubation is appropriate for the vast majority of pediatric patients; and many of the difficult cases are due to a combination of inadequate preparation, the anxiety that accompanies any ED intubation, and deviation from the standard approach when "unexpected" issues arise after laryngoscopy begins. References are provided for statements where we are aware of available evidence in the peer-review literature. In the absence of evidence in the peer-review literature, we attempt to provide guidance based on experience.

BRIEF HISTORY OF RSI

Rapid-sequence intubation is derived from approaches developed by anesthesiologists to make emergency airway management as safe as possible for unfasted patients by attempting to limit the risk of vomiting and aspiration. We are not aware of randomized trials of RSI in a prehospital or ED setting, but decades of experience and numerous observational studies have demonstrated greater endotracheal intubation success with the addition of an NMB compared with a sedative alone.[2,1,5,6] For neonatal intensive care unit patients, randomized trials of RSI have demonstrated higher first-attempt success and improved safety when RSI is used.[7,8]

SAFETY OF RSI

Although RSI is the preferred approach for the vast majority of pediatric patients, prolonged and/or failed endotracheal intubation attempts and adverse effects are common, especially in neonates and young children.[8–12] One potential explanation for these findings may be that RSI is performed infrequently by individual providers for pediatric patients, including in the ED setting. In a study of RSI in a pediatric ED with more than 90 000 annual visits, endotracheal intubation was performed 147 times in a single year, with 123 of these instances representing RSI.[9] Nearly two thirds of pediatric emergency medicine faculty and fellow physicians in this pediatric ED did not perform a single endotracheal intubation during the 12-month study period.[13] Although data were not collected to evaluate the exposure of individual respiratory therapists, nurses, paramedics, and resident physicians, it is likely that few, if any, providers from these groups participated in enough cases of RSI to ensure optimal procedural performance based on clinical experience alone. When the relative infrequency of pediatric RSI is coupled with its complexity, significant risk emerges with substantial variation in the process and threat to patient safety.

DECISION TO PERFORM RSI

The decision to establish a definitive airway is based on many factors. In pediatric ED patients, some of the considerations include the ability to oxygenate and ventilate (eg, apnea or hypoventilation), presence or absence of airway protective reflexes, and anticipated clinical course (eg, septic shock, severe head injury in need of diagnostic neuroimaging, altered mental status). As important as knowing the indication to perform RSI is the identification of clues that RSI may prove more challenging than anticipated. Before committing to the RSI procedure, the emergency provider should assess for: (1) anticipated difficulties with performing bag mask ventilation (BMV), (2) indicators of a potentially difficult airway, and (3) an understanding of the patient's present physiology to the extent possible.

Difficult Bag Mask Ventilation

Questions to consider include the following: (1) Does the patient's facial anatomy allow for an effective mask seal? (2) Can the jaw be easily manipulated? (3) Is the airway patent when maintained by external manual manipulation? (4) Can a few breaths be given easily with BMV?

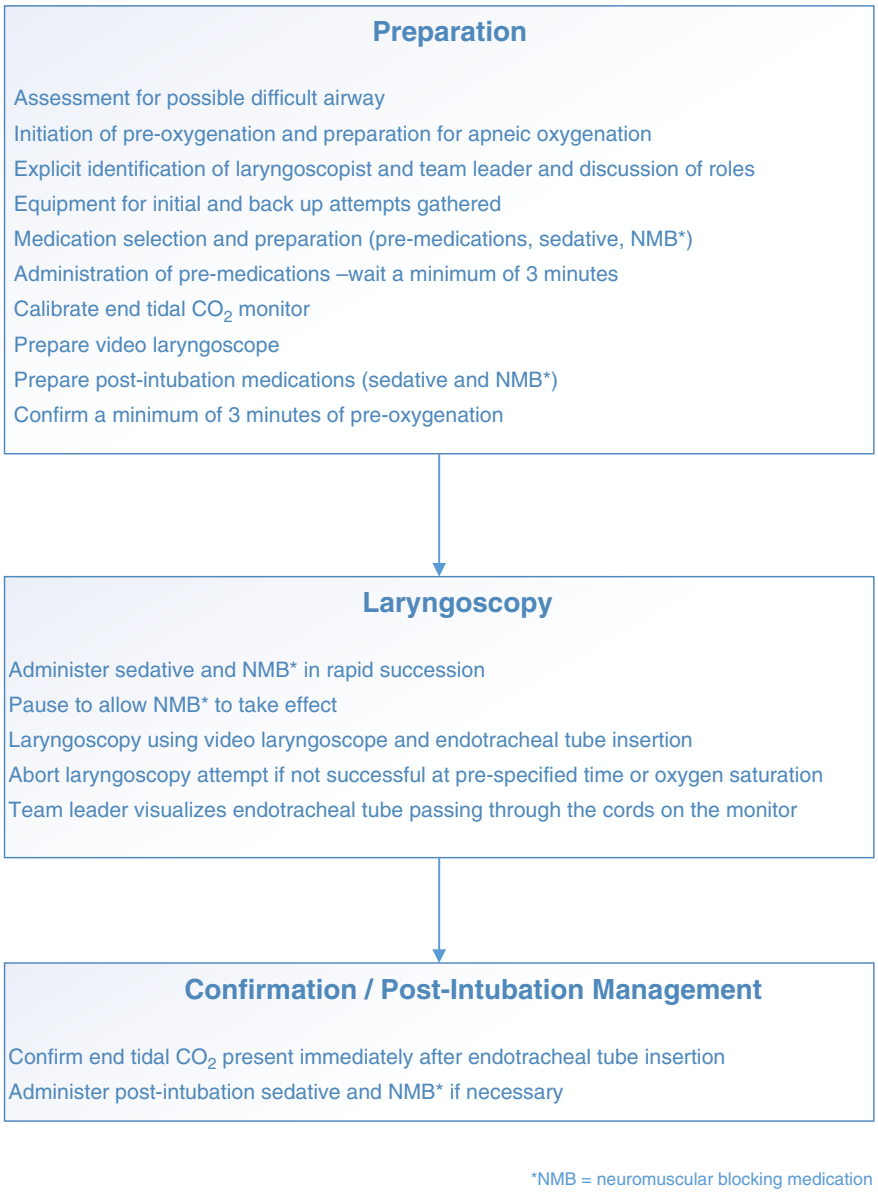

Figure 1. General approach to pediatric RSI.

Pharmacologic paralysis will alter the airway but likely not to such an extent that a pediatric patient that was easy to bag will become impossible to bag. The importance and effectiveness of achieving a mask seal using 2 hands should not be underestimated and should be the criterion standard in all cases of difficult BMV.

Difficult Airway

The basic question should be asked—Is there anything obvious to suggest that a patient's airway will not be readily visualized with a commonly used laryngoscope? The traditional anatomical measurements, as taught in airway courses, have not been evaluated in pediatric patients. A careful evaluation of neck mobility, degree of mouth opening, and for any syndromic features leading to altered facial anatomy (micrognathia, macroglossia, midface hypoplasia, etc) should be performed. Available evidence suggests that much of "difficulty" is a combination of young patients with small airways (<24 months especially), inadequate preparation, and operator inexperience and anxiety. These difficulties may be avoided by a combination of thoughtful and thorough preparation and controls on certain aspects of laryngoscopy.

In our experience, the truly difficult airway and the "can't intubate, can't ventilate" scenario are both rare in pediatric ED patients. For many emergency providers, especially for those who trained in pediatrics followed by pediatric emergency medicine, this rarity results in a false sense of security when managing the pediatric airway and undertaking the RSI procedure. The first major pitfall in the pediatric RSI process is the failure to identify a backup plan should laryngoscopy prove difficult and endotracheal tube insertion not possible. Fortunately, BMV is possible in most instances for pediatric patients, allowing the emergency provider time to formulate a new strategy when laryngoscopy and endotracheal tube insertion are not successful. However, if a backup plan has not been formulated before administration of the NMB and BMV proves difficult or impossible, the likelihood of patient morbidity and/or mortality significantly increases.

The rescue devices that are easiest to use in the pediatric ED patient are supraglottic airways including devices such as the laryngeal mask airway and the King laryngeal tube (Kingsystems, Nobleville, IN). Supraglottic airways have uncomplicated insertion techniques and can facilitate oxygenation and ventilation when laryngoscopy is difficult and BMV cannot be effectively performed.

Assessing the Patient's Physiologic Status

Questions to consider include the following: (1) Are the patient's lungs and pulmonary physiology expected to be normal or altered (eg, a patient with pneumonia [altered because of V/Q mismatch] vs a heroin overdose with apnea [normal as long as an adequate respiratory rate is provided and aspiration has not occurred])? (2) What is the maximal oxyhemoglobin saturation expected for this patient at the conclusion of the preoxygenation process? The answer to this question is directly related to that of the first question. How long is the patient likely to tolerate apnea? Has adequate circulatory support been provided to the extent possible before initiating RSI, and what are the anticipated effects of pharmacologic paralysis on hemodynamics (eg, risk of acute decrease in cardiac preload for a patient with status asthmaticus)?

PREPARATION

Failure of the procedure and untoward patient outcomes are often ascribed to a perceived inadequate performance of laryngoscopy. With optimal patient and team preparation, the laryngoscopy and endotracheal tube insertion portions of the RSI process can be safe with risk to the patient anticipated and mitigated. The following sections will highlight important considerations as preparations for RSI are made.

ROLES DURING RSI

The power and risk associated with both task fixation and loss of situational awareness have been well documented in the patient safety literature.[14,15] Rapid-sequence intubation is a complex process, and specific role assignments can help mitigate these risks. At a minimum, specific roles should include a resuscitation team leader responsible for insurance of proper preparation of all necessary equipment, orchestration of the RSI process as a whole, and monitoring of important time intervals and a laryngoscopist to visualize the glottic opening and insert the endotracheal tube. Nurses or pharmacists specifically assigned to medication preparation and administration roles should also be considered. Because of the risk associated with task fixation and loss of situational awareness, we recommend that the provider performing laryngoscopy should not simultaneously function in the role of resuscitation team leader. If the emergency physician must perform laryngoscopy and insertion of the endotracheal tube, resuscitation team leader responsibilities can temporarily be reassigned, with appropriate guidance, to a nurse team leader or other appropriately qualified member of the team.

PREOXYGENATION

The second major pitfall in the pediatric RSI process is failure to adequately preoxygenate the patient. Children are at increased risk of rapid oxyhemoglobin desaturation and hypoxia during RSI. Although this is a concern for all patients undergoing RSI given the significance of the underlying illness or injury leading to the need for RSI and the apnea induced by NMBs, the risk is amplified with younger age.[9,16] This is likely related to an increased metabolic rate and oxygen consumption in younger, critically ill or injured patients compared with those who are older. Historically, the risk of oxyhemoglobin desaturation in pediatric patients undergoing RSI in the ED was thought to be low and, in some studies, bordered on negligible.[3] Contemporary studies with improved data collection methods have demonstrated that a significant proportion of pediatric patients undergoing RSI are at risk for oxyhemoglobin desaturation[9,10] and that

young age is among the strongest predictors. Oxyhemoglobin desaturation places the patient at further risk for secondary organ injury and cardiopulmonary arrest.[17–19]

Adequate preoxygenation is typically defined as 8 vital capacity breaths in a patient that can comply or 3 uninterrupted minutes of administration of the highest achievable fraction of inspired oxygen (FIO_2).[4] The purpose of preoxygenation is to provide an oxygen reservoir from which the patient can draw once the apneic period ensues following administration of the NMB. This is accomplished through the process of nitrogen washout, which is repletion of the functional residual capacity of the lungs with the highest possible oxygen concentration compared with its usual content of room air with its 21% FIO_2.

There are several potential causes of inadequate preoxygenation. First, the period of preoxygenation may be shorter than 3 minutes in duration; or significant interruptions in the continuous administration of the oxygen occur. Interruptions in the preoxygenation process are common given the nature of critical illness/injury and the multiple competing priorities during resuscitation of the patient. If the emergency provider in charge of the RSI process is not cognizant of and monitoring for these possible interruptions, they will go unnoticed; and the patient will be suboptimally prepared for the apnea associated with the NMB, laryngoscopy, and endotracheal tube insertion attempts. Second, although a high concentration of oxygen may be being administered by nonrebreathing face mask or by the application of continuous positive airway pressure using a flow-inflating anesthesia bag, the patient's minute ventilation is inadequate to achieve optimal preoxygenation; and this goes unrecognized by the emergency provider orchestrating the RSI process. Inadequate minute ventilation can result from an insufficient respiratory rate (eg, apnea or bradypnea) or reduced tidal volume (eg, hypopnea). Apnea or bradypnea can be recognized through auscultation of breath sounds or through cardiorespiratory monitoring equipment; but in the chaos of resuscitation, these findings may be underappreciated. Capnography/capnometry provides information regarding not only the respiratory rate but also the adequacy of tidal volume and can aid emergency providers with recognition of hypopnea. Of the 2 types of hypoventilation (apnea/bradypnea and hypopnea), hypopneic hypoventilation is likely more common and is also more challenging to recognize without the use of capnography/capnometry because the respiratory rate may appear normal by auscultation or traditional cardiorespiratory monitoring. When tidal volume is inadequate, the proportion of dead space ventilation increases, thereby limiting the effectiveness of preoxygenation and placing the patient at risk for rapid oxyhemoglobin desaturation once the NMB is administered. For preoxygenation to be effective, any patient demonstrating hypoventilation or apnea requires preoxygenation with BMV and 100% FIO_2 rather than a nonrebreathing face mask or continuous positive airway pressure.

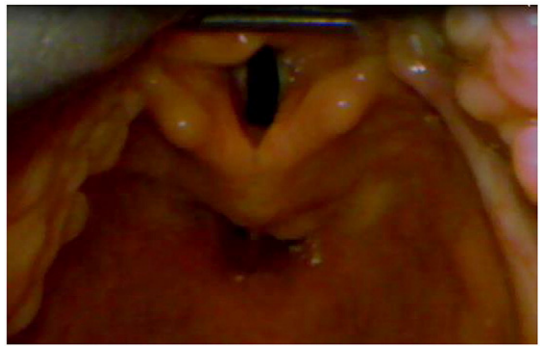

Figure 2. Typical view available on video laryngoscope screen.

APNEIC OXYGENATION

Once the NMB has been administered, a period of apnea ensues within approximately 30 to 60 seconds and lasts anywhere from a few minutes up to 45 minutes depending on the specific NMB administered and its associated dosing. With the onset of apnea, depletion of the oxygen reservoir that was achieved with effective preoxygenation begins. Once the reservoir is depleted, oxyhemoglobin desaturation will occur. Apneic oxygenation represents supplemental oxygen administered via a nasal cannula that is thought to passively diffuse through the large airways to the alveoli to supplement the oxygen reservoir during the apneic period with a goal of prolonging the time before oxyhemoglobin desaturation occurs. Although the evidence basis for clinical effectiveness is limited, apneic oxygenation is recommended by experts to delay the onset of hypoxemia.[20] Specific recommendations for flow rates for apneic oxygenation have been proposed for adult patients, but evidence-based recommendations are lacking for pediatric patients. If used, we recommend 2 L/min for patients younger than 3 years, 4 L/min for those 3 to 8 years of age, and 6 L/min for those older than 8 years, although data regarding optimal flow rates are currently not available. The nasal cannula should be applied and the flow rate initiated before administration of the NMB.

EQUIPMENT SELECTION

Laryngoscope and Blades

The third major pitfall in the pediatric RSI process is having only a single person, especially when a trainee is performing laryngoscopy, with a view of the glottis during laryngoscopy and endotracheal tube insertion. Historically, direct visualization of the larynx and glottic opening with a curved or straight laryngoscope blade was the standard approach. Video laryngoscopes provide the added functionality of a video image of the events transpiring intraorally, events traditionally only visible to the emergency provider using the laryngoscope to perform direct laryngoscopy. Figure 2 depicts a typical view available on a video laryngoscope screen. Video laryngoscopy, in which the emergency provider responsible for inserting the endotracheal tube visualizes the larynx and glottic opening on a video screen rather than directly, is increasingly popular and is perhaps the most intensely researched aspect of emergency airway management presently. Recent evidence suggests that video laryngoscopy may be superior for glottic visualization and successful endotracheal tube insertion during emergent adult intubation, including in the ED.[21–26] However, there are also studies from several settings to suggest that video laryngoscopy is associated with longer duration of laryngoscopy,[27,28] which we have found to be independently associated with oxyhemoglobin desaturation.[16] Some video laryngoscopes, such as the Storz C-MAC (Karl Storz, Tuttlingen,Germany), use laryngoscope blades almost identical in size, shape, and curvature to traditional direct laryngoscope blades, allowing the performance of direct laryngoscopy by the intubating provider while projecting the intraoral view on the video screen. Providing a view of laryngoscopy to other resuscitation team members can enhance cross-checking during laryngoscopy and raise team-level situational awareness, facilitating earlier recognition of a failing laryngoscopy attempt and decreasing the likelihood that a misplaced endotracheal tube goes unrecognized. We strongly encourage use of a blade/device that allows other providers in the room to view the laryngoscopy and endotracheal tube insertion process as a means of decreasing the risk of esophageal intubation and increasing the margin for patient safety.

Endotracheal Tube Types and Stylets

The selection of endotracheal tube size and curvature, and the use of a stylet are not without potential risks. Tube size selection is based on the internal diameter of the tube, with smaller-diameter tubes also being shorter to allow for correct positioning in the central trachea. Risks associated with a tube that is too large include airway injury and main stem intubation, and those associated with a tube that is too small include air leak resulting in inadequate oxygenation/ventilation and high tracheal positioning with risk for unplanned extubation. We recommend always preparing a smaller-sized endotracheal tube with stylet before administering the sedative and NMB in the event that the initial endotracheal tube choice ends up being too large. This allows for rapid exchange of the tubes with minimal impediment during the laryngoscopy attempt.

Traditional teaching has been to use uncuffed endotracheal tubes in children younger than 8 years based on the funnel-shaped nature of the pediatric airway providing a physiologic seal. Before wide adoption,[29] there were concerns about an increased risk of airway mucosal injury when cuffed tubes were used for children. Newer evidence suggests that there is no increased risk of subglottic injury or stenosis as long as cuff pressures are monitored.[30,31] The benefits of a cuffed endotracheal tube include the ability to provide higher peak inspiratory pressures often required to maintain oxygenation in patients with intrinsic lung disease and associated decreased compliance. Cuffed endotracheal tubes may also decrease the risk of aspiration.[30,32–35]

Occasionally, the cuffed portion of the endotracheal tube may catch on the vocal cords when tube insertion is attempted and the oral mucosa is desiccated from underlying dehydration or as a result of BMV. This risk can be minimized by the application of a small amount of sterile, water-based lubricant to the cuffed portion of the endotracheal tube before the insertion attempt. Newer Micro-cuff endotracheal tubes[36] have a more streamlined profile, specifically at the cuffed portion of the tube, also minimizing this risk. Although endotracheal tubes are often inserted in the operating room setting without the presence of a stylet, we would encourage routine use of a stylet for pediatric emergency patients.

Suction

It is prudent to prepare both Yankauer-tip suction as well as catheter-tip suction devices that may be required during laryngoscopy to clear secretions or blood. Likewise, it is wise to test the function of the suction apparatus before initiating RSI. Organizing the right-sized suction catheter adjacent to the endotracheal tubes selected will reduce confusion and potential error during the procedure.

TABLE 1. Commonly used RSI sedative medications.

Sedative	Benefits	Risks
Etomidate	Minimal risk of hypotension Rapid onset Established record of effectiveness	Adrenal suppression—especially in septic shock Inadequate duration of sedation if used in combination with a long-acting NMB
Ketamine	May augment blood pressure in shock state and prevent post-RSI hypotension Established record of effectiveness	Medication administration error due to difference in rate of administration for sedation (slow push over 1-2 min) vs RSI (rapid push followed by NMB) Increased systemic vascular resistance may be deleterious in cardiogenic shock Theoretical risk of neuronal injury in neonates based on animal studies
Fentanyl	Less risk of hypotension than benzodiazepines and barbiturates Established record of effectiveness	Medication dosing error due to difference in dosing for pain control (1-2 μg/kg per dose) vs sedation for RSI (5-10 μg/kg per dose followed by NMB) Rigid chest
Propofol	Rapid onset Established record of effectiveness	Hypotension

RSI MEDICATION SELECTION

RSI medications include premedications, sedative, and NMBs, each category with unique considerations.

Premedications

In our experience, premedications are often prepared with the sedative and NMB; and if brought to the bedside together, co-preparation may result in a delay in the administration of the sedative and NMB, as premedications should be given a minimum of 3 minutes before the sedative and NMB.[37] A timer can be useful when activated at the time of administration of the premedications and set to alarm after 3 minutes. This allows the emergency provider in charge of the RSI process to be easily notified once the appropriate amount of time has passed without having to watch the clock themselves when cognitive load is already high.

Traditional RSI premedications include: (1) atropine for the prevention of bradycardia associated with laryngoscopy in infants and also with the administration of succinylcholine in all young patients and, (2) lidocaine and/or fentanyl to mitigate potential cardiovascular and neurological effects of laryngoscopy. The American Heart Association recommends the administration of atropine for any patient younger than 12 months and any patient younger than 5 years who will receive succinylcholine. It is also reasonable to consider atropine for any patient receiving a second dose of succinylcholine and any patient who has experienced bradycardia during the resuscitation before the initiation of the RSI process.[38]

Although high-quality studies have not been published and the subject remains controversial,[39,40] expert opinion supports the use of systemic lidocaine to mitigate increases in intracranial pressure due to laryngoscopy.[4] Fentanyl has also been recommended to mitigate both the risk of increased intracranial pressure and the cardiovascular response to laryngoscopy.[4] As the pediatric literature is especially limited, we defer to local standard of care on the use of lidocaine or fentanyl as premedications for pediatric RSI.

Sedative Medications

Sedative/dissociative medications are of most benefit to a patient whose mental state would allow them to experience the pain and anxiety associated with endotracheal intubation and pharmacologic paralysis. If a patient is obtunded or if his or her mental status is markedly altered (eg, a postictal seizure patient with hypoventilation or apnea resulting from the postictal state), then the benefit of the sedative may be negligible. If there is any doubt regarding the patient's ability to appreciate noxious stimuli, the sedative should be used. Choice of sedative is up to the emergency provider. Table 1 displays commonly used sedative medications with their potential risks and benefits.

The duration of action of candidate sedatives should be considered so as to prevent waning effect of the sedative resulting in an increasingly alert patient who continues to be pharmacologically paralyzed. The duration of action of etomidate, one of the most commonly used sedatives, is approximately 10 minutes or less. It should be followed by additional sedative medication if repeat laryngoscopy attempts are required or immediately after the endotracheal tube has been secured on the successful attempt. A benefit of ketamine, a sedative/dissociative increasing in popularity, is its longer duration of action. If fentanyl is used, significantly higher doses than those used for pain control are required if the goal is rendering the patient unaware during the procedure.

Neuromuscular Blocking Medications

The NMB achieves pharmacologic paralysis and leaves the patient in a flaccid state that provides optimal conditions for laryngoscopy and insertion of the endotracheal tube, increasing the likelihood of success in the shortest period of time. Aside from cases of cardiac arrest, most patients will likely retain some muscle tone and protective airway reflexes, inhibiting the effectiveness of laryngoscopy and visualization of the glottic opening in the absence of the NMB. Therefore, the NMB is almost always of benefit. Table 2 displays commonly used NMBs with potential risks and benefits.

Succinylcholine and rocuronium are the 2 most commonly used NMBs for pediatric RSI, with rocuronium being preferred over vecuronium because of a shorter duration of action. In a meta-analysis updated in 2008 including 37 studies, succinylcholine was associated with superior intubating conditions compared with rocuronium overall; but in a subgroup analysis for children, there was no difference noted in intubating conditions or time to achieve them between the 2 medications when succinylcholine was dosed at 1 to 1.5 mg/kg and rocuronium at 0.9 to 1.2 mg/kg.[41–44] Rocuronium dosed at 0.6 mg/kg was noted to take significantly longer to achieve desired intubating conditions.[42,44,45] It should be noted, however, that the pediatric studies constituting the subgroup analysis had small sample sizes leading to limited power to detect a difference. Succinylcholine should be avoided in patients with unstable skeletal muscle membranes/neuromuscular junctions (eg, certain muscular diseases, long-standing crush/burn injuries, stroke). Succinylcholine should also be used with caution in patients at risk for hyperkalemia because it has been shown to acutely increase the serum potassium concentration by 0.5 to 1 mEq/L.[46,47] Many emergency providers prefer succinylcholine because of its short duration of action with the thought that if the endotracheal tube is not able to be successfully inserted, then the patient will resume spontaneous respiration in a relatively short period of time. This is true as long as the patient can be bag mask ventilated during the apneic period. If a "can't intubate, can't ventilate" scenario were to arise, the apneic period associated with succinylcholine is likely long enough to induce morbidity. Rocuronium can be used for patients at risk for hyperkalemia that might be exacerbated by the administration of succinylcholine. Rocuronium has a prolonged duration of action, up to 45 minutes.

RSI MEDICATION ADMINISTRATION

Because of the infrequency of the RSI procedure, nurses, especially those who have worked only in a pediatric emergency department setting, may be unfamiliar with the optimal method for administration of the RSI medications, especially when medications such as ketamine are used, which are administered over different time periods depending on whether the indication is procedural sedation or sedation for the RSI process. The sedative should be rapidly pushed followed by an isotonic sodium chloride solution flush; and immediately thereafter, the NMB should be rapidly pushed followed by an isotonic sodium chloride solution flush. A common error is the slow or prolonged administration of either/both the sedative and NMB. Although both medications are pushed in rapid succession, the sedative will take effect before the NMB, avoiding a "paralyzed but not sedated" situation. During pilot work for our RSI improvement initiative, we found that sedative flush–NMB flush could be completed in less than 30 seconds, which remains our standard approach.

The fourth major pitfall in the pediatric RSI process is initiating laryngoscopy before the NMB taking full effect.[9] In our original study of RSI, 10% of first-attempt failures were due to the emergency provider not waiting long enough after administration of the NMB to initiate laryngoscopy. Not only is laryngoscopy more difficult in this situation secondary to the persisting muscle tone, but vomiting and aspiration may be induced if protective airway reflexes remain intact. As a result of our improvement work around RSI, we now use a timer to "force" a 45-second pause after administration of the NMB; and when this time limit is adhered to, we have nearly eliminated attempt failure due to patient movement and/or gagging.

TABLE 2. Commonly used RSI neuromuscular blocking medications.

NMB	Benefits	Risks
Succinylcholine	Rapid onset Short duration of action Established record of effectiveness	Need for redosing if initial intubation attempt fails because of short duration of action Induction of hyperkalemia Bradycardia—especially with 2nd dose
Rocuronium	Safe with hyperkalemia Improved intubating conditions compared with vecuronium because of shorter time to onset	Long duration of action may impact ability to ventilate/oxygenate in case of failed intubation attempt
Vecuronium	Safe with hyperkalemia	Long duration of action Less optimal intubating conditions compared with rocuronium

LARYNGOSCOPY AND ENDOTRACHEAL TUBE INSERTION

The fifth major pitfall in the pediatric RSI process is the delayed recognition of a failing laryngoscopy attempt. In the pediatric emergency department and likely anywhere children are undergoing RSI, emergency providers performing laryngoscopy and intubation may not achieve true procedural proficiency in pediatric patients largely because of inadequate experience secondary to infrequent exposure. As a result, prolonged laryngoscopy attempts are more common. For young children with critical illness or injury, prolonged laryngoscopy attempts and the associated apnea are perhaps the single greatest threat during RSI. Historically, little objective evidence has been available to guide emergency providers in determining safe limits on the duration of individual laryngoscopy attempts for the pediatric emergency patient. The available peer-review literature has suggested that an increasing number of laryngoscopy attempts may be associated with an increased risk of adverse events.[10,12,48,49] However, as the length of an individual laryngoscopy attempt increases with the associated increase in apnea time for the patient, the risk of an adverse event likely increases as well because of depletion in the oxygen reservoir. As noted above, we have reported that the individual and cumulative duration of laryngoscopy, rather than the total number of laryngoscopy attempts, is more strongly associated with oxyhemoglobin desaturation.[16] Laryngoscopy attempts lasting beyond 30 seconds are 6 times more likely, when compared with those lasting 30 seconds or less, to result in oxyhemoglobin desaturation. After a certain point, it is likely that prolonging the laryngoscopy attempt duration further is unlikely to lead to a successful intubation and is more likely to lead to an adverse event.

In addition to laryngoscopy attempt duration, the emergency provider must consider individual patient physiology when assessing the safety of continuing a laryngoscopy attempt. When an oxyhemoglobin saturation of 100% can be achieved during the preoxygenation phase of the RSI process, a longer laryngoscopy attempt duration is likely to be tolerated without significant oxyhemoglobin desaturation. When starting on the steep portion of the oxyhemoglobin dissociation curve, little time remains available before a critical level of desaturation occurs. In one study, investigators found that intervening at the time of desaturation to 95% prevented nearly all episodes of hypoxemia to less than 90%, whereas patients allowed to fall to 90% were likely to drop significantly below that cutoff, and several experienced associated bradycardia.[50] Emergency providers performing pediatric RSI should be cautious of multiple, prolonged laryngoscopy attempts leading to progressively more profound episodes of hypoxemia because this is the situation that ultimately leads to bradycardia and pulseless arrest. Although fortunately uncommon, we have observed this scenario several times over 7 years of RSI investigation.

Based on the best available evidence and the results of our improvement work, we recommend ending a laryngoscopy attempt at 45 seconds or if the oxyhemoglobin saturation approaches 90%, assuming a beginning oxyhemoglobin saturation of 100%. In both our original study and improvement work, the vast majority of patients began RSI with oxygen saturations at or near 100%. As with duration of preoxygenation and the 45-second pause after NMB administration, a timer with an audible alarm may help improve situation awareness and promote safely ending the laryngoscopy attempt at 45 seconds, especially when an authority gradient exists or is perceived to exist between the

provider performing laryngoscopy and the provider supervising the RSI process.

CONFIRMATION OF ENDOTRACHEAL TUBE PLACEMENT

The sixth major pitfall in the pediatric RSI process is prioritization of methods other than capnography/capnometry to confirm tracheal location of the tube. The confirmatory method with the strongest evidence base to confirm tracheal location is capnography/capnometry.[51,52] In our experience, teams tend to default to auscultation as the primary confirmatory method, especially during critical situations or more chaotic resuscitations. With the exception of auscultation being used to distinguish between tracheal and main stem bronchus positioning of the endotracheal tube tip, available evidence clearly supports the superiority of capnography/capnometry in determining tracheal vs nontracheal position of the tube. In the absence of a capnography waveform and/or a reasonable capnometry value within 10 to 20 seconds of endotracheal tube placement in a patient with a perfusing rhythm, we recommend removal of the endotracheal tube and reoxygenation with BMV. Most importantly, providers should not wait for oxyhemoglobin desaturation to occur before removal of the misplaced endotracheal tube.

In our experience, video visualization, by a member of the care team in addition to the provider performing laryngoscopy, of the endotracheal tube passing through the vocal cords may be as accurate as capnography/capnometry. The combination of capnography and video visualization when available may be the ideal approach to confirmation of appropriate tube placement. Confirmatory methods such as bilateral chest rise, auscultation of breath sounds, mist in the endotracheal tube, and absence of sounds in the region of the stomach can all be used as adjunctive methods for confirmation once one or both of the abovementioned methods have primarily confirmed tracheal location of the tube. These methods should not be used as the primary mode of confirmation.

UNSUCCESSFUL ATTEMPTS

Unsuccessful laryngoscopy attempts should be expected and planned for when performing RSI, especially for children in academic settings where trainees perform laryngoscopy. Key aspects to consider include reoxygenation to optimally replete the oxygen reservoir; additional dosing of sedative and NMB, if indicated; keeping in mind the short expected duration of action of sedatives such as etomidate and NMBs such as succinylcholine; and a planned change in approach from the unsuccessful laryngoscopy attempt to optimize chances that the same result does not reoccur.

For reoxygenation, we recommend BMV to achieve the highest possible oxyhemoglobin saturation, with continued BMV for a minimum of 1 minute at the highest achievable oxyhemoglobin saturation before the next laryngoscopy attempt. The emergency provider should consider placement of an oral or nasopharyngeal airway to facilitate BMV.

If etomidate has been used as the sedative or succinylcholine as the NMB, we recommend additional doses of each if 10 minutes or more has elapsed since the initial medication administration. This time period often represents 2 unsuccessful cycles of laryngoscopy, endotracheal tube insertion attempt, and reoxygenation with BMV.

An explicit discussion of the planned change in approach from the unsuccessful attempt should occur. Potential changes to consider include adjusting positioning of the patient; selection of additional or different equipment, for example, an endotracheal tube that is 1 size smaller; switching the laryngoscopist; and a call for assistance from other airway management experts if available, such as anesthesia or otolaryngology.

IMMEDIATE POST-RSI CARE

As part of the preparatory process before laryngoscopy and endotracheal tube insertion, postintubation medications should be planned for and prepared. Key considerations include adequate postintubation sedation and continued pharmacologic paralysis if necessary. If these medications are prepared before laryngoscopy and endotracheal tube insertion, they will be readily available to facilitate securing the tube and decrease the risk of waning sedative effect while other postintubation management is performed.

Transition of the patient to the ventilator is also an important consideration. When performing BMV by hand during critical situations, there is a risk of overventilating the patient that could place the patient at increased risk in situations such as traumatic brain injury. The ventilator provides steady ventilation and optimizes oxygenation through the provision of positive end-expiratory pressure, thereby improving alveolar recruitment.

ADVERSE EVENTS ASSOCIATED WITH RSI

Table 3 displays common adverse events associated with the RSI process and potential mitigation strategies.

TABLE 3. Common adverse events associated with RSI and mitigation strategies.

Adverse Event	Mitigation Strategy
Desaturation	Adequate preoxygenation ·Minimum 3 min of 100% FIO_2 ·Uninterrupted ·Adequate minute ventilation to accomplish (use capnography to confirm) Apneic oxygenation Limit laryngoscopy attempt duration based on time elapsed, patient characteristics, and oxygen saturation Remove ETT if placement not confirmed immediately with capnography (do not wait for desaturation) Adequate reoxygenation between failed attempt(s) ·BVM with oral airway ·Minimum of 60 s at highest achievable oxygen saturation
Bradycardia	Premedication with atropine when indicated ·Age <12 mo ·Age <5 y and receiving succinylcholine ·Any patient receiving a 2nd dose of succinylcholine ·Any patient experiencing bradycardia during resuscitation before RSI Avoid desaturation (see above)
Hypotension	Assess for risk and treat preexisting hypotension with fluid administration or blood pressure support before initiating RSI
Inadequate paralysis	Wait 45 s after NMB before attempting laryngoscopy Careful consideration of need to redose sedative and NMB after failed attempt(s)
Esophageal intubation	Visualization of laryngoscopy by team members *other than the laryngoscopist* (video laryngoscope screen) Immediate capnography with removal of ETT before desaturation if capnography does not confirm tracheal placement
Right main stem bronchus intubation	Discussion of appropriate ETT depth before placement Auscultation to assess equality of breath sounds Attention to postintubation chest radiograph
Unanticipated extubation	Immediate and careful attention to postintubation sedation

ETT indicates endotracheal tube.

MISCELLANEOUS CONSIDERATIONS

The indication and optimal timing for placement of a nasogastric (NG) or orogastric (OG) tube during the RSI process are unclear. As BMV proceeds, either as required for preoxygenation in the apneic or hypoventilating patient or as needed for reoxygenation after an unsuccessful laryngoscopy attempt, the risk of gastric insufflation occurring and limiting lung expansion increases. This risk may be partially mitigated, depending on the anatomic relationship of the trachea and the esophagus, by the application of gentle cricoid pressure that has been demonstrated in some studies to limit gastric insufflation.[32,53–55] The restrictive physiology created by gastric inflation can limit effective oxygenation. Placement of an NG/OG tube can decompress the stomach, resolving the restrictive physiology. It can also be used to evacuate stomach contents, reducing the likelihood of passive regurgitation. The risks associated with placement of the NG/OG tube include interruption of preoxygenation; induction of vomiting, with the potential for aspiration, if the gag reflex is intact; and increased difficulty achieving an adequate mask seal during BMV.

GONE BY THE WAYSIDE

The manual application of cricoid pressure (Sellick maneuver) used to be a standard component of the RSI process thought to decrease the risk of passive regurgitation and aspiration. There is evidence that the esophagus is not directly posterior to the trachea in some patients and may only be moved laterally with cricoid pressure.[56,57] Cricoid pressure may still be used during BMV, as mentioned above, in an attempt to prevent gastric

insufflation in physiologically or pharmacologically sedated patients. However, there are numerous studies reporting that routine, blind application of cricoid pressure leads to unpredictable effects on glottic exposure.[58–60] Therefore, cricoid pressure should not be routinely used during endotracheal intubation and should be distinguished from dynamic external laryngeal manipulation, an approach that might be made more effective when combined with the use of a video laryngoscope.[61,62]

CUTTING-EDGE TECHNIQUES/AREAS OF UNCERTAINTY

Delayed-sequence intubation represents a departure from the typical sequence of medication administration described for RSI. Characteristics of certain patients including altered mental status, combativeness, and agitation may prevent the delivery of optimal preoxygenation. Delayed-sequence intubation has been described as a method to facilitate preoxygenation taking advantage of ketamine's dissociative properties.[20] Ketamine is the sedative of choice for this procedure given that airway reflexes and spontaneous ventilation are unimpeded. The dissociated state then allows for the delivery of preoxygenation in the usual manner.

RSI QUALITY ASSURANCE PROGRAM

The final major pitfall in the pediatric RSI process is the lack of a formal quality assurance and quality improvement program. Based on our experience, ongoing monitoring of the process and regular and timely feedback on performance to the emergency providers who perform RSI are what ultimately promotes culture change. Ongoing monitoring allows for detection of unnecessary variation that may lead to increased risk and unwelcome outcomes. Formal standardization of the approach to RSI can decrease variation in the process. Reduction in variation increases the familiarity of all staff with the expected process, thereby leading to improved situation awareness and empowerment of nonphysician team members to speak up and contribute to the safety of RSI when practice deviates from the standard.

SUMMARY

Rapid-sequence intubation is best viewed as a stepwise process where the sequence and timing of steps are vital. Laryngoscopy and endotracheal tube insertion are but one step in the process. Planning and preparation in combination with knowledge of the associated risks and potential pitfalls will enhance the likelihood of success in this high-risk procedure.

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