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What is This?
A Systematic Review of Simulators in Otolaryngology

Luv Javia, MD¹, and Ellen S. Deutsch, MD²

Sponsorships or competing interests that may be relevant to content are disclosed at the end of this article.

Abstract

Objective. To conduct a systematic review of published articles that describe simulators that could be used in otolaryngology for education, skill acquisition, and/or skill improvement.

Data Sources. Ovid and Embase databases searched July 14, 2011.

Review Methods. Three hundred fifty-three abstracts were independently reviewed by both authors, then 154 eligible articles were reviewed by both authors, and 95 articles were categorized by organ system (eg, otologic); type of simulator (eg, physical, virtual); whether the simulator was a prototype, could be purchased, or was constructed; validation; and level of learning assessment. Discrepancies were resolved by re-review and discussion.

Results. In addition to 11 overview articles, 28 articles described 16 otology simulators, most of which are virtual and prototypes. Nineteen articles described 10 sinus/rhinology simulators; most are virtual surgery simulators and prototypes. Eight articles described 8 oral cavity simulators, and 8 articles described neck simulators. Seventeen articles described 13 bronchoscopy simulators; several are full-body high-technology manikins adapted from other purposes. Five articles described eclectic simulators, including some for learning nontechnical and teamwork skills. Half of the simulators have been validated. Learning levels were often not assessed or assessment was limited to the learners’ perceptions.

Conclusion. A wide variety of simulators are available or under development. Lack of unified validation concepts and limited descriptions restricted our ability to assess model characteristics, availability, and validation. Simulators are emerging as powerful tools to facilitate learning; this review may provide a platform for discussion and refinement of the information reported and analyzed in evaluating simulators.

Keywords
systematic review, otolaryngology, mouth, salivary glands, facial bones, frontal bone, temporal bone, simulators, simulator, medical education

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Simulators range from devices that can be used to practice technical skills, such as suturing, performing mastoidectomy, or removing aspirated foreign bodies, to “standardized patients” (trained actors) who can help learners practice nontechnical skills such as leading a team in the operating room or delivering “bad news” to a family; simulators can also be developed from creative combinations of components. Simulators can range from simple, low-cost, low-technology models, such as using plastic tubing stretched between nails in a board to practice suturing, to elegant, high-technology simulators with life-sized, realistic anatomy and electronic interfaces that can track task times and motion.¹ For students, residents, and fellows, simulators can be used to develop new skills; for faculty, simulators can be used to refresh an infrequently used skill or to perform procedures using new technologies. Simulators allow learners to practice selected skills, receive faculty or electronic feedback, and continue to practice as needed, based on the educational needs of the learner, rather than the medical needs of the patient, and allow this practice to occur without direct risk to the patient.² Simulation can be used to develop, refresh, remediate, or document skills.

Simulation-based medical education with directed practice has been demonstrated to be superior to traditional clinical medical education in achieving specific clinical skill acquisition goals³ and in improving actual patient outcomes⁴ in other fields. Acceptance of and even requirements for simulation-based education are expanding. Simulation and

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The study protocol was developed based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) process, which is intended to “help authors improve the reporting of systematic reviews and meta-analyses.” The literature search strategy was developed in conjunction with a medical librarian. As relevant articles could be classified using diverse coding schemes and a broad range of terminology, eligible articles addressing otolaryngology were sought using a variety of general terms (such as ear and otology) as well as specific anatomic terms (such as temporal bone). The search was limited to simulators, rather than simulation, as the latter term resulted in the inclusion of thousands of articles addressing computerized processes used in pharmacologic, genetic, and other fields, the vast majority of which were not relevant for this study. From this list, articles addressing simulators were selected. Ovid and Embase databases were searched on July 14, 2011, and only articles published in English were selected. Details of the search strategies are presented in Table 1.

Three hundred ninety-two citations were identified based on the eligibility criteria above; 39 duplicates identified electronically were removed, leaving 353 citations (Figure 1). Titles and abstracts were independently reviewed for relevance, using exclusion and inclusion criteria listed in Table 2. Abstracts that did not provide sufficient information were included for further review.

The remaining articles were reviewed in their entirety; those that met the exclusion criteria listed above when the entire article was reviewed or referred to simulation but did not provide sufficient information about specific simulators for further analysis (eg, commentaries addressing simulation or simulators in general) were also excluded; the remaining articles were thoroughly analyzed.

### Data Collection Process

A pilot data form was created to collect data items listed below. Descriptive parameters were established based on similar publications in other fields; anatomic groupings commonly used in otolaryngology; general types of simulators (eg, physical model, virtual model, biologic tissue, etc); whether the simulator was a prototype, could be purchased, or was constructed validation; and level of educational assessment.

Each author reviewed 4 articles using the pilot data collection form; results were compared and the form revised. An attempt was made to categorize validation of simulators according to the schema used by other authors, including

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Figure 1. Flowchart of criteria for excluding citations, abstracts, and articles and the remaining articles with their anatomic categories.

*One simulator described both neck and bronchoesophageal simulators and is listed in both categories; 1 article described both bronchoesophageal and other simulators and is listed in both categories.

Table 2. Inclusion and Exclusion Criteria for Identified Articles

Inclusion Criteria:
- Results of literature search based on relevant terms (see Table 1)
- Simulators with potential usefulness in otolaryngology, including those reported by nonotolaryngology health care workers (eg, simulator designed to teach control of epistaxis, reported by emergency department physicians, but applicable in otolaryngology) 36

Exclusion Criteria:
- Simulators that did not address the use of simulators for otolaryngology education, skill acquisition, or skill improvement
- Non-English articles
- Dental simulators (eg, durability of dental crowns, orthognathic surgery)
- Simulators for the direct care of individual patients (eg, simulation used in planning an individual's radiation therapy)
- Simulators used to assess other processes or equipment (eg, medication delivery methods, intubation devices)
- Simulators that included anatomic locations that are relevant to otolaryngologists but addressed procedures that were not performed by otolaryngologists (eg, esophageal sclerosis, neurosurgical procedures)
- Simulators designed to improve general medical skills (eg, cardiopulmonary resuscitation)
- Articles that did not provide sufficient information about specific simulators for further analysis (eg, commentaries addressing simulation or simulators in general)
- Duplicate references
Table 3. Learning Levels, Based on Kirkpatrick,1 Adapted for Simulation

<table>
<thead>
<tr>
<th>Learning Level</th>
<th>Adaptation for Simulation</th>
<th>Examples (Hypothetical)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1: Reaction</td>
<td>Evaluation could be either quantitative or qualitative</td>
<td>The learner believes that using the simulator is helpful</td>
</tr>
<tr>
<td>2: Learning</td>
<td>Subjective or objective measurement of skills was demonstrated using any type of simulator, such as virtual models, physical task trainers, animal models, standardized patients,* and so on</td>
<td>The learner was able to demonstrate leadership skills during management of a simulated crisis</td>
</tr>
<tr>
<td>3: Behavior</td>
<td>The learner demonstrates skills during the care of actual patients</td>
<td>The learner was able to accomplish a task more quickly on a simulator</td>
</tr>
<tr>
<td>4: Results</td>
<td>The outcome for real patients</td>
<td>The learner performed a procedure with fewer errors and more efficiency</td>
</tr>
</tbody>
</table>

*Standardized patient: people trained to role-play as patients (or family members, etc), to allow learners to practice or demonstrate skills. Standardized patients are also trained to participate in debriefing and/or evaluating learners.

Schout et al12 in their qualitative systematic review of training models in endourology,12,13 but review of an additional 10 articles by both authors demonstrated that validation criteria were sometimes not described in sufficient detail to be categorized, and even when fully described, validation criteria were very diverse. A description that experts “liked” the simulator was considered face validity; otherwise, a summary of the description offered by authors of each article was used. All articles were reviewed using the final criteria.

The schema of educational assessment was based on Kirkpatrick’s 4 levels of learning,14 adapted to include demonstration of learning in a simulated environment (Table 3). A category of none was added for articles in which no description of learning was provided.

Simulator availability was categorized by whether the models were prototypes, could be purchased (eg, commercially manufactured devices), could be constructed (eg, built locally), could be created by augmenting a purchased device, or were live humans. Production status was sometimes difficult to determine. We did not investigate whether further progress in simulator manufacturing had occurred after the article was published.

After analysis, the articles were sorted into categories by anatomic region (eg, otology, sinus) plus review articles. Within each anatomic category, simulators were grouped by the earliest article addressing each particular simulator, if that could be determined. These groupings were made by comparing the name of the simulator, the names of the authors, and their institutions. Overview articles were then re-reviewed to ensure full capture of simulators that were not named in other (“primary”) articles. Summary measures were descriptive. Data items are described in Table 4, and simulator types are described in Table 5.

Results

Three hundred ninety-two citations were identified, and 39 duplicates identified electronically were removed; the remaining 353 abstracts were reviewed, and 199 abstracts determined to not be appropriate were removed; after review of the remaining 154 articles, 59 were removed, leaving 95 articles for detailed analysis.

The earliest publication about a simulator identified in this systematic review, which addressed the use of a physical model as a simulator for learning intubation, was published in 1973 (Figure 2). Following this publication, no additional publications were identified for more than 2 decades, and then an additional 9 articles were published before 2000, and 49 articles (excluding review articles) were published in the decade spanning 2000 through 2009 (inclusive).

In otology, 28 articles were identified describing 16 simulators (Table 6; Suppl. Fig. S1, available at otjournal.org). Most of the simulators are virtual, and most have haptic components; several also have acoustic components (Suppl. Fig. S2). Many are prototypes, although 1 physical simulator with an electronic interface and 2 virtual simulators are described as commercially available (Suppl. Fig. S3). Most simulators reported in otology are designed to teach temporal bone drilling; however, simulators for middle ear prosthesis placement and for myringotomy and pressure equalization tube placement are also described. Most have been validated, and the learning levels evaluated range from none to level 2 (Figure 3). Level 2 learning was demonstrated using physical models with and without electronic capabilities as well as virtual models.

Nineteen articles discuss 10 sinus/rhinology simulators (Table 7). Although the majority are virtual sinus surgery simulators, intranasal and epistaxis models are also described. All virtual sinus simulator models included a physical interface composed of an actual surgical instrument or a tool handled in a similar manner (vs completely virtual simulators, which would be controlled by a joystick or keyboard). As a group, the sinus simulators have undergone the most rigorous validation, particularly the E3S, and some have been demonstrated to support level 3 learning, indicating improved outcomes in actual patients following simulation-based training16; however, most of the models are prototypes.

Eight articles describe 8 simulators related to the oral cavity (Table 8). Most of the oral simulators are locally constructed, not validated, and do not have documentation
Simulators have been designed for diverse procedures, including throat examination, cleft palate repair, tonsillectomy ligature, laryngeal mask airway insertion, and tonsillectomy.

Each of the 8 articles describing simulators used for neck procedures discussed at least 1 and up to 3 different models for learning cricothyroidotomy (Table 9). Learning through level 2 is documented.

Seventeen articles describe 13 bronchoscopy simulators (Table 10). Various bronchoscopy simulators can be purchased, augmented, or constructed, ranging from physical models to high-technology manikins and virtual models. Several of the commercially available simulators have been developed for other purposes, but they can be adapted for use in bronchoesophagology. One simulator, www.thoracicanesthesia.com, is unique in that the simulator is “online” and completely virtual (eg, there is no instrument interface with the device), and the site solicits cases for expert review. Level 3 learning in bronchoesophagology skills has been demonstrated with the use of both physical and virtual models.

Five articles, comprising the “other” group, describe the most eclectic simulators and combinations of components to create simulators (Table 11). Validation is not addressed for most of these simulators, with the exception of a high-technology manikin used for team training. Simulators include confederates used to practice delivering “bad news,” standardized patients trained to support psychosocial skills, and moulage added to a standardized patient to simulate a specific cutaneous malignancy.

Eleven articles were classified as overview articles, as they mentioned 1 or more simulators in the context of a larger discussion but did not necessarily describe the simulators in sufficient detail for further analysis.

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Table 4. Data Items Used in Reviewing Articles

1. Title, authors, year of publication
2. Organ system (simplified)
   a. Otologic, including external and middle ear and entire temporal bone
   b. Sinu- or rhinologic (including nasal)
   c. Oral or pharyngeal
   d. Neck; external
   e. Bronchoesophageal or laryngeal; internal or endoscopic
   f. Other
3. Type of simulator (Table 5)
   a. Physical (eg, task trainer)
   b. Physical, including electronics
   c. Virtual (including joystick or other interface) without haptic (tactile or force) feedback
   d. Virtual (including joystick or other interface) with haptic feedback
   e. Manikin: full body, high technology
   f. Animal (live, anesthetized)
   g. Biologic tissue (including cadavers)
   h. Live human (standardized patient, confederate, etc)
   i. Other
4. Availability
   a. Pre-prototype: preliminary engineering, prior to development of a device, but with articulation of eventual use to facilitate learning
   b. Prototype
   c. Purchase: commercially available
   d. Augmented purchased device: simulator based on a commercially available device, with significant modification or adaptation
   e. Construct: homemade or made in-house
   f. Biologic tissue (including cadavers)
   g. Live humans: “standardized patients,” trained actors, or confederates; excluding patients
5. Validation:
   a. Yes: the concept of validation is addressed either as a topic of the article or by referencing previous articles; a statement that experts “like” the simulator is considered face validity
   b. No: no reference, either direct or indirect, to validation
6. Level of learning, adapted from Kirkpatrick
   a. None specified
   b. Level 1: Reaction, learner satisfaction
   c. Level 2: Learning, improved skills in simulation
   d. Level 3: Behavior, improved skills in real patients
   e. Level 4: Results, patient outcome
Discussion

Education in otolaryngology is rapidly evolving, both for new trainees and for skilled surgeons who seek to learn new skills or refresh old ones; this is paralleled by an increasing interest in simulators (Suppl. Fig. S1). Particularly for the early stages of learning, simulators can be used synergistically with improvements in the understanding of adult learning, advances in surgical instruments and surgical techniques,20,21 efforts to improve patient safety,1,9,29 the need to overcome challenges in accessing certain traditional learning modalities,27 and challenges in allocating time and financial resources.

Simulators have been successfully used for skill acquisition or improvement, as well as for certification, in fields such as aviation,30 and they are emerging as powerful tools for learning in otolaryngology, but simulating living human anatomy is far more complex than simulating mechanical systems of human design.31 Characterizing the validation reported for the simulators identified in this review proved challenging; this is consistent with literature addressing validation of surgical simulators in other fields.12 There are a variety of definitions of validation, but it is difficult to synthesize them and also difficult to categorize the different ways that various authors described their own validation processes. Several authors accomplished elegant, methodical validations for specific learning situations. Many articles described face validity, which is a statement of usefulness or realism as assessed by an expert in the field. It does seem that understanding the validation of a particular simulator must include understanding the context in which that simulator is used, so that validation is contextual and is accomplished relative to specific types of learners and specific learning objectives and circumstances. As one simulator could be used in a variety of learning situations or with a variety of learners or learning objectives, it is conceivable that a simulator could be validated for some learning circumstances and not others.

Distinguishing whether simulators are commercially available also proved challenging. Authors were not always explicit in describing the development status of their simulators. Conversely, authors using commercial simulators did not always state the product name.

Most of the virtual simulators, particularly those designed for otology and sinus surgery, are prototypes that are not yet commercially available. Simulators built on

Table 5. Description of Simulator Characteristics and Terminology

| Physical: Model that can be directly manipulated, touched, incised, and so on. The simulator may represent a body part (eg, a “task trainer”) or an entire human. |
| Physical + electronic: Physical model with electronic interfaces that can be used to collect data (eg, number of times an instrument contacts a specific structure, duration of interaction, force used, motion pathways) and/or provide information to the participant (eg, audible warning of proximity to a critical structure) |
| Virtual: Anatomic representation viewed on a computer screen |
| Virtual with haptic: Virtual simulator that also provides tactile sensory feedback (eg, dense structures may provide more physical resistance to the motion of an instrument functioning as a virtual drill than thin, fragile structures) |
| Full body, high technology: Full-sized manikins with variable physical findings (eg, palpable pulses) and electronic capabilities to change the manikin’s physical characteristics (eg, develop laryngospasm evidenced by physical closure of the vocal folds) and sense and respond to interventions. These may be newborn, infant, child, or adult models. High-technology models used without their electronic capabilities are considered physical models for the purpose of this report. |
| Animal live: Live, anesthetized nonhuman animals |
| Biologic tissue: Cadaveric tissue or nonliving animal parts, such as excised porcine larynges |
| Live human: Person participating in the simulation as a “standardized patient” (eg, an individual trained to demonstrate symptoms or behaviors of a patient or a patient’s family member and to provide feedback and/or evaluate learners) or as a collaborator (eg, an individual role-playing as a nurse to support the other participants in a simulation or an individual role-playing an uncooperative colleague to challenge the other participants in a simulation) |

Figure 2. Number of articles organized by anatomic site and year of publication. Note that the graph is condensed between 1973 and 1996. Articles that addressed more than 1 simulator were arbitrarily assigned to 1 category and counted once. The year 2011 is not included as the literature search only encompassed the first half of the year.
virtual platforms offer unique capabilities to provide educational information, such as labels for anatomic structures, as well as tracking surgical metrics, such as motion efficiency or inappropriate contact with critical structures during simulated procedures. The lack of production may represent an evolutionary stage in the process of simulator development, but, as several of these simulators have had extensive validation and demonstration of a positive impact on learning at several levels, other factors may be affecting the process of production or commercialization. Producing virtual simulators for the specialized needs of otolaryngologists may not be economically viable at this point in time. Beyond production costs, even validation requires a financial investment as well as a sufficient number of subjects, which may be hard to accomplish. Contemporary simulation is relatively young and interest is growing, but there has not yet been extensive investment in purchasing simulators by otolaryngology training programs. It is hoped that increased demand for simulators in the future will spawn the production of affordable simulators.

The limitations of this review include an apparent lack of a broad definition of the term simulator during the database article categorization processes, which likely would have enabled identification of more articles describing simulators within the databases we searched; this resulted in the omission of an unknown number of articles relevant to our search. Anesthetized animals and cadaveric temporal bones are well-established resources for training20 and meet our broad

<table>
<thead>
<tr>
<th>Simulator</th>
<th>Authors</th>
<th>Characteristics</th>
<th>Model Availability</th>
<th>Validation Addressed</th>
<th>Learning Levels Assessed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temporal bone drilling VR</td>
<td>Kuppersmith et al, 1997</td>
<td>Virtual, haptic, acoustic</td>
<td>Pre-prototype</td>
<td>No</td>
<td>None</td>
</tr>
<tr>
<td>Incus and stapes footplate simulator</td>
<td>Mathews et al, 1997</td>
<td>Physical</td>
<td>Construct</td>
<td>No</td>
<td>None</td>
</tr>
<tr>
<td>Temporal bone drilling VR</td>
<td>John et al, 2001</td>
<td>Virtual, haptic</td>
<td>Prototype</td>
<td>Yes</td>
<td>None</td>
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<tr>
<td></td>
<td>Agus et al, 2002</td>
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<tr>
<td></td>
<td>Agus et al, 2003</td>
<td></td>
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<tr>
<td>Temporal bone drilling VR (Ohio State)</td>
<td>Wiet et al, 2002</td>
<td>Virtual, haptic, acoustic</td>
<td>Prototype</td>
<td>Yes</td>
<td>Level 1</td>
</tr>
<tr>
<td>Middle ear simulator for prosthesis placement</td>
<td>Owa et al, 2003</td>
<td>Physical</td>
<td>Construct</td>
<td>No</td>
<td>None</td>
</tr>
<tr>
<td>Temporal bone drilling VR (Interactive Virtual Dissection)</td>
<td>Bernardo et al, 2003</td>
<td>Virtual, nonhaptic</td>
<td>Prototype</td>
<td>No</td>
<td>None</td>
</tr>
<tr>
<td>Temporal bone drilling VR (Stanford)</td>
<td>Sewell et al, 2005</td>
<td>Virtual, haptic, acoustic</td>
<td>Prototype</td>
<td>Yes</td>
<td>Level 2</td>
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<tr>
<td></td>
<td>Sewell et al, 2007</td>
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<td>Sewell et al, 2008</td>
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<tr>
<td>Temporal bone drilling VR (VOXEL-MAN TempoSurg)</td>
<td>Zirkle et al, 2007</td>
<td>Virtual, haptic</td>
<td>Purchase</td>
<td>Yes</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>Malik et al, 2011</td>
<td></td>
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<tr>
<td>Temporal bone drilling VR (Visible Ear Surgery Simulator)</td>
<td>Trier et al, 2008</td>
<td>Virtual, haptic</td>
<td>Prototype</td>
<td>Yes</td>
<td>None</td>
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<td></td>
<td>Sorensen et al, 2009</td>
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<td>Temporal bone drilling VR (Melbourne)</td>
<td>O’Leary et al, 2008</td>
<td>Virtual, haptic, acoustic</td>
<td>Purchase</td>
<td>Yes</td>
<td>Level 1 Level 2</td>
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<td></td>
<td>Zhao et al, 2010</td>
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<td>Zhao et al, 2011</td>
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<tr>
<td>Myringotomy and PET insertion</td>
<td>Volsky et al, 2009</td>
<td>Physical</td>
<td>Prototype</td>
<td>Yes</td>
<td>Level 1 Level 2</td>
</tr>
<tr>
<td>Temporal bone drilling VR</td>
<td>Kerwin et al, 2009</td>
<td>Virtual, haptic, acoustic, fluid rendering</td>
<td>Prototype</td>
<td>Yes</td>
<td>Level 1 Level 2</td>
</tr>
<tr>
<td>Temporal bone drilling VR</td>
<td>Day et al, 2009</td>
<td>Virtual</td>
<td>Prototype</td>
<td>Yes</td>
<td>Level 1</td>
</tr>
<tr>
<td></td>
<td>Sowerby et al, 2010</td>
<td></td>
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<tr>
<td></td>
<td>Wheeler et al, 2010</td>
<td>Virtual, nonhaptic</td>
<td>Yes</td>
<td>Level 1</td>
<td></td>
</tr>
<tr>
<td>Myringotomy</td>
<td>Allison et al, 2010</td>
<td>Physical + electronic</td>
<td>Purchase</td>
<td>Yes</td>
<td>Level 1 Level 2</td>
</tr>
<tr>
<td>Portable temporal bone lab with plastic (Pettigrew) bones</td>
<td>Varadarajan et al, 2010</td>
<td>Physical</td>
<td>Construct</td>
<td>Yes</td>
<td>None</td>
</tr>
</tbody>
</table>

Abbreviations: PET, positron emission tomography; VR, virtual reality.
definition of simulators, but they were generally not captured in this systematic review. In 2 cases, articles were identified that were commentaries on original articles that contained descriptions of simulators, but the original articles were not identified in the literature search. Refining the apparent definitions of simulation and simulator MESH terms to Ovid, in recognition of the development of the field of simulation, might make it easier to identify appropriate articles. Otolaryngology terminology was also complex since the same anatomic site could be categorized under a variety of terms (eg, temporal bone, otolaryngology); searches were conducted using multiple terms with potential overlap to be as comprehensive as possible.

Again in parallel with the development and the challenges of understanding simulators in other health care fields, it would be easier to analyze and potentially replicate studies of simulators if the details about the simulators’ characteristics, how the simulator is used, and the procedures of data collection and analysis are described in greater detail. For example, is “airway” management in a trauma simulation limited to intubation, or does it imply that a cricothyroidotomy was performed?

Informative descriptions of virtual simulators provide additional challenges, as the technology has advanced more quickly than our descriptive capabilities. Does the surgeon’s physical interaction with the virtual simulator use an intermediary device that replicates a surgical tool, such as a drill, forceps, or telescope, or is the interface “nonclinical” such as via a keyboard or a gaming control? Features of simulators are assumed in many studies to be understood but may not be obvious.

Even if the characteristics of a particular simulator are precisely defined, this does not necessarily guarantee a valuable learning experience. Although simulators may be very

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### Table 7. Articles Describing Simulators for Sinus and Rhinologic Procedures

<table>
<thead>
<tr>
<th>Simulator</th>
<th>Authors</th>
<th>Characteristics</th>
<th>Availability</th>
<th>Validation Addressed</th>
<th>Learning Levels Assessed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Virtual reality</td>
<td>Hilbert and Muller, 1997</td>
<td>Virtual, acoustic</td>
<td>Prototype</td>
<td>Uncertain</td>
<td>None</td>
</tr>
<tr>
<td>Madigan Endoscopic Sinus Surgery Simulator: ES3</td>
<td>Weghorst et al, 1998</td>
<td>Virtual, haptic, anatomic interface</td>
<td>Prototype</td>
<td>Yes</td>
<td>Level 1</td>
</tr>
<tr>
<td></td>
<td>Rudman et al, 1998</td>
<td></td>
<td></td>
<td></td>
<td>Level 2</td>
</tr>
<tr>
<td></td>
<td>Edmond, 2002</td>
<td></td>
<td></td>
<td></td>
<td>Level 3</td>
</tr>
<tr>
<td></td>
<td>Arora et al, 2005</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Glaser et al, 2005</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Jakubowic et al, 2005</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Solyar et al, 2008</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Glaser et al, 2006</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fried et al, 2010</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nasal Endoscopy Simulator: NES</td>
<td>Bockholt et al, 1999</td>
<td>Virtual, haptic, anatomic interface</td>
<td>Prototype</td>
<td>No</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>Tolsdorff et al, 2010</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Caversaccio et al, 2003</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nasal model</td>
<td>Ossowski et al, 2008</td>
<td>Physical</td>
<td>Prototype</td>
<td>No</td>
<td>Level 2</td>
</tr>
<tr>
<td>Epistaxis Simulator</td>
<td>Pettino et al, 2008</td>
<td>Physical</td>
<td>Construct</td>
<td>No</td>
<td>None</td>
</tr>
<tr>
<td>Low Fidelity Dry Model Cadaver</td>
<td>Leung et al, 2008</td>
<td>Physical</td>
<td>Construct</td>
<td>Attempted</td>
<td>None</td>
</tr>
<tr>
<td>Sinus Model Otorrino-Neuro Trainer: SIMONT</td>
<td>Nogueira et al, 2008</td>
<td>Physical</td>
<td>Prototype</td>
<td>No</td>
<td>Level 1</td>
</tr>
<tr>
<td></td>
<td>Stamm et al, 2009</td>
<td></td>
<td></td>
<td></td>
<td>Level 2</td>
</tr>
</tbody>
</table>

Although the nasal model used by Ossowski et al was tested in a live human, that person was functioning as a simulator (eg, a standardized patient) and was not undergoing actual medical care, so the learning level was assigned as level 2. Additional simulators were identified in the review article by Fried et al: a paranasal sinuses simulator using a soft dummy with force sensors and computerized analysis, a virtual reality functional endoscopic sinus surgery and a transsphenoidal hypophysectomy simulator, and a transsphenoidal endonasal pituitary surgery (STEPS) simulator.
elegant, technologically sophisticated, or occasionally expensive, they are only tools that must be selected and fitted into appropriately structured educational experiences. Several descriptions of simulators did not address any formal assessment of learning. In some cases, the authors may have felt the potential benefits to be intuitive or obvious, and in other cases, the authors may have been describing a preliminary phase of simulator development that was not yet ready for testing. Several articles reported Kirkpatrick14 level 2 results, indicating that learners perceived benefit from using the simulator. Although this is important, particularly as lifelong learners are responsible for designing many aspects of their own ongoing professional education, demonstrating effective impact at higher levels is also desirable. The ultimate goals of simulation-based education include improving operational performance and patient outcomes (Kirkpatrick levels 3 and 4), as well optimizing the safety, quality, and value of health care at a system level. These benefits are inherently challenging to demonstrate for educational interventions but have been demonstrated relative to simulation in other fields3,4 and can be accomplished within otolaryngology if we leverage multi-institutional collaborations and develop objective measurements of skill and performance.

Conclusions

Simulators, broadly defined, are emerging as powerful tools for learning. Simulators have been used in otolaryngology for almost a century,35 but a variety of current conditions have brought increased attention to simulator development. Optimal incorporation of simulators into training and skill refreshing schema is hindered by the limited descriptive terminology available for these tools and the lack of standardized or even unified conceptual structures addressing validation and effectiveness as learning modalities.

This systematic review of publications addressing simulators used in otolaryngology education, skill acquisition, and/or skill improvement identifies and characterizes 95

Table 8. Articles Describing Simulators for Procedures in the Oral Cavity and Pharynx

<table>
<thead>
<tr>
<th>Simulator</th>
<th>Authors</th>
<th>Characteristics</th>
<th>Model Availability</th>
<th>Validation Addressed</th>
<th>Learning Levels Assessed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tonsillectomy</td>
<td>Pearson et al, 199779</td>
<td>Physical</td>
<td>Purchase</td>
<td>No</td>
<td>None</td>
</tr>
<tr>
<td>Palm Laryngical Airway Simulator</td>
<td>Sivanandan et al, 200380</td>
<td>Physical</td>
<td>Purchase</td>
<td>No</td>
<td>None</td>
</tr>
<tr>
<td>Tonsillectomy ligation</td>
<td>Street et al, 200681</td>
<td>Physical</td>
<td>Purchase</td>
<td>No</td>
<td>None</td>
</tr>
<tr>
<td>Cleft palate repair</td>
<td>Vadodaria et al, 200782</td>
<td>Physical</td>
<td>Construct</td>
<td>No</td>
<td>None</td>
</tr>
<tr>
<td>Virtual Throat Exam</td>
<td>Ruthenbeck et al, 200883</td>
<td>Virtual, haptic</td>
<td>Prototype</td>
<td>Yes</td>
<td>None</td>
</tr>
<tr>
<td>Tonsillectomy Tie Training</td>
<td>Ross et al, 200813</td>
<td>Physical</td>
<td>Construct</td>
<td>No</td>
<td>None</td>
</tr>
<tr>
<td>Cleft palate repair</td>
<td>Nagy et al, 200984</td>
<td>Physical</td>
<td>Construct</td>
<td>Yes</td>
<td>None</td>
</tr>
<tr>
<td>Oral simulator</td>
<td>Schebesta et al, 201185</td>
<td>Physical</td>
<td>Purchase</td>
<td>Attempted</td>
<td>None</td>
</tr>
</tbody>
</table>

Table 9. Articles Describing Simulators for Procedures in the Neck

<table>
<thead>
<tr>
<th>Simulator</th>
<th>Authors</th>
<th>Characteristics</th>
<th>Model Availability</th>
<th>Validation Addressed</th>
<th>Learning Levels Assessed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cricothyroidotomy and other emergent airway</td>
<td>King et al, 199686</td>
<td>Full body, high technology</td>
<td>Purchase</td>
<td>No</td>
<td>None</td>
</tr>
<tr>
<td>Virtual Simulator for cricothyroidotomy</td>
<td>Liu et al, 200587</td>
<td>Virtual, haptic</td>
<td>Prototype</td>
<td>Yes</td>
<td>None</td>
</tr>
<tr>
<td>Cricothyroidotomy</td>
<td>John et al, 200788</td>
<td>Physical</td>
<td>Purchase</td>
<td>No</td>
<td>None</td>
</tr>
<tr>
<td>Cricothyroidotomy</td>
<td>Friedman et al, 200889</td>
<td>Physical, full body, high technology</td>
<td>Construct</td>
<td>No</td>
<td>Level 2</td>
</tr>
<tr>
<td>Porcine laryngeal model for cricothyroidotomy</td>
<td>Murphy et al, 200990</td>
<td>Physical, biologic tissue</td>
<td>Construct</td>
<td>Yes</td>
<td>None</td>
</tr>
<tr>
<td>Cricothyroidotomy</td>
<td>Pettineo et al, 200991</td>
<td>Biologic tissue</td>
<td>Construct</td>
<td>Yes</td>
<td>Level 1</td>
</tr>
<tr>
<td>Cricothyroidotomy</td>
<td>Ryzynski, 201092</td>
<td>Physical</td>
<td>Construct</td>
<td>Yes</td>
<td>Level 1</td>
</tr>
<tr>
<td>Cricothyroidotomy</td>
<td>Siu et al, 201093</td>
<td>Full body, high technology</td>
<td>Purchase</td>
<td>Yes</td>
<td>Level 2</td>
</tr>
</tbody>
</table>
articles describing a diverse variety of simulators with potential relevance to otolaryngology and demonstrates a recent increase in the number of such articles. Categorizing information thought to be of potential interest, such as simulator characteristics, availability, validation, and impact on learning, proved challenging, but this work may provide a platform for further discussion and refinement of these concepts. Undoubtedly, additional experience, insight, and maturation of the field will lead to improvements in our ability to describe and assess simulators.

### Table 10. Articles Describing Simulators for Laryngology and Bronchoesophagoscopy

<table>
<thead>
<tr>
<th>Simulator</th>
<th>Author</th>
<th>Characteristics</th>
<th>Availability</th>
<th>Validation Addressed</th>
<th>Learning Levels Assessed</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;Adult intubation manikin&quot; (Laerdal)</td>
<td>Howells et al, 197315</td>
<td>Physical</td>
<td>Purchase</td>
<td>Yes</td>
<td>Level 2</td>
</tr>
<tr>
<td>SimMan (Laerdal)</td>
<td>Hesselbein et al, 200594</td>
<td>Full body, high technology</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Human anatomy simulator (Laerdal)</td>
<td>Latif et al, 201095</td>
<td>Physical, unclear, high technology</td>
<td>Yes</td>
<td></td>
<td>Level 2</td>
</tr>
<tr>
<td>Adult Human Patient Simulator: HPS (Loral, METI, now CAE)</td>
<td>King et al, 199686</td>
<td>Full body, high technology</td>
<td>Purchase</td>
<td>Yes</td>
<td>None</td>
</tr>
<tr>
<td>Glottis simulator</td>
<td>Lyra et al, 199997</td>
<td>Physical</td>
<td>Construct</td>
<td>No</td>
<td>Level 2</td>
</tr>
<tr>
<td>Accutouch bronchoscopy simulator (Immersion, now CAE)</td>
<td>Rowe and Cohen, 200298</td>
<td>Virtual, haptic</td>
<td>Purchase</td>
<td>Yes</td>
<td>Level 1</td>
</tr>
<tr>
<td></td>
<td>Deutsch et al, 200999</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mandal et al, 2010100</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Patel et al, 2010101</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Latif et al, 2011102</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>De Hoyos et al, 2009103</td>
<td></td>
<td>Augment purchased device</td>
<td>Yes</td>
<td>None</td>
</tr>
<tr>
<td>Laryngeal Dissection Module (SOMSO)</td>
<td>Contag et al, 2009104</td>
<td>Physical</td>
<td>Augment purchased device</td>
<td>Yes</td>
<td>Level 2</td>
</tr>
<tr>
<td>SimBaby (Laerdal)</td>
<td>Deutsch et al, 200999</td>
<td>Full body, high technology</td>
<td>Purchase</td>
<td>Yes</td>
<td>Level 1</td>
</tr>
<tr>
<td></td>
<td>Schebesta et al, 201185</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Animal laboratory</td>
<td>Deutsch et al, 200999</td>
<td>Biologic tissue</td>
<td>No</td>
<td>Level 1</td>
<td></td>
</tr>
<tr>
<td>Airway Part Task Trainer</td>
<td>Ryzynski, 2010102</td>
<td>Physical</td>
<td>Construct</td>
<td>Yes</td>
<td>Level 1</td>
</tr>
<tr>
<td>Static bronchial tree model</td>
<td>Patel et al, 2010101</td>
<td>Physical</td>
<td>Unclear</td>
<td>No</td>
<td>Level 1</td>
</tr>
</tbody>
</table>

In addition to the simulators listed, overview articles mention these simulators: "larynx virtual surgery software,"19 Dexter physical simulator,23 and simulators used for difficult airway management and a constructed bronchoscopy anatomic landmark simulator.25

### Table 11. Articles Describing Miscellaneous Simulators

<table>
<thead>
<tr>
<th>Simulator</th>
<th>Authors</th>
<th>Characteristics</th>
<th>Model Availability</th>
<th>Validation Addressed</th>
<th>Learning Levels Assessed</th>
</tr>
</thead>
<tbody>
<tr>
<td>HPS (METI, now CAE) used for team training</td>
<td>Holcomb et al, 200296</td>
<td>Full body, high technology</td>
<td>Purchase</td>
<td>Yes</td>
<td>Level 2</td>
</tr>
<tr>
<td>Role play, confederate</td>
<td>Deutsch et al, 200999</td>
<td>Live human</td>
<td>No</td>
<td>Level 1</td>
<td></td>
</tr>
<tr>
<td>Cadaver</td>
<td>Boaz et al, 2009105</td>
<td>Biologic tissue</td>
<td>No</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>Standardized patient</td>
<td>Pugh et al, 2010106</td>
<td>Live human</td>
<td>No</td>
<td>Level 1</td>
<td></td>
</tr>
<tr>
<td>Dermatologic lesion moulaged onto standardized patient</td>
<td>Haley et al, 2011107</td>
<td>Other</td>
<td>Construct lesion</td>
<td>No</td>
<td>Level 2</td>
</tr>
</tbody>
</table>

In addition to the simulators listed, Tsue et al18 mention using a Penrose drain to practice suturing skills.
Author Contributions

Luv Javia, design, acquisition and analysis of data, drafting the manuscript, final approval of the manuscript; Ellen S. Deutsch, conception and design, acquisition and analysis of data, drafting the manuscript, final approval of the manuscript.

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Supplemental Material

Additional supporting information may be found at http://oto.sagepub.com/content/by/supplemental-data

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20. George AP, De R. Review of temporal bone dissection teaching: how it was, is and will be. J Laryngol Otol. 2010;124:119-125.


