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Advances in Pediatric Airway Simulation Training: A Review of Current Instructional Methods

Calista L. Dominy[1*], Margaret Downes[1], Orli Weiss[1], Grace Rabinowitz[1], Sida Chen[1], Aldo Londino[1]

Department of Otolaryngology, Icahn School of Medicine at Mount Sinai, USA

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[*]Corresponding author: Calista L. Dominy, Department of Otolaryngology, Icahn School of Medicine at Mount Sinai, USA

ABSTRACT

Aims: Simulation in creates an educational environment to practice techniques and work through clinical scenarios. Endoscopic management of the pediatric airway is high acuity and risk, but low frequency, thus serving as an ideal candidate for simulation training. The goal of this study was to assess the state of resident simulation training in management of the pediatric airway.

Methods: A literature review was performed through PubMED, with the following terms queried: [pediatric airway simulation], [simulation AND airway management], [(Virtual Reality OR Augmented Reality) AND pediatric airway], [simulation training AND pediatric otolaryngology]. 34 studies were selected and evaluated by 2 independent reviewers, with 9 deemed appropriate for further review based on relevance to pediatric airway simulation.

Results: Pediatric airway management training options include virtual and augmented reality simulators, which are the most accessible but least realistic for tactile skills. Physical models include animal models, isolated laryngeal models, and full mannequin simulators. These are more expensive, less mobile, and require more extensive assembly than virtual models. Three dimensional (3D)-printed physical models are another option not yet widely used. Situational simulation-based training is a method that combines traditional immersive didactic methods with recent advancements in simulation technology.

Conclusions: Current pediatric airway simulation options lack soft tissue models with anatomical or procedural specificity. 3D-printing pediatric airway simulators could make physical models more accessible and less expensive for residency programs to implement. An increase in access to teaching modalities that combine in-person didactics with tactile simulation models can potentially improve pediatric airway management training.

Keywords: Pediatric airway simulation; Resident education; Virtual reality; 3D-printing

INTRODUCTION

The role of simulation in medical education is evolving rapidly. The COVID-19 pandemic disrupted surgical training on a global level, highlighting a need for accurate and immersive simulation as a strong supplement to surgical training.[1] As a low-prevalence, high acuity clinical scenario, pediatric airway surgery is an especially appropriate opportunity for the use of simulation. The combination of complicated operative equipment, delicate surgical technique, patient instability, and limited time create significant challenges for the early learner. Through simulation training, as the technology and fidelity continue to improve, these challenges can be offset, providing a safe and controlled environment for repetitive exposure to complex cases, improving confidence and the probability of real-time success. In this study, the current state of simulation training in pediatric airway surgery is evaluated with a focus on recent advances and future directions.

Airway procedures make up a large proportion of the pediatric otolaryngologist's practice, including a broad array of interventions ranging from foreign body removal to repairing upper airway defects. As is often stated, pediatric patients are not simply "little adults." Different anatomy and physiology can make airway management in this age group challenging for even the most experienced of clinicians.[2,3] One study of five neonatal intensive care units (NICUs) reported that 203 out of 455 (44%) tracheal intubation first attempts were successful.[4] Another study showed that the level of experience of the trainee can significantly affect intubation success. This study found that pediatric post-graduate year (PGY) 1 residents had a 33% success rate, PGY 2 and 3 residents had a 44% success rate, and neonatal fellows had a 68% success rate.[5] Previous studies have demonstrated that multidisciplinary simulation training can improve resident comfort and reduce complication rates in intubation and airway management.[6,7] Compared to controls, simulation training for airway management has been associated with improved patient outcomes (standardized mean difference = 0.86, 95% CI 0.12-1.59).[8] Accreditation bodies recognize the utility of simulation training tools. In 2020, the American College for Graduate Medical Education (ACGME) in Otolaryngology-Head and Neck Surgery accepted simulation training as a means by which residency programs can offer required didactic training to its trainees.[9]

In evaluating the current technology, surgical simulators can be virtual or physical, but many involve both elements. Virtual models may feature augmented reality, and may be more accessible due to reproducibility, reusability, and ease of transport. Some may offer haptic feedback, although this is not common to all virtual models. At this time, physical models are often able to simulate the haptics of a procedure in a way virtual simulators sometimes cannot, and include animal, isolated laryngeal, and full mannequin simulators. However, physical models can be more costly to produce, are less easily duplicated for multiple learners, and cannot be moved as easily. They vary in durability, requiring frequent maintenance or replacement. Prices can range from thousands to tens of thousands of dollars.[10] Although some simulator models currently exist to familiarize physicians with upper airway structures, otolaryngologists may require simulators more specific to their field, which go beyond securing the airway and involve more detailed anatomical structures like the subglottis, trachea, and bronchi.[11,12] The goal of this review is to assess the state of resident simulation training in the management of the pediatric airway and suggest possibilities for future advances in simulation within our field.

METHODS

A literature review was performed using search queries in the PubMED database. The following terms were used to query for articles relating to pediatric airway simulation methodologies and technologies: [pediatric airway simulation], [simulation AND airway management], [(Virtual Reality OR Augmented Reality) AND pediatric airway], [simulation training AND pediatric otolaryngology] (Table 1). After search terms were applied, 119 articles were identified. After exclusion criteria were applied, a total of 34 studies were selected for further evaluation (Table 2).[9] studies were selected for further review based on relevance to pediatric airway simulation (Figure 1).

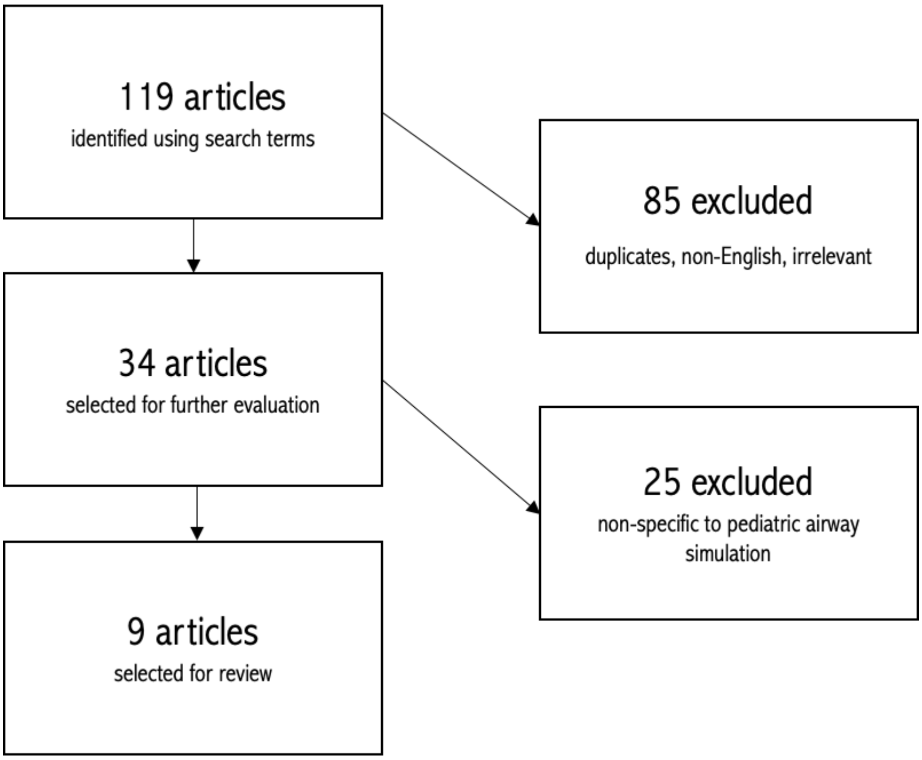

Figure 1: Flowchart depicting article selection process.

Table 1: Search methods for article identification.

Table 1. Search methods for identifying articles relevant for review
<u>PubMed</u> ▪ [pediatric airway simulation] ▪ [simulation AND airway management] ▪ [(Virtual Reality OR Augmented Reality) AND pediatric airway] ▪ [simulation training AND pediatric otolaryngology]

Table 2: Inclusion and exclusion criteria.

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Inclusion ▪ Results from term-based literature search ▪ Simulators relevant to pediatric airway management training in the field of otolaryngology **Exclusion** ▪ Simulators non-specific to pediatric population ▪ Simulators non-specific to airway management ▪ Non-English studies ▪ Duplicates ▪ No information about specific simulators available

RESULTS

Current pediatric airway management training includes virtual and physical simulation models. Of the 9 studies selected for further review, three studies focus on virtual simulators, 4 studies focus on physical simulators, one focuses on 3D-printed simulators, and one focuses on situational simulation-based training. An overview with descriptions of all reviewed simulator types can be found in Table 3. A complete list of studies included for review can be found in Table 4.

Table 3. Current options in pediatric airway simulation training.

	Type of Model	Description	Study
VR with haptics	Virtual	Virtual reality headset with gloves for touch sensation	Busaidy et al, Agasthya et al
VR without haptics	Virtual	Virtual reality headset alone	Busaidy et al, Putnam et al, Agasthya et al
IAR simulator	Virtual	Augmented reality goggles that overlay images over real world	Busaidy et al
Laryngeal model	Physical	Physical model of an isolated human larynx	Sawyer et al
Full manikin model	Physical	Full human physical model	Sawyer et al, Hinojosa et al, Schebesta et al, Blackburn et al
3D-printed model	Physical	Physical model of human larynx produced by human printer	DeBoer et al

Table 4: Descriptions of pediatric airway management training studies included for review.

Title	Author	Year	Study type	Summary
Advances in Surgical Training Using Simulation	Busaidy et al	2019	Narrative review	Review of simulation technologies and use of simulation in OMS.
Virtual reality simulation for critical pediatric airway management training.	Putnam et al	2017	Prospective	Compared efficacy and feasibility of video vs. VR in training subjects in pediatric airway emergency management.
Virtual Reality Simulation for Pediatric Airway Intubation Readiness Education.	Agasthya et al	2020	Prospective	Compared the effect of VR vs non-VR simulation on pediatric intubation training.
Neonatal airway simulators, how good are they? A comparative study of physical and functional fidelity.	Sawyer et al	2016	Retrospective	Compared 8 neonatal airway stimulators tested by a cohort of 27 neonatal healthcare professionals for model fidelity.
Anatomic accuracy, physiologic characteristics, and fidelity of very low birth weight infant airway simulators.	Hinojosa et al	2021	Comparative review	Compared the fidelity and anatomical accuracy of neonatal airway simulators with cadavers.
A comparison of paediatric airway anatomy with the SimBaby high-fidelity patient simulator.	Schebesta et al	2011	Comparative review	Compared CT images of upper airway anatomy of two simulators to MRI images of upper airways in children aged 1-11 years.
Anatomic accuracy of airway training manikins compared with humans.	Blackburn et al	2021	Comparative review	Compared CT scans of 3 adult airway training manikins to airways of patients.
Three-Dimensional Printed Pediatric Airway Model Improves Novice Learners' Flexible Bronchoscopy Skills With Minimal Direct Teaching From Faculty	DeBoer et al	2018	Prospective	Compared resident performance in bronchoscopy skills after receiving 3D simulation vs no 3D simulation.
Managing the airway catastrophe: longitudinal simulation-based curriculum to teach airway management.	Nguyen et al	2019	Prospective	Residents participated in 4 simulation-based training modules based on various clinical settings. Participants completed a self-assessment questionnaire and an exit survey using five-point Likert scales.

Virtual simulators

In virtual reality (VR) simulations, users are immersed in computer generated environments where they can engage with virtual objects or other VR users.[13-15] VR simulations can be 2- or 3-dimensional and are displayed on computer screens or through virtual reality goggles or headsets.[14-16] Virtual reality simulations rely on a completely digitized visual and auditory environment or incorporate haptic technologies which provide users with sensory feedback in addition to the virtual environment.[14,15] Augmented reality (AR) is another form of virtual model which provides computer-generated images and applies them to the external environment as overlays.[14] AR can overlay images of a patient's diagnostic scan to the patient's body during a procedure 14. Currently, the use of VR training models for various otolaryngology procedures has been linked to increased resident confidence, more efficient procedure times, and fewer intraoperative errors.[14] Additionally, learners showed increased confidence in managing pediatric airway emergencies, and had some significant improvements on pediatric anatomy and emergency airway management (i.e. how to use the Magill forceps, the proper use of the Heimlich, physical exam findings of anaphylaxis) after watching interactive teaching videos and then using a VR model to simulate the emergency procedure. Of note, feedback from participants suggested that users preferred a combination of instructional videos and VR rather than VR training alone.[13]

Physical simulators

Physical simulators are defined as models that can be directly manipulated and touched, either representing body parts, such as task trainers (head and neck models used for intubation simulation) or manikins (full-body simulators).[17] Models were scored based on a combination of anatomic fidelity, functional fidelity, visual/haptic appearance, and overall recommendation. Because the spatial relationships between oral cavity, nasal inlet, larynx and esophagus can significantly affect laryngoscopy, it was key that the models replicated anatomic relationships as accurately as possible. In addition, accurately reproducing airway resistance and compliance is essential to train users in the appropriate amount of pressure and force to use during ventilation.

For the neonatal task trainers currently on the market, evaluators ranked the order of fidelity from highest to lowest Neonatal Intubation Trainer (Laederal Medical), Newborn Airway Trainer (Syndaver Labs), and AirSim Baby (TrueCorp Medical). The Neonatal Intubation Trainer was the least expensive model at $600 with the other two priced at $1,500 each. The Syndaver Labs device was unique in its composition of SynTissue made from salt, water and fiber; although this made the model feel more realistic, it also required storage in specialized fluid when not in use. In the full-term manikin category, SimNewB was significantly more expensive at $24,000 compared to $2,100 for NewBorn Anne, likely due to increased capabilities to emulate medical distress, replicating features like cyanosis, chest and limb movements, vocal sounds, and seizures in addition to having visible chest rise and audible breath sounds with lung inflation. Despite this, SimNewB (Laederal Medical) and Newborn Anne had equally high fidelity scores, and were both considered good models for use in neonatal airway training. Price did not appear to directly correlate with value. For instance, NewBorn HAL (Gaumard Scientific) was noted to have a lower fidelity score despite having similar characteristics of SimNewB, and a similarly high price of $19,000. Although Preterm Anne was more expensive at $2,500 compared to $2,100 for Premie Blue, Premie Blue was unique in its ability to simulate cyanosis. Preterm Anne (Laederal Medical) still had the higher fidelity score for a preterm manikin compared to Premie Blue (Gaumard Scientific).[18]

Overall, reviewers gave Preterm Anne a favorable ranking and noted it as the only model that had no air leakage as well as a distance from the nasal and mouth inlets to the glottis similar to equally-sized cadavers. In spite of Preterm Anne's high anatomical accuracy, experts noted the weakness of the mouth and skin in this model and reviewers ultimately ranked two other premature manikin models, Premature AirwayPaul (SIM-Characters) and Preterm Baby (Lifecast), higher in score with Premature Airway Paul receiving the highest recommendation level overall. The final model, Premie HAL (Gaumard), was ranked unfavorably in all subcategories. Reviewers found that the anatomic features of SimBaby do not adequately simulate upper airway anatomy when compared to both CT scans and MRI images of children ages 1-11 years.[19,20] Large variations were discovered in retroglossal airspace volume, dimensions of the epiglottis, and distance between the mandible and posterior pharyngeal wall. For a full breakdown of the different physical models for pediatric airway simulation currently on the market, refer to Table 5.

Table 5: Physical models currently available for pediatric airway simulation.

Simulator Name	Company	Type	Price	Picture
SimNewB	Laerdal Medical	Full manikin	$24,000	
NewbornHAL	Gaumard Scientific	Full manikin	$19,000	
Newborn Anne	Laerdal Medical	Full manikin	$2100	
Premature Anne	Laerdal Medical	Full manikin	$2500	
Premie Blue	Gaumard Scientific	Full manikin	$2100	
Newborn Airway Trainer	Syndaver Labs	Laryngeal model	$1500	
AirSim Baby	TrueCorp Medical	Laryngeal model	$1500	
Neonatal Intubation Trainer	Laerdal Medical	Laryngeal model	$600	
Premature AirwayPaul	SimCharacters	Full manikin	Not available	
Preterm Baby	Lifecast Body Simulation	Full manikin	Not available	
Premie HAL S2209	Gaumard Scientific	Full manikin	Not available	

3D-Printed simulators

3D-printed pediatric airway models were found to improve novice learners' bronchoscopy skills. Pediatric residents trained on these 3D-printed models identified more anatomical lung markers and demonstrated shorter procedure times when compared to those not trained on the 3D-printed models. The 3D-printed models were shown to be lower in cost than traditional physical models.[21-25]

Situational simulation-based training

There have been increasing efforts to incorporate simulation-based training directly into standard curriculums of otolaryngology residency programs. Longitudinal simulation-based training that involves animal models, cadavers, and high-fidelity manikins were found to significantly improve resident technical skills in pediatric airway management, such as tracheostomy, cricothyroidotomy, and pediatric intubation. Improvements in non-technical skills like group communication, delegation, and management were also achieved after the simulation-based trainings.[26]

DISCUSSION

In the field of pediatric airway management training, opportunities exist to increase anatomic fidelity in physical models while decreasing cost through 3D printing, which has been used to create patient-specific models from computed tomography data in the past.[12] VR training is a more accessible avenue to train physicians in pediatric airway management, as elaborate scenarios can be recreated digitally and modified/personalized to maximally benefit the group in training. Although simulation training has been shown in multiple studies to be associated with improved patient outcomes, current pediatric airway models have varying levels of fidelity, mobility, and affordability. Anatomy of the upper airway is often acceptable in these models, but quality deteriorates when the realism of the glottis, subglottis, trachea and bronchial tree is scrutinized.[27] In this review, we analyzed current options for pediatric airway simulation and how they apply to training.

Virtual reality models provide the opportunity for repetitive, individualized training for different types of learners at different levels of experience. Several studies describe VR training as a method for pediatric airway management training used by physicians in multiple fields.[15] Both VR and AR can be used to connect users who are not in the same physical space, as people with access to VR technologies can use video conferencing platforms to share VR simulations with remote participants.[16] AR can be used as a tool to bring remote colleagues or experts "into" the training space virtually, to inform, guide or supervise training sessions without being physically present, expanding the presence of teachers beyond traditional limits.[14] Ideal training simulates real clinical scenarios and procedures as accurately as possible, including the feel and handling of instruments or tissue, but even a partially accurate recreation using VR can help residents improve their skills.[14] The ability to deliberately practice in a safe environment as many times, as the learner requires is common to all types of simulation and an important reason for their success. Institutions without reliable access to physical simulation laboratories or models may consider VR training as they do not require large amounts of physical space or maintenance expenses when compared to physical simulation laboratories, which can range from hundreds of thousands to millions of dollars.[16]

Findings suggest that VR may work best when incorporated with more traditional methods of didactics when compared to using the VR headset alone. This may be due to an inherent learning curve present when new technology is introduced; however, the high interest in VR from both younger residents and seasoned attending physicians suggests marked potential for growth in the field despite the growing pains of a new learning method.[13,14] As technology like the Oculus, Vive, and Playstation devices improve within the gaming industry, we may see some of these advancements leak into education and medical training.

Still, virtual reality teaching and didactics in pediatric airway management is not without criticism. Complaints are largely directed at the awkwardness of the technology.[13] Additionally, though VR simulations may be less expensive than other options, they still present cost barriers of their own. Generating virtual reality simulators relies on collaboration across disciplines of medicine, computer science, and engineering.[15] VR simulation is also an intellectual investment coordinated between experts, and learning via VR requires the purchase of supporting technology.[15] Studies evaluating specific VR systems may also not be generalizable to other VR systems because the technology could be designed in an entirely different way from company to company.[13] Finally, if VR uses haptics, it may not mimic the tactile sensations of procedures in the clinical environment with enough accuracy.[14]

In addition to virtual options, several physical models currently exist for laryngoscopy and bronchoscopy intervention training, including animal airway, biological tissue, and full manikin simulators (infant and neonatal). Comparison of certain physical models with CT and MRI imaging suggested significant deviation from the anatomic standard.[19,20] While these findings point out the difficulty of recreating an accurate physical model, they do not suggest models are an invalid method of learning, rather that there is significant room for improvement. Further refinement, perhaps with the use of compiled databases of CT or MRI imaging, may push manikins closer and closer to anatomical fidelity. Other options to increase the accuracy of how models feel and react may include the use of 3D printing, which can duplicate anatomical structure and tactile feel with increasing detail. At this point in time the technology is already advanced enough to provide real pediatric patients with long-term stents suitable for treating airway malacia.[28,29] 3D-printed models are quickly emerging as training modalities in pediatric airway simulation, with clinical trials underway to bring these options to the general marketplace.[21-34] The fidelity and validity of these models for airway intervention simulation suggest that they may solve some of the problems associated with current physical models, like anatomical inaccuracy or unrealistic mechanical properties of tissue and bone.[31,32] 3D-printed implants can also exhibit shape changes that complement growth and resorption, which is especially important for pediatric patients undergoing rapid developmental growth changes early in life, something not as relevant to the adult population.[33-36] While certain manikins reviewed had complex compositions to emulate real tissue, some unique mixtures also required special storage which may complicate their distribution or longevity, or even make them less affordable.[10] Additionally, since price did not strongly correlate with the highest fidelity rating, the ideal manikins should be cost effective as well as realistic, easy to distribute, use and re-use.[10] 3D-printing can be a great asset to training, but at this time remains expensive, with quotes ranging from $20,000 to $300,000, which may remain out of reach of a typical training program's capabilities.[36,37]

Lastly, situational simulations may provide additional benefit to technical and non-technical skills alike. They present the opportunity to practice procedures like intubation or cricothyrotomy, followed by immediate discussion and debriefing. Allowing time to process the simulation, discuss what went right and wrong and troubleshoot any technical obstacles maximizes learning and teamwork while providing an immediate opportunity to modify or improve the simulation.[26,38-39] Certain simulation-based training programs that focus on optimal team performance in pediatric airway management have shown to be beneficial in improving both technical skills (i.e. surgical manipulation and handling, dexterity, speed) and non-technical skills (i.e. group communication, leadership).[38]

Future directions

The best training may actually include a combination of multiple methods, combining traditional lecture formats with physical models in the classroom and virtual simulation for learners to use on their own time. Learners reacted better to a combination of virtual reality and traditional lecture, rather than the virtual reality system alone and preferred situational simulations that combined didactics and debrief with physical models.[13,38,39] Whether this was due to an implicit learning curve from new technology that may not exist for later generations or due to an inherent benefit of in-person instruction, it suggests that a didactic format to at least introduce new forms of simulation to learners promotes better use of the technology.[40,41]

Learning is so multifaceted that it remains difficult to make absolute statements about the best methods to teach without unintentionally barricading other options. The key takeaway from this review is that a broad approach seems best, and simulation is among the newest in an array of options for medical education with data that supports its reliability. The ideal learning tools will simulate the situation or patient realistically, be easily and accurately replicated, and widely distributed with low costs to the teacher. Simulation training, whether in physical or virtual models, represents an exciting avenue for modern medical education.

CONCLUSION

Simulation technology has proven a useful addition to pediatric airway management training. Different types of models offer their own unique benefits and disadvantages. Physical models, used in dentistry and orthopedics for years and now becoming increasingly common in otolaryngology, allow trainees to practice on devices similar to real patient anatomy without real patient risk. Virtual models offer easily accessible, affordable options that can be reused. These avenues now increasingly available to medical trainees may offer benefits to the field of pediatric otolaryngology, specifically when it comes to airway management, which can be complex, high-risk and difficult to practice in real-time clinical situations, especially for early learners. There is still ample room for growth. Although simulation training in resident education has been shown to improve technical skills and teamwork, current pediatric airway options often lack soft tissue models with enough anatomical and procedural specificity for otolaryngologists. Moreover, although virtual models for simulation (i.e. VR) offer accessibility and lower cost, users have sometimes criticized the technology for being cumbersome, or even inaccurate. The use of 3D-printing to build pediatric airway simulators could establish a middle ground between current physical and virtual models by eventually producing simulators that are more accessible, more accurate and less expensive. Finally, although we have discussed many exciting new paths that technology can take in the evolution of physician training, a balanced approach between traditional didactics and integration of simulation technology has been shown to produce the best results in terms of resident learning, comprehension, and reproducibility.

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