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REVIEW

Current State of Surgical Simulation Training in Otolaryngology: Systematic Review of Simulation Training Models

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ABSTRACT

Objective: To present an expansive list of otolaryngology-specific surgical simulation training models as described in Otolaryngology literature and to evaluate recent advances in simulation training in Otolaryngology.

Methods: An *a prior* qualitative systematic review protocol was designed. Ovid/Medline, PubMed, Embase, Web of Science, and Cochrane databases were searched from their inception with cross-referenced subject headings of *otolaryngology simulation training* and associated terms. Information from each study was systematically extracted and summary analysis was conducted.

Results: A total of 178 records were systematically reviewed to obtain 104 unique records of surgical simulation models (34 airway/laryngeal, 16 oncology/facial plastics/reconstructive, 17 rhinology, 37 otology). Of the records included, only 8 simulation models were reported in or before 2004, 20 reported between 2005 and 2009, 34 reported between 2010 and 2014, and 42 described in or after 2015. There were 50 synthetic, 21 computer-based, 19 animal cadaver, 6 human cadaver, and 8 hybrid models. Synthetic simulators were the most common type of simulators. A total of 18 of 50 synthetic simulators were formulated using 3D-printing.

Conclusions: Current literature shows the availability of several otolaryngology-specific simulation models that have proven beneficial in otolaryngologic surgical training. Recent advancements in manufacturing and computing technologies are contributing to a paradigm shift in surgical simulation education. With the availability of these options, there exists the potential to establish a well-structured and standardized approach to simulation activities across otolaryngology training programs.

INTRODUCTION

Despite the changing landscape of surgical education with work hour restrictions and decreased independence of trainees in clinical activities [1], most training programs uphold a traditional, dogmatic approach in training surgical residents that is based on a hierarchical, apprenticeship model. This model often presents a time-intensive learning curve that leaves trainees, who are often first responders, with limited knowledge, skills, and confidence to competently deal with clinical and surgical scenarios of varying complexity [2].

Given that surgical simulation training (SST) engages the two most important tenets of adult learning by permitting moderated *practical experience* in the setting of *guided reflection*, it holds great potential in the training of otolaryngologists [3]. Although surgical simulation activities can be resource intensive [4,5], the availability of an arena for deliberate practice in a risk-free, low stress environment is an effective way to acquire skills specific to the practice of a surgical subspecialty [6].

Simulation models remain a keystone in the design of high-yield simulation activities by providing apparatus for the acquisition of surgical skills which can then be transferred to patient care [7]. Simulation models fulfill the role of physical vessels that afford trainees an opportunity to hone their psychomotor and decision-making skills without the loom of patient risk [2].

With the exponential advancement of computing and manufacturing technologies, several simulation models and platforms have recently been developed and deployed in the training of surgical residents. On a broad scale, these simulation models can be categorized into synthetic bench models, computer-based models (virtual reality or web-based), animal models (tissue or live), and human cadaveric models [8], while a combination of any of these constitutes a hybrid model.

In this study, we aim to provide a systematically reviewed list of otolaryngology simulators that are documented in Otolaryngology literature and discuss recent updates in simulation training in the field of otolaryngology.

METHODS

Study Selection

With the assistance of an information specialist, an *a priori* research protocol was designed based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) methodology [9]. Subsequently, a sensitive systematic review was performed to obtain as many articles from five databases namely Ovid/Medline, PubMed, Embase, Web of Science, and Cochrane. The databases were searched from their inception through July 18th, 2018. Two investigators (M.A. and M.L.) conducted the search and reviewed selected articles. Subject headings for the search included *otolaryngology*, *otology*, *airway*, *laryngeal*, *rhinology*, *reconstructive*, *facial plastics*, and *head and neck oncology* cross-referenced with the terms *simulation*, *simulation training*, and *simulation models*. Bibliographies were manually searched to identify studies that met inclusion criteria. Inter-investigator discordances in the review process were resolved by consensus.

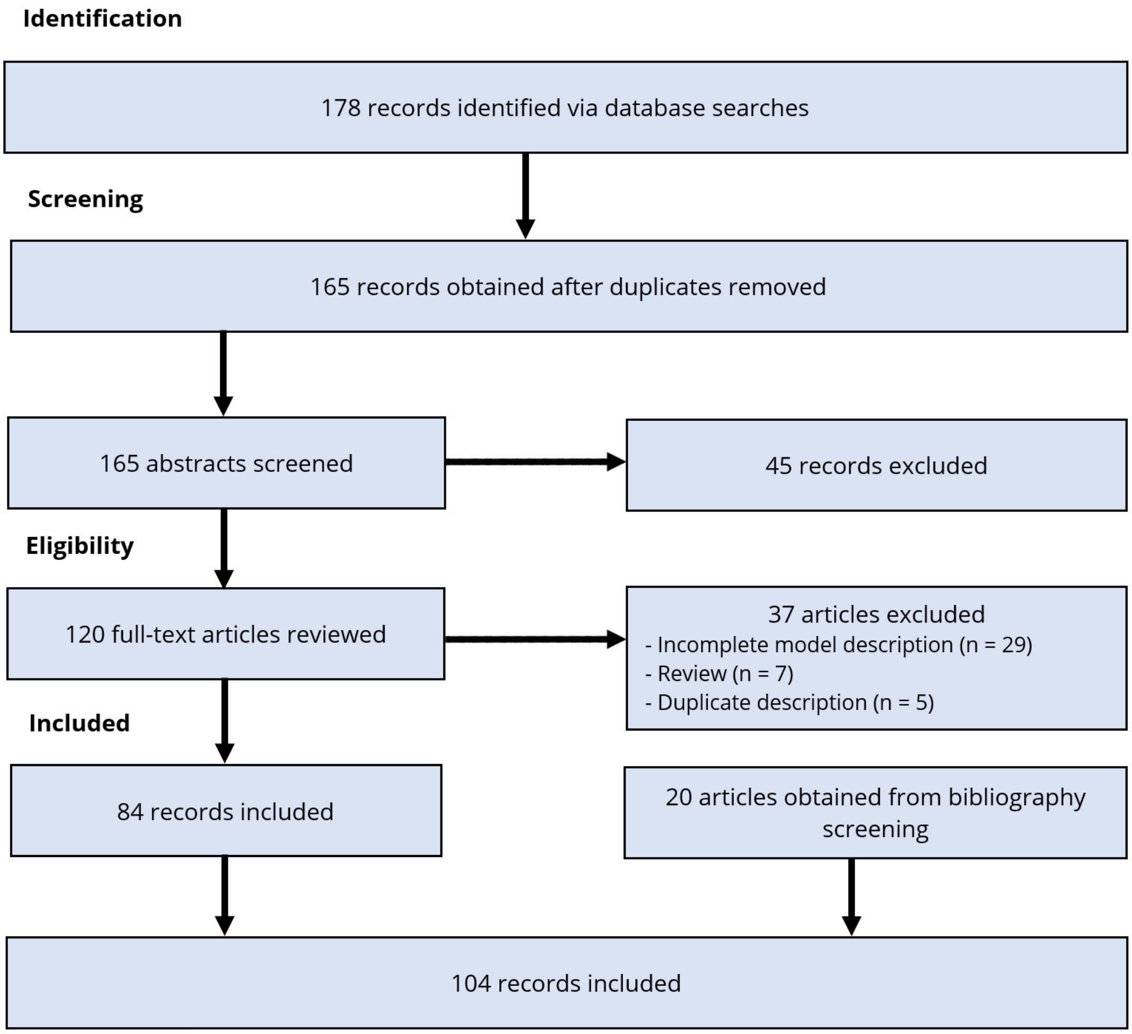

Figure 1. Systematic review flowchart based on the PRISMA methodology. PRISMA, preferred reporting items for systematic reviews and meta-analyses.

Eligibility Criteria

For the systematic review, all articles in the English literature reporting on simulation training in otolaryngology were eligible for inclusion. After elimination of duplicates, all articles were subjected to a title and abstract screen. Articles were excluded if they (1) did not report adequate data regarding the simulation model/platform, (2) did not report on otolaryngology-specific simulation, (3) were not unique (i.e., reporting simulation models already described at an earlier date in other included records), (4) were review articles not describing original simulation models and/or (5) were not reported in English language. Full texts of the remaining articles were then comprehensively reviewed. A flow chart of the systematic review design with complete numeric details is provided in Figure 1.

Data Extraction and Statistical Analysis

All data was systematically aggregated using Microsoft Excel software, version 16.12 (Microsoft). Extracted data end points included: author names, year of publication, type of simulation model, brief description of the simulation model, and key training objective of the simulation model. Data was analyzed using SPSS software, version 25 (IBM). Descriptive statistics were applied in the analysis of all studies that met inclusion criteria.

RESULTS

Overall Characteristics

The systematic review selection process and its results are captured in Figure 1. The aforementioned search strategy was applied to Ovid/Medline, PubMed, Embase, Web of Science, and Cochrane databases which yielded an output of 178 records. After elimination of duplicates, a total of 165 articles remained, which were subsequently subjected to title and abstract screening. The remaining 112 articles were subjected to comprehensive, full-text analysis. Ultimately 83 articles met final inclusion criteria. A manual bibliography screen of included articles yielded an additional 20 articles. A total of 103 records were deemed eligible for inclusion. A single record [10] was utilized as a double entry in two separate categories, yielding a grand total of 104 described otolaryngologic surgical simulation models. Of the records included, only 8 simulation models were reported in or before the year 2004, 20 were reported between 2005 and 2009, 34 models were reported between 2010 and 2014, and 42 models were described in or after the year 2015 (Figure 2). There were a total of 50 synthetic, 21 computer-based, 19 animal cadaver, 6 human cadaver, and 8 hybrid models described. Synthetic simulators were the most common type of simulators in all categories with the exception of oncology/facial plastics/

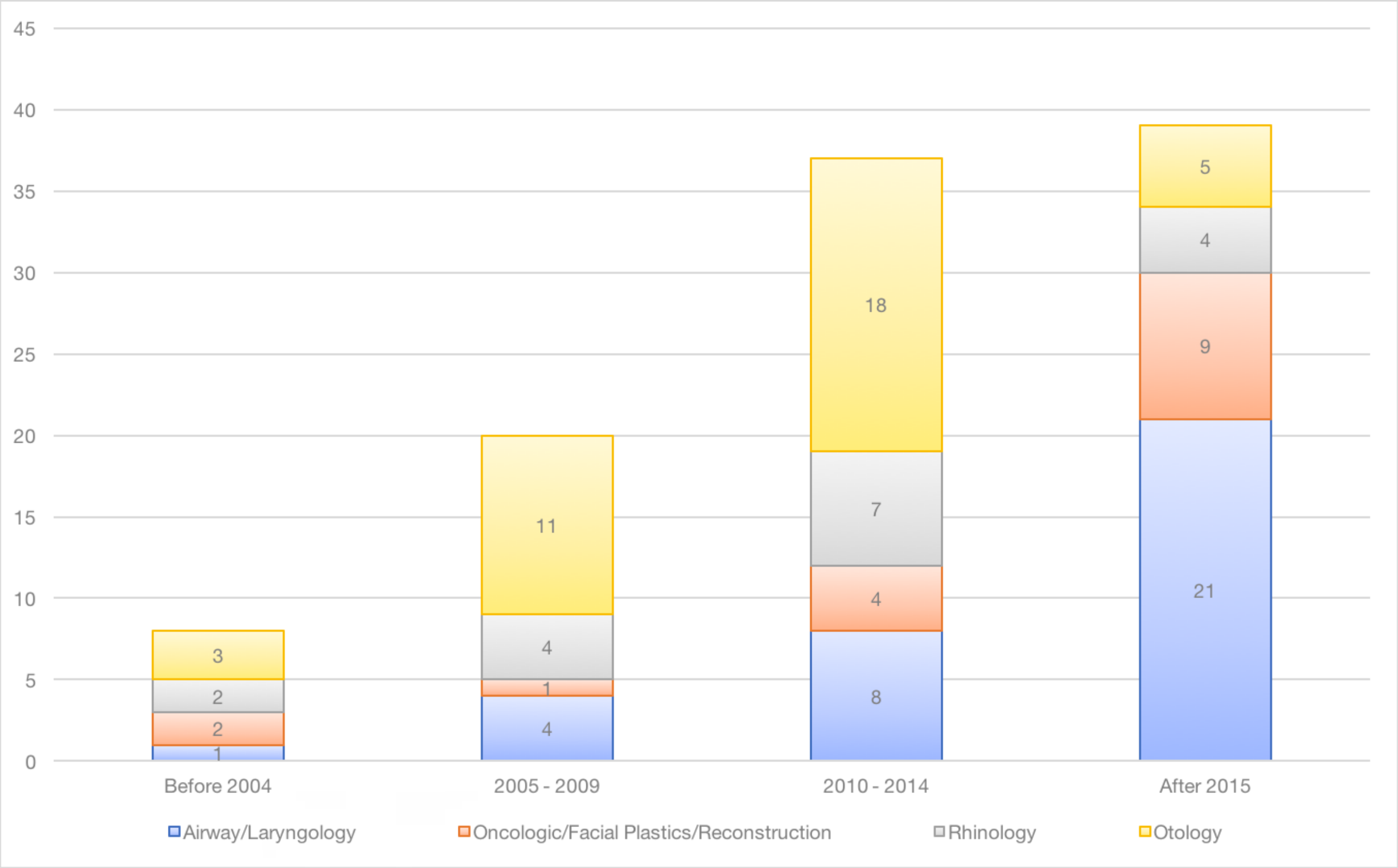

Figure 2. Number of simulation models described in literature over time.

reconstructive category, where animal cadaver models were more common. Otology had the highest number (n = 37) of reported simulation models while oncology/facial plastics/reconstruction had the lowest number (n = 16). A total of 18 of 50 synthetic simulators were purely formulated using 3D-printing techniques (36%), with only 5 such models described prior to 2015 (27.78%). A majority of 3D-printed synthetic simulators were described in or after the year 2015. Hybrid models most often constituted animal cadaver models combined with synthetic models (75%), with the remainder comprised of synthetic models combined with computer-based platforms (25%).

Airway/Laryngeal Surgical Simulation Models

A total of 34 airway and laryngeal surgical simulation models were identified (Table 1). These models consisted of 18 synthetic, 4 computer-based, 8 animal cadaver, 4 human cadaver, and 4 hybrid models. Of these 34 models, 15 models were aimed at establishing emergency surgical airways. Only 6 articles captured in our review reported on pediatric airway/laryngeal simulation models. Of all the airway/laryngeal surgical simulators, 9 models were manufactured by 3D printing (26.47%).

Oncology/Facial Plastics/Reconstruction Simulation Models

A total of 16 oncology/facial plastics/reconstructive simulation models were identified (Table 2). These models consisted of 5 synthetic, 1 computer-based, 10 animal cadaver, and 2 hybrid models. Of the 16 simulation models, 4 were manufactured by 3D-printing (25%). Animal cadaver models were the most common type of surgical simulation platform. Chicken cadaver parts remained the most widely reported simulation model for microvascular anastomosis training in otolaryngology literature.

Rhinology

A total of 17 rhinology surgical simulation models were identified in our systematic review (Table 3). These models consisted of 6 synthetic, 6 computer-based, 5 animal cadaver, and 2 hybrid models. Of these 17 models, 14 articles described simulation models aimed at enhancing overall skills required for Endoscopic Sinus and Skull Base Surgery (ESSS) (88%). Only 3 out of 17 simulation models were designed for specific endoscopic tasks (12%), and only 2 out of 17 models were manufactured by 3D-printing (11.76%).

Otology

A total of 37 neuro-otologic simulation models were identified (Table 4). These models consisted of 21 synthetic, 12 computer-based, 2 animal cadaver, and 2 human cadaver models. All computer-based models utilized virtual reality (VR) technology except for one web-based otoscopy simulator aimed for otoscopic examination described by Wickens et al. [11]. Of these 37 models, 13 were intended for temporal bone drilling (35%), 11 were aimed for ventilation tube insertion (30%), and others included a variety of other ear surgical procedures. Only 3 out of 37 simulation models were manufactured by 3D-printing (8.11%).

DISCUSSION

The implicit appeal of using simulation platforms in training is that mistakes on a simulation platform have no real-world consequences other than to serve as a marker of different degrees of task achievement [12]. Perhaps the

Table 1. Summary of Airway/Laryngeal Surgical Simulation Models

Author	Year	Type	Description of Model	Training Objective
Ainsworth et al [18]	2014	Synthetic[†]	Laryngotracheal framework created by 3D-printing	Transcervical laryngeal injection
Deutschmann et al [19]	2013	Synthetic	Hollow plastic ball with fenestrations placed inside of glove	Flexible nasolaryngoscopy
Doucet et al [20]	2017	Synthetic[†]	3D-printed trachea and artificial skin	Cricothyroidotomy
Fleming et al [21]	2012	Synthetic	Synthetic vocal cord model in airway manikin under microscope	Phonomicrosurgery
Gauger et al [22]	2018	Synthetic[†]	3D-printed laryngeal model placed in manikin head	Cricothyroidotomy
Giblett & Hari [23]	2016	Synthetic	Cod liver oil tablet in tonsil mold fitted in manikin	PTA drainage
Ha et al [24]	2017	Synthetic[†]	3D-printed representation of harvested human costal cartilage	Airway cartilage graft carving
Hughes et al [25]	2018	Synthetic[†]	3D-printed trachea with two-layer silicone containing artificial blood	Bleeding cricothyroidotomy
Jabbour et al [26]	2011	Synthetic[†]	3D-printed organo-silicate airway replica (SimNewB)	Pediatric airway endoscopy
Johnston et al [27]	2015	Synthetic	Nasolaryngopharynx model from plumbing pipes & plastic straws	FNL
Kavanagh et al [28]	2016	Synthetic[†]	Direct 3D-printed model versus silicone elastomer casted model	Pediatric laryngeal surgery
Melchiors et al [29]	2016	Synthetic	Plastic cricoid & laryngeal cartilage model (Airsim Advance Crico)	Cricothyroidotomy
Ng et al [30]	2018	Synthetic	Water balloon in cup behind ballistic gelatin velopharynx	US-guided PTA drainage
Ross et al [31]	2008	Synthetic	Neoprene in a potato chip tube container (Yorick's skull model)	Hemostatic tonsillar suturing
Schwartz et al [32]	2013	Synthetic[†]	Stereolithographic models of pediatric laryngeal framework	Pediatric laryngeal surgery
Washington et al [33]	2014	Synthetic	5cm plastic tubing covered by glove then toilet paper then tape	Cricothyroidotomy
Wiebracht et al [34]	2017	Synthetic	Intubation trainer with disposable diverticulum inserts	Zenker's diverticulotomy
Zambricki et al [35]	2016	Synthetic	Microscopic grape epithelium dissection through laryngoscope	Phonomicrosurgery
Demirel et al [36]	2016	Virtual Reality	Software linked to VR goggles and haptic feedback device (VAST)	ETI and Cricothyroidotomy
Liu et al [37]	2005	Virtual Reality	Hand immersive VR platform	Cricothyroidotomy
Campbell et al [38]	2009	Computer + Synthetic	Pediatric manikin with interface box linked to PC (SimBaby)	Pediatric BMV/ETI/LMI
Hesselfeldt et al [39]	2005	Computer + Synthetic	Adult manikin with interface box linked to PC (SimMan)	BMV/ETI/LMI
Ianacone et al [10]	2016	Animal cadaver	Disarticulated head and neck of pre-pubescent sheep	Cricothyroidotomy/Tracheotomy
Isaacson et al [40]	2015	Animal cadaver	Disarticulated head and neck of pre-pubescent sheep	Pediatric FNL
Isaacson et al [41]	2016	Animal cadaver	Disarticulated head and neck of pre-pubescent sheep	Suspension microlaryngoscopy
Netto et al [42]	2015	Animal cadaver	Porcine larynx placed on wooden surface, covered with pork skin	Cricothyroidotomy
Ram et al [43]	1999	Animal cadaver	Yearling porcine laryngotracheobronchial framework	Pediatric airway endoscopy
Soliman et al [44]	2018	Animal cadaver	Disarticulated head and neck of sheep	Open laryngotracheal surgery
Al-Ramahi et al [45]	2016	Animal cadaver + Synthetic[†]	Porcine and 3D-printed laryngotracheal model	Airway foreign body removal
King et al [46]	2016	Animal cadaver + Synthetic	Porcine larynx placed on a plastic task trainer tray (Surgicric)	Cricothyroidotomy
Aboud et al [47]	2015	Human cadaver	Perfused cadavers	ETI and Cricothyroidotomy
Demirel et al [48]	2016	Human cadaver	GoPro camera recording of procedure on human cadaver	Cricothyroidotomy
Redman et al [49]	2018	Human cadaver	Perfused cadaver	ETI and Cricothyroidotomy
van Emden et al [50]	2018	Human cadaver	Cadaver embalmed using the F4L method	BMV/ETI/LMI

[†] Models manufactured by 3D-printing. BMV, bag mask ventilation; ETI, endotracheal intubation; F4L, fixed for life; FNL, flexible nasolaryngoscopy; LMI, laryngeal mask insertion; PC, personal computer; PTA, peri-tonsillar abscess; US, ultra-sound; VAST, virtual airway simulation trainer; VR, virtual reality.

best example of the successful use of simulation in training is that of the flight simulator created by Edward Link in 1929 to train novice pilots [13]. In time, simulation-based training has grown to be the industry standard in avionics and is currently used for a variety of reasons from the training of novice pilots to flight testing of new aircraft systems [12].

The parallels to the use of simulation in surgical training are striking. With the increasing awareness of ethical concerns, complexity of surgical procedures, healthcare costs, and clinical governance, surgical trainees are faced with new-age hurdles to achieve proficiency and competency within the confines of a structured timeframe. Additionally, limited availability of time for teaching and learning due to work hour restrictions has led to a detachment from the traditional Halstedian dogma of "master and apprentice" [14]. Given that simulation provides a tool for aptitude testing, early skills acquisition, and advanced skills training [12], the development and use of surgical simulation training models have more recently gained exponent popularity as demonstrated by Figure 2. In their cross-sectional survey-based study, Deutsch et al managed to investigate interest amidst 43 US otolaryngology residency programs in advancing simulation training, with 92.9% of respondents confirming the presence of a simulation center or program at their institution and 83.8% of respondents indicating interest in participating in multi-center simulation initiatives [15]. These findings are reflective of a transition in the core philosophy of surgical education.

Historically, human and animal cadaver models and live animal models provided the mainstay raw material for simulation activities. As noted by Musbahi et al, the authors agree that it remains difficult to surpass the ability of human and animal cadaver models to provide anatomic accuracy, tissue con-

Table 2. Summary of Oncology/Facial Plastics/Reconstructive Surgical Simulation Models

Author	Year	Type	Brief Description of Model/Platform	Training Objective
Allak et al [51]	2016	Synthetic†	3D-printed laryngo-esophageal superstructure	Rigid esophagoscopy
Okamoto et al [52]	2018	Synthetic†	3D-printed bi-layered elastic model of face	Local flaps & cheiloplasty
Sillitoe & Platt [53]	2004	Synthetic	Neoprene fabric square attached to a thermoplastic frame	Z plasty
Taylor & Chang [54]	2016	Synthetic	Artificial gelatin facial skin on polystyrene foam head	Local flaps
Xu et al [55]	2012	Synthetic†	Neck mold created using 3D-printing technology	Clinical exam of neck masses
Dworschak et al [56]	2017	Virtual Reality	da Vinci skills simulation software on the da Vinci surgical robot	Robotic surgical skills
Akihiko [57]	2003	Animal cadaver	Chick wing vasculature	MVA
Barber et al [58]	2018	Animal cadaver + Synthetic†	Squid between 3D-printed tracheal and esophageal components	TEP placement
Chark et al [59]	2011	Animal cadaver	Porcine cartilage model with snout transected 4cm from the tip	Nasal tip surgery
Curry et al [60]	2012	Animal cadaver + Synthetic	da Vinci Si Robot used on manikin fitted with porcine tongue	TORS
Ianacone et al [10]	2016	Animal cadaver	Disarticulated head and neck of pre-pubescent sheep	Multiple FPR procedures
Ianacone et al [10]	2016	Animal cadaver	Disarticulated head and neck of pre-pubescent sheep	LTR & Laryngectomy
Isaacson et al [61]	2014	Animal cadaver	Galliform (turkey) thigh skin	Suturing and local flaps
Khalil et al [62]	2009	Animal cadaver	Chicken legs with skin	Z plasty
Pafitanis et al [63]	2017	Animal cadaver	Chick thigh adductor profundus	MAV & Myocutaneous free flap
Schoeff et al [64]	2017	Animal cadaver	Chicken thigh vessels	MVA

† Models manufactured by 3D-printing. FPR, facial plastics & reconstructive; LTR, laryngotracheal reconstruction; MVA, microvascular anastomosis; TEP, trachea-esophageal prosthesis; TORS, trans-oral robotic surgery.

Table 3. Summary of Endoscopic Sinus and Skull Base Surgical Simulation Models

Author	Year	Type	Brief Description of Model/Platform	Training Objective
Alrasheed et al [65]	2017	Synthetic†	3D-printed sinus model placed in manikin head	ESSS
Burge et al [66]	2012	Synthetic	Manikin with silicone nasal mucosa embedded with circuits	ESSS
Leung et al [67]	2008	Synthetic	Metal rings, bulb drain suction, and foam	ESSS
Malekzadeh et al [68]	2011	Synthetic	Ballistic gel, two eggs, & colored beads covered by silicone manikin head	Basic ESSS
Narayanan et al [69]	2015	Synthetic†	Sinonasal model created using 3D-printing	ESSS
Nogueira et al [70]	2008	Synthetic	Model made of resin covered with Neoderma mucosal material (SIMONT)	ESSS
Barber et al [71]	2018	Virtual Reality	Immersive VR using head mounted display with optical tracking system	ESSS
Caversaccio et al [72]	2003	Virtual Reality	VR with 3D glasses, mirror, joystick, and EM stylus (Dextroscope)	ESSS
Dharmawardana et al [73]	2015	Virtual Reality	Simulation software linked to haptic feedback system	ESSS
Edmond et al [74]	2002	Virtual Reality	Simulation software linked to haptic feedback system (ES3)	ESSS
Tolsdroff et al [75]	2009	Virtual Reality	Software paired with haptic feedback system (VOXEL-MAN SinuSurg)	ESSS
Varshney et al [76]	2014	Virtual Reality	Simulation software linked to haptic devices & pedals (MSESS)	ESSS
Awad et al [77]	2014	Animal cadaver	Sheep head with shortened nose to 5 cm	ESSS
Kaplan et al [78]	2015	Animal cadaver	Endoscopic dissection of chicken wing vasculature	Endoscopic microdissection
Touska et al [79]	2013	Animal cadaver	Sheep head with shortened muzzle	ESSS
Ogino-Nishimura et al [80]	2012	Animal + Synthetic	SIMONT with boiled quail egg (egg shell depicted medial orbital wall)	Orbital decompression
Valentine et al [81]	2016	Animal + Synthetic	SIMONT connected to ICA of anesthetized sheep	ESSS vascular emergency

† Models manufactured by 3D-printing. ES3, endoscopic sinus surgery simulator; ESSS, endoscopic sinus and skull base surgery; ICA, internal carotid artery; MSESS, McGill simulator for endoscopic sinus surgery; SIMONT, sinus model otorhino neuro trainer; VR, virtual reality.

sistency, and surgical conditions [8]. However, the rapid expansion and development of manufacturing and computing technologies holds the promise of delivering a paradigm shift in surgical simulation education.

As shown by our results, an ever-increasing number of anatomically accurate, customized 3D-printed models are being created as this technology becomes more available, accessible, and user-friendly. We are inclined to agree with VanKoevering and Malloy [16] in that 3D-printing provides surgical educators a unique advantage by affording an opportunity to rapidly create complex head and neck anatomical models that can be utilized for procedural training. These 3D-printed models hold an advantage over computer-based platforms because they permit tactile sensation and the use of real instruments. Given that these factors are intrinsic components in psychomotor skills training, 3D-printed models hold a distinct advantage over computer-based simulation platforms [16].

In the last five years, the arena of surgical simulation has seen a sharp increase in VR simulation platforms [17]. With the advancement in digital 3D-

Table 4. Summary of Otology Surgical Simulation Models

Author	Year	Type	Brief Description of Model/Platform	Training Objective
Awad et al [82]	2014	Synthetic	Malleable plaster foam model with elastic TM	Multiple otologic surgeries
Bakhos et al [83]	2010	Synthetic†	3D-printed synthetic temporal bone	TBD
Barber et al [84]	2016	Synthetic†	3D-printed middle ear dome interfacing with EAC + donuts/pegs task trainers	TEES
Campisi et al [85]	2011	Synthetic	Anatomic ear canal model with distal screen to display otoscopic findings (OtoSim)	Otoscopic examination
Carr & Benjamin [86]	2006	Synthetic	2mL syringe EAC with rubber glove TM placed in 'surgical skills box'	VTI
Duijvestein et al [87]	2005	Synthetic	2 ear specula in series with silicone/latex strip stretched over smaller specula (BGT)	VTI
Hochman et al [88]	2013	Synthetic†	3D-printed synthetic temporal bone	TBD
Hong et al [89]	2014	Synthetic	UHMWP base connected to syringes & Vinyl gloves	VTI
Jesudason & Smith [90]	2005	Synthetic	Two auricular temperature probe covers assembled in series	VTI
Leong et al [91]	2006	Synthetic	Plastic cylinder fitted over Vinyl on a 2.5mL glass bottle	VTI
Luu et al [92]	2017	Synthetic	Base unit with inserts, cigarette paper or glove for TM (The Ear Trainer)	Ear foreign body removal
Malekzadeh et al [93]	2011	Synthetic	3mL syringe with plastic glove embedded mounted in a glove box	VTI
Mathews et al [94]	1997	Synthetic	Tongue depressor placed through slits in a disposable cup with toothpick incus	Stapes prosthesis placement
Morris et al [95]	2012	Synthetic	Manikin head with auricles, EAC, and cartridge with TM and mesotympanum	Pneumatic otoscopy
Okada et al [96]	2010	Synthetic	Acrylic and resin replica mould	TBD
Owa et al [97]	2003	Synthetic	2mL syringe EAC, paper TM, and 21G cannula incus placed in a paper basin	Stapes prosthesis placement
Pichichero & Poole [98]	2001	Synthetic	Manikin head with auricles, EAC & TM cartridge	VTI
Singh et al [99]	2005	Synthetic	Tape over end of Shah ventilation tube container	VTI
Torgerson et al [100]	2007	Synthetic	Drilling on a saw bone block	TBD
Volksy et al [101]	2009	Synthetic	Plastic canal component and plastic cartridge simulating TM & mesotympanum	VTI
Walker et al [102]	2006	Synthetic	2 pieces of oxygen tubing in series with cellophane over one end of proximal piece (WT)	VTI
Arora et al [103]	2012	Virtual Reality	3D glasses + software linked to haptic feedback system (VOXEL-MAN TempoSurg)	TBD
Arora et al [104]	2014	Virtual Reality	3D glasses + software linked to haptic feedback system (VOXEL-MAN TempoSurg)	Case-specific TBD
Fang et al [105]	2014	Virtual Reality	Computer software linked to force-feedback hand stylus	TBD
Ho et al [106]	2012	Virtual Reality	Computer software linked to 3D stereo visor and haptic arm	Myringotomy
Huang et al [107]	2015	Virtual Reality	Computer software linked to silver screen mirror viewed with 3D glasses + haptic arm	VTI
O'Leary et al [108]	2008	Virtual Reality	3D glasses + software linked to haptic feedback system (CSIRO/UOMVRTBS)	TBD
Sorensen et al [109]	2009	Virtual Reality	Simulation software linked to haptic feedback system (Visible Ear Simulator)	TBD
Sowerby et al [110]	2010	Virtual Reality	Computer software linked to 3D stereo visor and haptic arm	Myringotomy
Wheeler et al [111]	2010	Virtual Reality	Visor viewed with 3D mock microscope stereo-headset + optical tracking system	Myringotomy
Wickens et al [11]	2015	Web Based	Web-based otoscopy simulator (OtoTrain)	Otoscopic examination
Wiet et al [112]	2012	Virtual Reality	Microscope + software linked to haptic feedback system (OSUVTBS)	TBD
Zhao et al [113]	2010	Virtual Reality	Microscope + software linked to haptic feedback system (MSDS)	TBD
Garcia et al [114]	2014	Animal cadaver	Porcine temporal bone	TBD
Gocer et al [115]	2007	Animal cadaver	Transcanal access to middle ear of fresh sheep head	Transcanal stapedectomy
Awad et al [116]	2015	Human cadaver	Human cadaver temporal bone for modified radical mastoidectomy	TBD
Mowry & Hansen [117]	2014	Human cadaver	Human cadaver temporal bone for transcochlear approach and jugular bulb dissection	TBD

† Models manufactured by 3D-printing. BGT, Bradford Grommet Trainer; CSIRO/UOMVRTBS, Commonwealth Scientific and Industrial Research Organization/University of Melbourne virtual reality temporal bone simulator; EAC, external auditory canal; MSDS, Mediseus Surgical Drilling Simulator; OSUVTBS, Ohio State University virtual temporal bone simulator; TBD, temporal bone drilling; TEES, transcanal endoscopic ear surgery; TM, tympanic membrane; UHMWP, ultra-high molecular weight plastic; VR, virtual reality; VTI, ventilation tube insertion; WT, Wigan grommet trainer.

visualization along with haptic sensory technology, VR simulation models are providing a more interactive experience than ever before. Our findings are in line with the findings of Arora et al in that VR simulators appear to be most commonly employed in the subspecialties of rhinology and otology [17].

Although prior review articles have attempted to provide a database of otolaryngologic simulation models, the recent rapid increase in the number of documented simulation models warranted an updated review of otolaryngology simulation models. To the best of our knowledge, our paper presents the most expansive database of otolaryngology-specific simulation models, such that we report a total of 104 simulation models compared to the 60 models reported by Javia et al. [118] and the 64 models reported by Musbahi et al [8]. Additionally, in contrast to works such as that of Bhutta et al. [119] and Chan et al. [120], our article discusses simulation models in all divisions of otolaryngology, rather than addressing simulation training in only a single otolaryngologic sub-specialty. Our article also serves as the first to describe otolaryngology-specific simulators under a dedicated Oncologic/Facial Plastics/Reconstruction category in addition to other more commonly described categories such as Airway/Laryngeal, Pediatric, Rhinology, and Otology.

Due to the vast and ever-growing number of documented simulation models, the systematic review performed may not have captured a comprehensive list of all available surgical simulators. Evaluation of quality and validity of individual simulation platforms was also not conducted given that this be beyond the scope of this paper. The data presented by the authors is instead intended to provide an expansive list that contains simulation options that would adequately suffice the breadth of otolaryngologic training for medical students and residents alike. Future projects can be geared towards the expansion and validity testing of this dynamic and constantly growing list, and utilize it to create a standard, uniform, cost-effective, and high-fidelity simulation curriculum that can be employed by otolaryngology training programs.

CONCLUSION

Current literature shows the availability of several otolaryngology-specific simulation models that have proven beneficial in otolaryngologic surgical training. Recent advancements in manufacturing and computing technologies are contributing to a paradigm shift in surgical simulation education. With the availability of these options, there exists the potential to establish a well-structured and standardized approach to simulation activities across otolaryngology training programs.

ARTICLE INFORMATION

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