Simulation in Otolaryngology

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Introduction

Otolaryngologists have been at the forefront of creatively using simulation to enhance education, research, and systems processes and are now at the forefront of developing simulators and expanding the field of simulation. Simulation is not new to otolaryngologists; we have a long and proud history of developing creative ways to teach and to provide experiential learning opportunities. For example, using models almost 100 years ago that might today be called simulators, Dr. Chevalier Jackson developed bronchoesophagology techniques and principles that are still important. Dr. Jackson is said to have collaborated with George Pilling, who made medical equipment, so that custom endoscopy equipment could be created as needed based on the specific structure of the aspirated or ingested foreign body that Dr. Jackson was called upon to remove. Dr. Jackson established the bronchoesophagology course, which allowed surgeons to practice endoscopic techniques on animal models. A movie from 1925, entitled "Chevalier Jackson Demonstrating Proper Tracheotomy Technique," features Dr. Jackson performing a tracheotomy on a rag doll in the back of his limousine [1]. In a movie entitled "Chevalier Jackson 1945 Endoscopy," Dr. Jackson demonstrates the proper technique to remove an open ingested safety pin without perforating the esophagus [2]. Both movies can be viewed on the American Broncho-Esophagological Association website (http://www.abea.net).

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In other historic examples of simulation, the House Ear Institute, established in 1946, embraced practicing otologic surgical procedures on cadaveric temporal bones [3]; temporal bone laboratories remain important in otolaryngology education. Dr. Ted A Cook's classic text entitled "Basic Soft Tissue Surgery," published in 1982, uses a pig's foot model as the medium for practicing the construction of rotation flaps, Z-plasties, and other local soft tissue flaps [4]. New technologies, such as lasers and Hopkins rod telescopes, have enabled both more aggressive and less invasive surgical techniques, and even experienced surgeons value the opportunity to learn new techniques or hone existing skills using simulators.

Now, firmly in the twenty-first century, the use of simulators in otolaryngology has blossomed. There is a growing body of evidence specific to otolaryngology demonstrating the effectiveness of simulation as a learning modality [5, 6], and specific skills relevant to otolaryngology have been demonstrated to be transferrable from simulation to procedures on actual patients ("in vivo") [6]. In addition to using simulation to improve the capabilities of individuals and teams, patient care is not delivered in a vacuum, and simulators have also been integrated into otolaryngologic simulations designed to improve the systems we work within [7].

This chapter will explore the wide array of simulators that are currently available to otolaryngologists, whether purchased or adapted or constructed locally, as well as simulators which are being developed by creative otolaryngologists collaborating with engineers, educators, and others.

Otology

There is an abundance of simulators for otologic procedures. This discipline in otolaryngology is perhaps one of the most developed and active in terms of producing a variety of simulators for a wide range of procedures. Otology simulators range from simple physical models to complex,

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technologically sophisticated virtual reality devices. Physical models are often easily constructed from parts which are readily available and inexpensive. While some simulators achieve utility despite their simplicity and low cost, some provide engaging virtual reality experiences, including complex electronic assessment and feedback processes, based on high-level technology.

One of the most basic training necessities for medical students and otolaryngology residents is learning proper otoscopy including how to properly identify normal versus pathologic findings on exam. The OtoSim™ (OtoSim, Inc., Toronto, Ontario, Canada) is a commercially available otoscopy simulator that uses a realistic model ear, otoscope and high-fidelity images of tympanic membranes, and varied middle ear pathologies. One version incorporates insufflation, to simulate pneumatic otoscopy. In a study of medical students, 93% of respondents reported increased confidence in otoscopy after using OtoSim [8].

Myringotomy and ear tube insertion are often a trainee's initial experience with microscopic surgery. Simulators for this procedure allow preliminary exposure and practice with eye-microscope-hand coordination as well as experience manipulating small instruments in small spaces prior to working with real patients. There are a number of physical models that have been described for myringotomy with ear tube insertion [9–11]. Many are constructed with syringes simulating the external auditory canal and stretched plastic from a glove or other source for the tympanic membrane. These are easily constructed and can be loaded repeatedly for multiple myringotomy attempts. Volsky et al. describe a model which consists of a three-part simulator. Although this allows for greater fidelity of the auricle and external auditory canal, a consideration is that this model would require purchase of basic pieces for repeated use. It is unclear whether this is commercially available for purchase [10]. Clark, Westerberg, and Mitchell describe a low-cost microsurgery ear trainer that allows removal of ear canal foreign body, myringotomy tube placement, tympanomeatal flap elevation, myringoplasty, and middle ear tasks [12].

At our institution, our 2nd-year otolaryngology residents practice with a low-tech model, constructed from scraps of wood and a couple of hinges prior to operating on real pediatric patients. Despite the simplicity of construction, the model provides realistic challenges as instruments are manipulated in tight spatial confines with only indirect visualization of the patient's anatomy and the surgeon's hands and instruments (Fig. 1).

Others have described virtual reality simulators for myringotomy [13], with some incorporating haptic feedback [14, 15]. These require special computer programing and hardware and are not as easily available. Optimizing the quality of haptic feedback has been challenging. Monfared has developed a middle ear simulator which is high fidelity and inexpensive to produce. The middle ear ossicles are 3-D printed and loaded in a cartridge which includes other adjacent structures such as tendons, nerves, and ligaments [16]. This platform has the potential to support the performance of various middle ear surgeries.



Fig. 1 Ear simulator designed to develop skills in myringotomy in both normal and narrow ear canals. A piece of plastic inserted between the layers creates the tympanic membrane. (Courtesy of Steve Handler)

Endoscopic ear surgery is a relatively new surgical approach in otology which is gaining acceptance with surgeons. This requires surgeons to shift how they perform ear surgery, as they have only one hand available for dissection, in contrast to the availability of two hands when using a microscope. Surgeons can benefit from training with simulators to get more experience with endoscopic ear surgery. The transcanal endoscopic ear surgery (TEES) simulator is a reusable 3-D-printed task trainer. Trainees use endoscopic equipment through a simulated ear canal to move rings between posts in a simulated middle ear chamber [17]. In an ovine model, endoscopic equipment is used to perform canalplasty, middle ear dissection, myringoplasty, and ossiculoplasty [18].

For more experienced otolaryngologists, there are several temporal bone simulators that have been developed to teach the central skill of an otologic surgeon: temporal bone drilling. The conventional method of learning by drilling cadaveric temporal bones was not always called "simulation" but is consistent with the educational principles and advantages of simulation. The traditional resource of cadaveric temporal bones has been augmented by synthetic physical temporal bones that can be drilled, similarly accompanied by irrigation and suction. Some are synthetic temporal bones that can be purchased [19]. Because they are primarily bony structures, rather than soft tissue, temporal bones may be particularly suitable for 3-D printing, and several authors have described 3-D-printed temporal bones that can be drilled [20–24]. The 3-D-printed bones

allow customization to support training based on different pathologies. There are also a multitude of virtual reality temporal bone simulators including the VOXEL-MAN, Visible Ear Simulator, Mediseus temporal bone simulator, Ohio State University Simulator, and Stanford temporal bone surgical simulator, which typically combine a virtual image of the temporal bone with a physical interface shaped and held like a drill [25–29]. With advances in virtual reality technology, these simulators get better and better. Most provide haptic feedback and 3-D visual interfaces to enhance their realism. For example, the Ohio State University Simulator allows an immersive experience with audible drill sounds, haptic feedback, varied pathologies, and even training modules that evaluate and provide feedback for the trainee (Fig. 2). The VOXEL-MAN (Voxel-Man, Hamburg, Germany), Ohio State University Simulator, and Mediseus (Medic Vision, Melbourne, Australia) virtual temporal bone simulators are probably the three most studied [26, 27, 29]. Virtual temporal bone simulators can be expensive, although the software for the Visible Ear Simulator (Alexandra Institute, Aarhus, Denmark) is available for free, and only the hardware must be purchased [25]. Many virtual temporal bone simulators are not available for purchase and remain prototypes.

The future is bright with the probability of a greater variety of 3-D-printed temporal bones with more realistic coloration and enhanced feel during drilling. The potential to custom print different bones with a variety of pathologies will be helpful both for training purposes and presurgical planning. One area that is ripe for advances is the further development and availability of middle ear simulators for training residents in ossiculoplasty. Moreover, no one thus far has developed a cholesteatoma simulator – a difficult surgical entity that would likely benefit trainees.

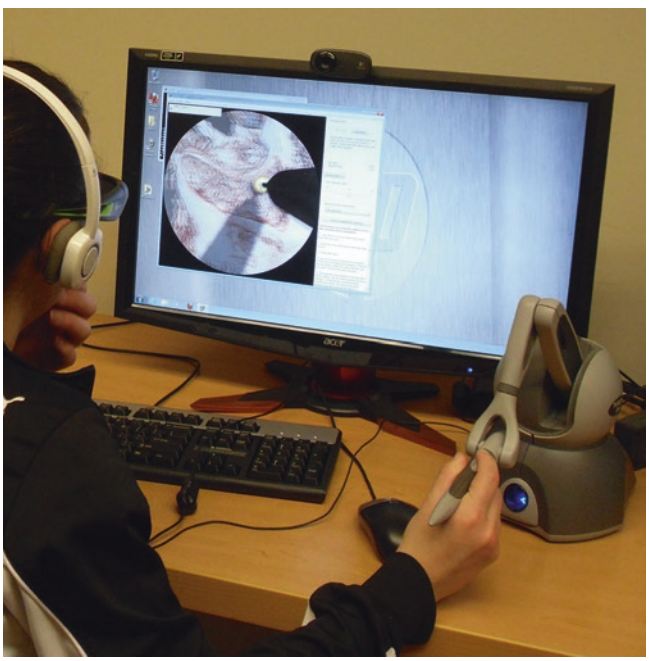


Fig. 2 Ohio State Virtual Temporal Bone Simulator, which provides 3-D visualization, as well as haptic and audible feedback

Sinus and Rhinology

Simulation for sinus and skull base procedures is especially valuable because sinus and skull base procedures have the potential to be particularly high acuity and can carry significant risk of ophthalmologic, neurologic, and intracranial complications. In addition, rhinology is the most litigated field of otolaryngology with endoscopic sinus surgery (ESS) being the most commonly litigated rhinology procedure and two-thirds of cases in a 10-year review resulting in high payouts [30]. Minor complication rates have been noted to be higher and major complication rates lower in settings with residents [31], which highlights the impact of training and experience. ESS involves keyhole surgery with advanced instrumentation, and thus there is limited opportunity for simultaneous participation of trainers and trainees. Traditional sinus surgery education, employing human and animal cadavers and live animal models [32, 33], has been shown to improve performance in an ex vivo setting and continues to be used as a primary training modality [33] However, cadaveric and animal models can be costly and complex to manage.

Fortunately, sinus and skull base surgery are particularly amenable to simulation applications since sinus tissues are more rigid and less vulnerable to deformation than many other anatomical sites. This reduces the computational requirements of electronic and virtual reality models [34]. In addition, sinus procedures rely heavily on instrumentation which can serve as devices for capturing motion data for analysis and feedback.

At the most fundamental level, simulation has been used for sino-nasal and skull base anatomical education, providing an interactive three-dimensional vantage; newer simulators can demonstrate patient-specific characteristics [35]. Medical students also reported a positive attitude toward use of the simulator as a training tool in general [36], and sinus simulation has been shown to improve test scores and time to test completion compared with controls [37].

For procedural training, several virtual-reality-based simulators for sinus surgery have been developed. The nasal endoscopy simulator (NES), among the earliest to be described, used a graphics workstation, a tracking system for measuring the position of the endoscope and surgical instruments in space, a head model, and image data sets of the nasal cavity and paranasal sinus area [38]. The lack of haptic feedback in its initial release posed a limitation; subsequent

models have incorporated haptic feedback [39, 40] but have limited validation data [41].

The endoscopic sinus surgery simulator (ES3) developed through Lockheed Martin [34] has amassed the most validity evidence of any sinus simulator currently in existence. This procedural simulator trains and assesses the performance of tasks such as sinus injection which require navigation, ambidexterity, and accuracy [42]. The hardware includes four components: (1) an SGI Octane workstation simulation platform (Silicon Graphics Inc., Mountain View, CA); (2) a personal computer-based haptic controller, providing control and coordination between a universal physical instrument handle and a set of virtual surgical instruments; (3) a personal computer-based voice-recognition-enabled instructor, which operates the simulator by responding to spoken commands; and (4) an electromechanical platform, which serves as the human interaction interface, with a replica of an endoscope, a surgical tool handle, and a rubber-headed manniquin. This simulator collects performance data throughout trainee use. Performance errors measured by this simulator were defined using a rigorous modified Delphi method with participation from experts in otolaryngology, surgical education, statistical analysis, behavioral science, and simulator development. A list of error categories was generated, and each category was discussed item by item until consensus was reached on each error attribute, classification, measurement, and reporting standard. The simulator analyzes performance data to provide formative feedback in real time regarding performance errors. It also archives data for summative result analysis and reporting [43].

Performance on the ES3 has been shown to correlate strongly with scores on the pictorial surface orientation (PicSOr), a simulator involving visuospatial perception tasks [44]. The PicSOr provides an objective test of perceptual skill that requires the respondent to orient an arrow perpendicular to a cube using cursor keys and has been shown to predict laparoscopic technical skill in three initial studies of laparoscopic performance [45]. Additional validity evidence has been shown for the ES3 in multi-institutional testing of participants ranging from novices to experts [42, 46]. Individual subjects demonstrate improvement across repeated trials and moderate term (average 35 days) skill retention [47]. The ES3 is also one of the few simulators to shown improved time, reduced errors, and greater instrument manipulation dexterity on tasks such as scope navigation, mucosal injection, middle turbinate medialization, uncinectomy, and maxillary antrostomy [6]. Despite extensive validity evidence, commercial production of the ES3 and other sino-nasal and skull base simulators has been limited by a small market, and new models are currently not available for off-the-shelf purchase.

This financial limitation has prompted exploration of lower-cost alternatives. Malekzadeh et al. described an easily reproducible sinus task trainer using a stainless steel bread pan, unflavored gelatin, eggs, suture, plastic beads, and silicone cardiopulmonary resuscitation (CPR) manniquin mask (Laerdal, Wappinger Falls, NY) [48]. The total cost was less than US$5, and it provided trainees' exposure to tasks including probing sinus recesses, targeted injections, removal of tissue (represented by suture and beads), and creating an endoscopic antrostomy into the maxillary sinus. The model was shown to have some validity evidence and has potential as a tool to evaluate endoscopic sinus skills [49]. One limitation of this model was the incorporation of biological materials, such as eggs, that decompose over time.

Subsequent sinus surgery models, such as the Seattle Sinus Simulator, have incorporated nonbiological alternatives such as silicone, molded using modeling dough, Styrofoam, and a silicone manniquin mask [50]. Combining this task trainer with a knowledge-based curriculum has shown some validity evidence. Specific tasks which can be performed include endoscopic visualization using a 0° nasal endoscope, suctioning the nasal cavity and nasopharynx, sinus injection, removing a nasopharyngeal pin using Takahashi forceps, "uncinectomy" involving removing a pin from the uncinate region with a backbiter, suctioning the maxillary sinus, using a 30° endoscope to remove a vertically oriented pin in the middle meatus, and using 45° forceps to remove a pin from inside the maxillary sinus. The overall cost was less than US$15. This model, similar to the other low-cost models described, also requires model construction time which is another required resource. In addition, though components are reusable, the silicone rubber rendering of the sinus anatomy will ultimately become worn and will need to be replaced.

Despite the limitations of the various simulators that have been developed, ESS remains a critical area within otolaryngology that benefits from simulation education given the technical and anatomical complexity, surgical risks, and keyhole nature of these procedures. With each iteration, the sophistication and complexity of sinus task trainers and curricula improve.

Airway

Laryngeal and airway simulators are well established in otolaryngology. Surgeons have been using airway simulators for a long time to teach airway skills such as intubation, microlaryngoscopy, and bronchoscopy. This has developed into using simulators to teach retrieval of airway foreign bodies and running evolving simulation scenarios that teach residents how to manage patients with difficult airway situations. For example, at our institution, collaboration with the animal care facility allows trainees to practice bronchoscopy and retrieval of a variety of airway foreign bodies from

anesthetized pigs [51]. Additionally, at a 1-day, intensive simulation-based boot camp for mid-level otolaryngology residents, simulation sessions use high-fidelity manniquin to simulate a variety of scenarios with attending surgeons acting in the role of confederates as residents manage the mannequin's deteriorating medical conditions. Sample scenarios include a tracheostomy false passage leading to a tension pneumothorax requiring quick assessment and intervention with needle decompression and management of a manniquin with a simulated post-tonsillectomy hemorrhage that requires bronchoscopic evaluation and aspiration of simulated clot from the manniquin's lower airways.

Simulation difficulty can run the gamut from accomplishing discrete psychomotor tasks using low-technology physical simulators to complex scenarios requiring high-technology manniquins and attending physician participation as confederates. The important role of simulation in airway management cannot be overstated. Practice managing airway scenarios that require quick evaluation and intervention, increasing familiarity with surgical equipment such as bronchoscopes and their attachments, and simulating rare situations such as emergent "slash" tracheotomy or needle decompression of a pneumothorax can potentially mean the difference between life and death in a real patient situation. The unpredictability and rarity of these events make them difficult to study, but testimonials demonstrate the value of preparing by using simulation [52]. The field of laryngology has also spawned new, ingenious simulators that can be used to teach microlaryngeal surgery and the safe and effective application of lasers to laryngeal surgery.

Intubation training with manniquin simulators has been described for at least 40 years using a variety of models ranging from neonatal to pediatric to adult simulators [53–56]. Some simulators are full body and include high-fidelity technologic elements that allow for realism in simulation. Capabilities include chest wall motion (e.g., unilateral chest movement to represent right main stem intubation or foreign body occlusion of one bronchus), eye blinking, ability for a confederate to supply "voice" remotely, vital signs that can change in response to medical interventions, laryngospasm and variable tongue volume, and pharyngeal obstruction. Manniquin anatomy allows participants to adjust the head and neck position and intubate and ventilate using a variety of airway devices. Several vendors make full-body electronic manniquins suitable for complex airway scenarios, and many vendors make low-technology manniquins which can be used for preliminary airway skill training (e.g., mask ventilation, intubation) or in combination with either high-technology manniquins or standardized patients to create hybrid simulations. Figure 3 shows a low-technology simulator used in a hybrid simulation based on controlling intraoral hemorrhage and then removing endobronchial clots using rigid bronchoscopy. Simulators can be used in simulating scenarios that are limited only by one's imagination. The full-body simulators can be modified to allow for more realism or to suit training needs; for example, rice cereal was placed in a bag under the skin of the SimMan (Laerdal, Wappinger Falls, NY) to simulate crepitus during simulation of a pneumothorax.



Fig. 3 Low-technology manniquin prepared to allow rigid airway endoscopy and removal of simulated clot positioned at the manniquin's carina

Besides simulators for basic airway management and intubation, there has been a flourish of development in the field of laryngology. Earlier simulators included human, porcine, or sheep larynges used for procedures such as vocal fold biopsy, vocal fold medialization with injectable materials, or submucosal vocal fold flap elevation [32, 57, 58]. The use of real biological tissue provides incredible realism; however access to these tissues or a tissue lab can be prohibitive and expensive, and organizers should be aware of local regulations. This has led to the development of nonbiological laryngeal simulators for training a variety of laryngologic surgeries. Sophisticated laryngology simulators include industry-produced custom vocal cord replicas [59], 3-D-printed models with an electromagnetic tracking system [60], 3-D-printed laryngotracheal frameworks [61], and fabricated laryngeal models with replaceable vocal cords [62]. As in other fields, 3-D printing is being used more and more to construct custom

anatomy and pathology. Ainsworth et al. describe a 3-D-printed high-fidelity laryngeal framework used with molded arytenoid cartilages and intrinsic laryngeal musculature [61]. The thyroarytenoid muscle was constructed with conductive silicone such that there is real-time feedback of successful needle placement during transcervical vocal fold injection. 3-D printing will likely be an area of growth in the future as it becomes more readily accessible by academic institutions and training programs. Ross et al. describe a 3-D-printed airway with embedded LEDs that is used to train endoscopic psychomotor skills [60].

While some of the models rely on custom manufactured systems, there are a few ingenious low-technology, low-cost models that are more readily constructed. Specifically, the Georgetown Laryngeal Model uses modular laryngeal cartridges made from rubber bands surrounded by plastic wrap within a PVC pipe [63]; the ingenious design can be used to practice a wide variety of laryngeal surgical procedures [63]. The model can be used to practice grasping and cutting sutures from the vocal cords, as well as resection of papillomas and epithelial and subepithelial lesions. The simplicity yet modularity of this simulator makes it a favorite at a regional simulation-based boot camp for mid-level otolaryngology residents. Cabrera-Muffly and colleagues describe a laryngeal injection simulator constructed from toilet paper tubes, zip ties, thin balloons, and other easily found objects [64].

Dr. James Burns has also shared a useful simulator for laser laryngeal surgery at a regional boot camp, based on his work using chick chorioallantoic membranes as a model for simulating human vocal fold microcirculation within the superficial lamina propria [65]. Residents were able to practice ablating vessels in the chorioallantoic membrane with lasers in the simulation laboratory.

Virtual reality bronchoscopic simulators replicate flexible bronchoscopy with accurate distal airway anatomy; some can give haptic feedback [51, 66–70]. There is also a bronchoscopy simulator website that provides the opportunity to explore virtual bronchoscopy using real-time video [71].

Additional Types of Simulators

There are many additional simulators to address the diversity of otolaryngology procedures, which are valuable additions to the training armamentarium. Epistaxis control is a common consultation request that junior residents often field. A high-fidelity task trainer can be constructed with a cadaveric head and IV tubing with fake blood going through the posterior cribriform plate and nasal cavity simulating a sphenopalatine artery bleed [72]. To simulate epistaxis from an anterior vascular source, a non-electronic CPR trainer can be modified in a similar manner, with the IV tubing and blood flow emerging near the nare [73].

One of the most common surgical procedures in otolaryngology and arguably one of the first for trainees to learn is the tonsillectomy. Surprisingly, there are not a lot of published reports of simulators for doing a tonsillectomy [74]; however there are several for ligation of bleeding vessels as may be encountered during tonsillectomy [74–77]. There is a virtual reality simulator of a subtotal or intracapsular tonsillectomy, with haptic feedback [78].

Interestingly, there are a myriad of peritonsillar abscess drainage simulators [72, 79–81]. Each can be constructed fairly easily using water balloons in gelatin, latex gloves filled with vanilla pudding, or even cod liver oil capsules embedded in silicone tonsil molds. All of these simulated tonsils with abscesses are inserted into the oral cavity or pharynx of a cadaveric head or task trainer.

With the expansion of robotic surgery into otolaryngology, it is important that residents get appropriate training in this novel modality. Basic maneuvering and operation of the da Vinci robot can be taught with the da Vinci Skills Simulator (Intuitive Surgical, Delaware) [82–84]. Instead of actual surgical procedures, this simulator involves the use of the da Vinci controls to navigate in a virtual reality world to complete nonanatomic tasks such as camera targeting, placing objects on a match board, placing rings on pegs, needle targeting, and energy dissection. Others have described using cadaveric heads and using the robot in a curriculum with residents to learn how to perform radical tonsillectomy, supraglottic partial laryngectomy, and base of tongue resection [85].

Simulation provides benefit in practicing techniques in facial plastics and complex wound closures. In our boot camp, we routinely use one of the most widely used simulators – a pig's foot – upon which various skin defects are created and then reconstructed using a variety of local rotation and advancement flaps. Others have described the use of open-cell foam and elastic foam tape, readily available in a hospital setting, to practice interrupted suturing maneuvers and to construct and execute local flaps [86]. Some have used a polystyrene head with molded, pigmented latex on top that can then be used to create facial defects with flap reconstruction [87]. A low-cost gelatin prosthetic facial skin simulator can be used to perform Z-plasties and bilobed, rhomboid, and paramedian forehead flaps [80].

A recent report discusses the use of ovine head and neck tissue as a simulator for performing blepharoplasty, ptosis repair, orbital floor exploration, mandibular plating, facial nerve dissection and repair, tracheotomy, laryngofissure, tracheal resection, and laryngectomy [33]. The authors found this model to be anatomically compatible, affordable, and useful for a variety of procedures.

A fine needle aspiration biopsy virtual reality simulator, which includes haptic feedback, has been described for thyroid nodules [88]. Microvascular anastomosis skills can be

practiced using chicken thigh vasculature or commercially available synthetic materials ranging from Penrose drains to small caliber tubes. IV tubing and fake blood can be used to simulate bleeding or to test for anastomotic leaks. The inverting Connell stitch commonly used in total laryngectomies can be practiced on simulated bowel.

Griffin et al. describe the first published neck dissection simulator in which they use a Blue Phantom Central Line Placement Training Model (CAE Healthcare, Montreal, Quebec, Canada) and modify it such that a selective neck dissection could be performed with real surgical instruments, complete with vascular and neural structures commonly encountered during a neck dissection [89].

Rigid esophagoscopy is an important skill to learn which can result in significant morbidity or even mortality if not performed carefully. Recently a group constructed an esophagoscopy model with force sensors under the maxillary incisor and at the tip of the esophagoscope [90].

Skills for Teams

The skills for individuals which were described in the preceding paragraphs are essential, but may not be sufficient, as almost all healthcare is delivered by teams. Otolaryngologists work with a large variety of teams because our patient care settings include the operating room, hospital inpatient and intensive care units, emergency departments, testing and rehabilitation units, and outpatient clinics. Whether an episode of patient care is routine, such as scheduled, elective surgery, or emergent, like responding to a patient in the emergency department with airway obstruction who cannot be ventilated and cannot be intubated, teams must somehow distribute responsibilities and integrate the varied capabilities of the team members. Some teams are relatively stable, such as office or operating room teams, for elective cases. Others teams are spontaneous, such as the providers who may participate in an unscheduled, emergent procedure in the operating room in the middle of the night. In either case, responsibilities are distributed by participant roles. In larger organizations, there may be several people capable of fulfilling specific roles (e.g., lead physician, medication nurse, respiratory therapist), so the exact combination of people who are available to participate in a single event may have many possible permutations.

Insufficient or ineffective communication among team members is often cited as a contributing factor when patient outcomes fall short of desires or expectations [91], but this assessment may provide a veneer of analysis with only minimal exploration of team function. Concepts related to creating and optimizing a shared mental model have been extensively explored in the human factors literature. Salas and colleagues propose a model for five key dimensions of effective teams: team leadership, mutual performance monitoring, backup behavior, adaptability, and a team orientation [92]. Weller, Boyd, and Cumin describe shared mental models, mutual respect and trust, and closed-loop communication as requirements for effective teams [93]. Endsley's classic work describes three increasingly insightful levels of situational awareness in dynamic decision-making: Level 1, perception of elements in the environment; Level 2, comprehension of the current situation; and Level 3, projection of future status [94].

Simulation, including debriefing, can be used to practice communication, improve situational awareness, and increase interdisciplinary understanding [93]. Geis et al. simulated the care of a patient with a post-tonsillectomy hemorrhage during in situ evaluations of new patient care areas before they were opened for actual patient care, with the goal of improving the capabilities of both the teams and the facilities [95].

Dr. James Kearney, Dr. Kelly Malloy, and Maria Magro developed simulations involving otolaryngology residents and student registered nurse anesthetists as learners managing a high-technology manniquin with a simulated airway fire during tracheotomy and, separately, a simulated airway fire during tonsillectomy. The simulations took place in a simulated operating room, with typical layout and equipment (e.g., monopolar electrosurgery device), and otolaryngology attendings, certified registered nurse anesthetists (CRNAs), and surgical nurses participated as "confederates" to complete the typical staffing of an operating room team. The "fire" was simulated using a commercial fog machine. Debriefing includes discussion about the information communicated between team members and the roles and responsibilities of the participants.

Volk et al. developed a simulation course involving teams of otolaryngology residents and fellows, anesthesiology residents and fellows, CRNAs, and operating room nurses as learners [96]. Providing the simulations in situ (in actual patient care locations) allowed integration of the course into regular working hours; the elimination of travel time (e.g., to a simulation center) facilitated residents' ability to spend the morning accomplishing patient care, participate in the simulation for several hours, and then participate in afternoon rounds. The authors report that the interprofessional structure improved the realism and the interpersonal and team dynamics. During debriefing, participants recognized that perceptions of the patient's diagnosis and management goals differed between team members, helping participants understand the value of good communication skills and a shared mental model.

Our teams also include the patients and their families who learn to care for themselves or for family members who have tracheotomies or other medical devices or technologies. Patients and families may improve both their skills and their

comfort by practicing tracheotomy changes on commercially available manniquins prior to having a family member with a tracheotomy discharged from the hospital. Finally, otolaryngologists also collaborate with members of teams who may not be quite as obvious. Simulation has been used to help providers learn how to use new modules in electronic health records [97] and can be used to develop and test software improvements for electronic health records.

Systems Improvements

The use of simulation for systems evaluation, process implementation, and process improvement has been well-described in other areas of medicine [98] and is a budding field in otolaryngology. Low-frequency, high-acuity events such as intraoperative emergencies (e.g., airway fire) and surgical airway codes lend themselves to multidisciplinary complex scenario simulation that can evaluate and enhance interprofessional communication and teamwork skills along with identifying systems issues.

Development of the Difficult Airway Response Team (DART) at the Johns Hopkins Hospital in Baltimore, Maryland, provides an example of the use of simulation for interdisciplinary process improvement on a large scale in otolaryngology [99]. Review of prior adverse airway events in their institution suggested that most events occurred outside the operating room, involved multiple clinical disciplines, and had ineffective communication, an outdated paging system, unreliable access to equipment and staff, and unclear provider roles as contributing factors. The authors used their findings to develop the DART, which included mechanisms to identify and label patients with at-risk airways, establishment of specialized teams and tools, and formulation of appropriate management algorithms. The program was then implemented, tested, and refined using in situ simulation in five different clinical areas of the hospital including the surgical intensive care unit, labor and delivery unit, and inpatient floor. Initial trials were used to identify barriers to mobilization in various settings and ideal locations for the airway carts. Iterative simulations enabled improvement of the DART cart design, including replacement of non-safety sharps, relocation of fiber-optic scopes to optimize infection control, standardization of light boxes, protection of the cart with a locked cover, labeling of light source connectors to decrease confusion, and routine maintenance to ensure equipment integrity. Simulation was also used for training, and helped clarify provider roles and choice of airway algorithms, and established the importance of onsite post-event debriefings which then became a standard component of the DART program.

Similarly, Johnson et al. used simulation to identify and implement process improvements in the management of pediatric airway obstruction in an emergency department resuscitation setting [7]. The evaluation phase involved six simulations based on a complex scenario with a manniquin representing a 4-year-old boy who had aspirated a grape and needed management by an ED team with otolaryngologists and anesthesiologists available for consultation. Among the safety threats identified was lack of availability of appropriately specialized airway equipment in the ED. Following the evaluation phase, an airway cart with specialized equipment, a written procedural algorithm, and a designated airway team with a team-specific paging system was developed and implemented. The subsequent six simulations were used to assess this novel system, based on objective measures such as consultant time to arrival, as well as qualitative measures, such as participant opinion about institutional preparedness.

Both examples demonstrate how simulation can be used for evaluation of systems in addition to training. This is particularly valuable in otolaryngology where many conditions occur rarely but can be imminently life-threatening and can occur in varied settings (e.g., ED, operating room, postoperative care unit, intensive care unit, inpatient floor, outpatient clinic, and home).

Simulation can be an effective tool in otolaryngology patient education. Patient education during transitions of care has been shown to reduce readmissions in surgical patients in at least three randomized controlled trials [100]. Home care that requires technical skills, such as tracheotomy care, benefits from simulation training for both patients and caregivers in both pediatric populations and in adults. With the Affordable Care Act, the Centers for Medicare and Medicaid Services (CMS) dedicated US$1 billion over 3 years to test care models to reduce hospital-acquired conditions and improve transitions of care [101]. Strategies that enhance patient and caregiver participation through education about medical conditions, appropriate care, and monitoring promise to enhance patient experience and adverse outcomes. Simulation is likely to play a significant role when advanced technical skills are needed by patients and their caregivers.

Integration into a Comprehensive Curriculum

Despite simulation's attractiveness and proven value, integrating simulation into the curriculum of our residents and fellows has been challenging. An ethical imperative to practice on simulators [102] may conflict with production pressures, but otolaryngologists have come up with creative solutions such as taking advantage of weekly lecture or conference educational time that is already protected. Successful examples include 1-h sessions in which residents or fellows practice removing "aspirated" foreign bod-

ies from high-technology manniquins while recognizing and managing oxygen desaturation, laryngospasm, and other relevant responses [103] or 1-h sessions in which residents or fellows practice designing and completing local flaps on pigs' feet [4].

Contemporary circumstances make it difficult to provide 1- or 2-week simulation-based courses in the style of visionaries like Chevalier Jackson and his bronchoesophagology course from the early twentieth century or the house group and their otology courses beginning in the mid-twentieth century [3], but a number of brief but intensive boot camps have been developed. Boot camps are often designed for novices but have also been provided for experienced faculty seeking to refresh skills that may be infrequently used. Typically, boot camps last for 1 day and address a range of technical and nontechnical skills. Because of their short duration, they are often designed to provide exposure, rather than expertise, and stimulate anticipatory thinking. Some boot camps are intended for local participants, who are learning how to access local resources. Other boot camps can accommodate up to 30 or 40 residents, require 15–20 faculty members (plus simulation staff), and provide opportunities for both learners and faculty to try out and discuss a wide variety of procedures, techniques, and philosophies.

The "ORL Emergencies Boot Camp" follows a classic educational structure, with novice otolaryngology residents learning simpler technical skills during the morning and more complex technical skills mid-day and then applying these skills while participating in teams to manage a high-technology full-sized human simulator with a medical crisis as the finale in the afternoon [104–106]. Feedback and debriefing occur during or immediately following each simulation activity. Both learners and faculty find the boot camps exhausting but satisfying and valuable [107].

Similar simulation-based boot camps have been implemented across the USA and in Canada, and many faculty attend more than one boot camp, sharing ideas and techniques. The similarities between boot camps offer opportunities to standardize specific aspects of their curricula, which could enable more rigorous evaluation of their educational impact. The differences between boot camps allow faculty to develop new simulators and new simulations, which enrich the range of available teaching options.

The Accreditation Council for Graduate Medical Education (ACGME) program requirements for graduate medical education in otolaryngology specifically mentions the option to use "surgical simulator labs" as a method to allow residents to demonstrate knowledge of anatomy through procedural skills, as a component of the core competencies [108]. Although not specifically endorsed by the ACGME, it makes sense that simulation could be used to learn or demonstrate components of each of the core competencies. For example, professionalism could be incorporated in simulations that address obtaining informed consent or delivering bad news. Systems-based practice skills could be developed by designing or participating in simulations designed to improve system-level aspects of otolaryngology healthcare delivery, like the airway emergency projects mentioned earlier in this chapter.

Simulation also has relevance for many of the ACGME otolaryngology milestones, including some level 4 and level 5 ratings. For this discussion, from a simulation perspective, the milestones [109] can be distilled into three broad domains. One domain is technical skills, such as identifying specific otolaryngologic anatomic structures, and performing procedures such as otoscopy, myringotomy, tympanostomy tube placement, mastoidectomy, and endoscopic sinus surgery; each of these skills can be demonstrated or performed on simulators [5, 6, 11]. However, the number and variety of simulators which represent aspects of the broad range of normal and abnormal otolaryngic conditions at a level of physical fidelity that would be engaging for experts are limited [110].

The second domain is cognitive knowledge. Learning and demonstrating cognitive knowledge – like discussing therapeutic options, formulating treatment plans, and interpreting diagnostic studies – can be accomplished or demonstrated in an abstract manner (e.g., by asking theoretical questions), but embedding cognitive tasks into simulations can make the tasks less abstract and more engaging and can enhance their situational and psychological fidelity.

The third domain includes patient safety, resource utilization, lifelong learning, and professionalism. In this domain, simulation can be used to develop or evaluate the capabilities of residents and fellows, and, if trainees choose to develop simulation skills themselves, simulation provides techniques that can be added to their own leadership portfolios. Simulation can be used to evaluate and improve resource utilization, to help develop cost effective care practices, or to identify and mitigate potential patient safety hazards. Trainees can demonstrate skills in systems-based practices by using simulation to analyze morbidity and mortality ("M&M") findings and then provide feedback to improve patient safety. Simulation can be used as a tool to help residents and fellows practice leadership and communication skills, and trainees may also develop simulation skills that allow them to coach and educate others to improve their own communication skills. Debriefing is an essential component of simulation, based on principles that are also relevant and can be used to understand and improve actual patient care experiences. Finally, simulation, including nonjudgmental debriefing, provides affective experiences that can foster engagement in lifelong learning.

Summary

The field of otolaryngology is both exciting and demanding because of the unique importance of the anatomic structures encompassed and the diverse nature of medical conditions which must be understood and managed. Simulation will undoubtedly expand our patient care capabilities, but the validation process is challenging because of the small numbers of residents and relatively small numbers of faculty members in each otolaryngology program and the difficulty in demonstrating direct improvement in patient outcomes from educational interventions. For both individuals and teams, simulation with facilitated debriefing can provide formative and summative feedback and may ultimately serve as a valuable tool for evaluation and certification. In response, the SimTube project, sponsored by the American Academy of Otolaryngology–Head and Neck Surgery, is designed to develop a platform to support multi-institutional evaluations of educational interventions. Commercial simulator availability is similarly challenging because otolaryngology is a specialized market. Despite these obstacles, simulation promises to deliver significant benefits for cognitive and procedural training in otolaryngology, for reentry education, for expanding our expertise as new technologies arise, and for improving the systems that we work within, and many otolaryngologists are developing simulators and designing simulations that can benefit both trainees and experienced otolaryngologists and, ultimately, our patients.

Simulation has a long history in otolaryngology, with evidence of the use of task training over 90 years ago. The subspecialty of otology has well-developed and specialized task trainers which range from low-tech, low-cost models to high-fidelity virtual reality models that can provide quantitative formative and summative feedback. These simulators can provide training that addresses basic examination skills, intermediate skills like myringotomy and tube insertion, and highly specific skills like temporal bone and skull base surgery. Rhinosinology also has robust simulator technology including several low-cost models as well as high-fidelity trainers with strong evidence for validity. Simulation applications in laryngology are broad, and include airway management, which is often a multidisciplinary activity; airway simulations that incorporate team skills, communication, and resource management are particularly valuable. Salient examples include integrated courses such as otolaryngology emergency boot camps and airway management courses that couple task training with complex scenarios and provide andragological learning with an emphasis on self-reflection and feedback.

The technical complexity of combining very specific anatomy with the varying textures and tensile properties of head and neck tissues in close juxtaposition is a significant barrier to simulator development in otolaryngology. Additionally, otolaryngology involves focused and specific applications that are relevant to a smaller audience, limiting the commercial market, and thus reducing corporate investment. Once trainers and programs are developed, this small audience also poses challenges to achieving rapid and robust validity evidence, as sample sizes are necessarily limited and trainee populations are varied.

Despite these challenges, otolaryngologists, engineers, and educators have developed several robust models, and the scholarly work around these models, and around novel educational strategies, is expanding exponentially. This trend promises to continue with the advent of 3D printing, which will undoubtedly have a prominent role in future otolaryngology simulation, and brings the opportunity to incorporate patient-specific anatomy. With increasing emphasis on quality metrics, the budding application of simulation to process improvement, including evaluation, testing, and implementation of new programs in otolaryngology, promises to flourish.

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