Review Article

Simulations and simulators in head and neck endocrine surgery

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Abstract: Simulations and simulators have become an increasingly important tool in trainee education across many surgical disciplines, particularly for robotic and minimally invasive procedures. Thyroidectomy and parathyroidectomy are common procedures performed across multiple surgical disciplines, however, there is limited literature regarding training models/simulators for these operations. This is despite the advent and growing popularity of remote-access thyroidectomy techniques, where simulators may provide significant value in trainee education and safe implementation. Here we review the literature regarding available simulations/simulators in head and neck endocrine surgery for both conventional transcervical approaches and newer remote-access thyroidectomy techniques.

Keywords: Surgical simulation; transoral endoscopic thyroidectomy; remote-access thyroidectomy; virtual reality; augmented reality

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Introduction

Head and neck endocrine surgery is common, with conservative estimates of 250,000 combined thyroid and parathyroid surgeries performed in the United States yearly (1-3). Several studies have demonstrated that high-volume endocrine surgeons deliver both higher quality and more cost-effective care (1,4-9). Despite this, the majority of such cases within the United States continue to be performed by lower volume surgeons (1,4,10). The American Head & Neck Society has endorsed the creation of head and neck endocrine surgery fellowships to develop surgeons whose practices focus primarily on management of thyroid and parathyroid disease (11).

The addition of such surgeons to otolaryngology, head & neck surgery (OHNS) departments has increased the total volume of thyroid and parathyroid surgery considerably, and in turn the average number of thyroid/parathyroid cases performed by residents by over three-fold in these respective departments (11). However, not all OHNS and general surgery departments may have a dedicated head and neck endocrine surgeon. Moreover, trainees may derive significant benefit from simulation-based training in head and neck endocrine surgery regardless of their exposure to endocrine surgery expertise. Simulation-based training has previously been shown to be a valuable tool for both technical and nontechnical surgical-skill acquisition (12,13).

In addition to the need for skill acquisition during residency, experienced surgeons learning new techniques are also challenged. For example, simulation may be of greater utility within the growing field of remote-access thyroid and parathyroid surgery, which requires unfamiliar surgical approaches and skill sets, particularly with the exponential rise of the transoral vestibular approach (TVA) to the central neck (14-22).

In endoscopic and minimally invasive procedures, surgical computer-based simulators provide valuable experience for trainees; this may be particularly true when

Table 1 Literature review

Surgery	Simulation type	Approach	Publication (year)
Thyroidectomy	Augmented reality	Bilateral Axillo-breast approach	Lee *et al.*, 2018
	Animal (porcine) model	Bilateral Axillo-breast approach	Yu *et al.*, 2018
	Material model	Bilateral Axillo-Breast approach	Yu *et al.*, 2018
	Cadaveric model	Transcervical approach	Melo *et al.*, 2015
Parathyroidectomy	Virtual reality and augmented reality	Virtual neck exploration and transcervical approach	D'Agostino *et al.*, 2013

implementing new surgical techniques such as TVA (23-25). As it is estimated that up to 140,000 cases could be performed in the United States yearly via TVA, simulators may become an invaluable tool in head and neck endocrine surgery education (26). Moreover, as many early adopters of TVA will have already completed their residency training, this simulation-based training may become a primary tool in the safe adoption and implementation of these techniques (22). Here we review the literature regarding available surgical simulations/simulators in head and neck endocrine surgery, highlighting the need for widely available simulations/simulators for these surgeries, particularly for remote-access thyroidectomy techniques such as TVA.

Methods

PubMed, Google Scholar, Scopus, and Web of Science were reviewed for literature regarding surgical simulators or simulation for thyroidectomy and parathyroidectomy. The following keywords were used: "virtual reality" "VR" "augmented reality" "AR" "image guided" "simulator" "simulation" "virtual" "3D" "cadaver" "cadaveric" "model" "computer" "in silico" "robot" "robotic" "training" "trainer" "skill assessment" "thyroid" "thyroidectomy" "thyroid surgery" "parathyroid" "parathyroidectomy" "parathyroid surgery" "endocrine" "head and neck surgery" "otolaryngology "surgery". Inclusion criteria included: (I) augmented-reality, virtual-reality, or computerized simulators of thyroid or parathyroid surgery, (II) cadaveric or animal models of thyroid or parathyroid surgery, (III) artificial or material models of thyroid or parathyroid surgery. Exclusion criteria included: (II) cadaveric feasibility studies; (II) non-surgical simulators.

Results

This study was deemed exempt from Johns Hopkins School of Medicine Institutional Review Board review and approval. A total of five manuscripts met the inclusion criteria (27-31). Four of these manuscripts focused on thyroidectomy, one of which simulated traditional cervical approach thyroidectomy and parathyroid gland identification and three of which simulated the bilateral axillo-breast approach. Of these four manuscripts describing simulation of thyroidectomy, there was one study each for augmented-reality, cadaveric, porcine, and silicone models. One other manuscript described virtual neck exploration for parathyroidectomy (*Table 1*).

Discussion

Simulators and simulations can be categorized broadly using the following descriptors: animal-models, cadaveric-models, material-models, augmented reality (AR), and virtual reality (VR) models. Moreover, each of these models can be subsequently classified as low or high fidelity (32). In this review we found only five publications pertaining to simulations for thyroid and parathyroid surgery. One of these publications described an augmented reality model and another described both virtual and augmented reality models. The remaining three described material, cadaveric, or animal models. These latter models focused on technical skill acquisition, whereas the former two created augmented reality models in order to facilitate identification and preservation of pertinent anatomical structures intraoperatively (27,29). Although remote-access thyroidectomy was described in three of the publications, none was related to TVA.

Material model

In 2018, Yu *et al.* described a surgical training model consisting of two large silicone structures developed to mimic relevant anatomy for bilateral axillo-breast thyroidectomy with the goal of reducing the learning curve for the procedure. Life-sized thyroid, parathyroid, trachea, recurrent laryngeal nerves, internal jugular veins, and common carotid arteries made up the base plate structure, with the top plate consisting of the skin of the neck, thorax, breasts, and arms. Repeated use of the model resulted in improved performance, based on completion of structured tasks, for medical students, surgical residents, and surgical fellows (31).

Animal and cadaveric models

In a separate publication, Yu *et al.* described a porcine model for bilateral axillo-breast approach thyroidectomy. There were several advantages to the porcine model, including similar size and location of the thyroid as in humans, active bleeding, and allowing for flap formation (30). Although Yu demonstrated success with the porcine model as an educational tool, there were a few key anatomic limitations. In contrast to the bilobed, butterfly-shaped human thyroid, the pig thyroid is ovoid in shape, with only one lobe. Furthermore, in pigs, parathyroid glands are typically associated with the thymus, hence the porcine model fails to simulate the key steps of parathyroid identification and preservation in thyroidectomy.

Although cadaveric models lack the key advantage of active bleeding, Melo *et al.* showed the use of cadavers to simulate identification of parathyroid glands (28). Out of 92 cadavers, 242 fragments corresponding to suspected parathyroid glands were isolated, of which 154 (64%) were histologically confirmed to be parathyroid glands.

Augmented and virtual reality models

Beyond these educational applications, simulators may be utilized to enhance endocrine surgery itself. In a study of 114 patients, D'Agostino *et al.* generated 3D virtual neck models from patient CT scans. A computer-based virtual neck exploration was performed to identify the location of parathyroid adenomas. The accuracy of the virtual model was 77.2% in determining the correct side of the neck and 64.9% in determining the correct quadrant of the neck for parathyroid adenoma. These results were found to be superior to those of ultrasound, sestamibi scanning, and standard CT. These virtual renderings were then overlaid in real-time through a videoscope on three patients in an augmented reality fashion, with single adenoma successfully removed in all three cases (27).

Similarly, Lee *et al.* described the use of augmented reality for robotic, bilateral axillo-breast approach thyroidectomy (29). CT images were used to generate 3D CAD models of the thyroid, common carotid arteries, trachea, and esophagus. Using manual registration of 3D models to noticeable anatomic landmarks like the trachea, real-time images were displayed through the da Vinci monitor. These images allowed easy visualization of important structures throughout the robotic thyroidectomy, enhancing surgical safety.

Need for simulators in graduate and postgraduate surgical training

The potential role of simulators in head and neck endocrine surgery cannot be overstated, particularly given the wide variability in case volume among OHNS residents as well as the comparatively limited case volume of general surgery residents. According to ACGME case log data in 2014–2015, graduating general surgery residents had performed, on average, a total of 21 thyroidectomies and 10 parathyroidectomies (SD 15 and 8, respectively) (33). In 2014–2015, graduating OHNS residents had performed, on average, a total of 55 thyroidectomies and 16 parathyroidectomies (SD 26 and 13, respectively) (34). This data suggests that while OHNS residents may perform twice as many thyroidectomies and parathyroidectomies, there is considerable variation in individual resident experience. In a 2012 national survey of 526 general surgery and OHNS residents, both groups felt that a minimum of 30 thyroid operations were needed to obtain competence (35). Based on the ACGME data, approximately 15% of OHNS residents and 70% of general surgery residents may be graduating having performed fewer cases than what is thought to be needed to achieve competence. Both ACGME restrictions on resident work-hours and greater oversight in limiting resident surgical autonomy have presented a challenge in providing trainees with sufficient operative experience. As the publications reviewed above demonstrate, simulators offer the opportunity for structured and effective training in a relatively short amount of time, potentially expediting skill acquisition and helping to mitigate this challenge.

Although the existing literature on surgical simulators is primarily focused on the trainee (graduate) surgeons, the greatest impact may be had in the training of those who have already completed their surgical training (postgraduate). Whereas graduate surgeons are afforded a structured curriculum and expert supervision to gain competency in novel surgical techniques, the postgraduate surgeon faces considerable challenges to receiving training. Gross *et al.* highlighted these challenges for postgraduate surgeons, namely the limitations on time, personal and practice finances, hospital resources, and a lack of mentorship (36). Simulators may provide an economical and efficient solution to reduce the learning curve and these challenges faced by postgraduate surgeons.

For robotically-assisted thyroidectomy techniques, the need for effective simulation is particularly pressing. Although the utilization of the da Vinci Surgical System (Intuitive Surgical, Inc, Sunnyvale, CA, USA) has steadily increased, so too has the number of iatrogenic injuries from improper use and inadequate training with this system, including some within thyroid surgery (37,38). As with other novel surgical techniques, there is increased scrutiny of outcomes. As a result of these complications, the FDA prompted ISI to withdraw support for remote-access thyroid surgery in 2011 (39). This revocation and, more importantly, the serious complications, may have been avoided if adequate training, including effective simulations/simulators, had been available.

As TVA becomes more widely adopted, particularly with utilization of single port robotic technology, it is important that these same mistakes are not repeated and that new adopters are appropriately prepared (40). As the overwhelming majority of early adopters of TVA have been and will be postgraduate surgeons, the relative value of a TVA simulator is potentially greater than that of a transcervical thyroidectomy simulator.

It is noteworthy to review the current implementation guidelines for TVA. These include multiple cadaveric dissections prior to a surgeon's first TVA case, live proctoring, and exposure to live surgeries, among other recommendations (22). However, access to cadavers can be limited by cost or availability of dissection labs, and proctoring is not always available in some locales. As such, there is a need for TVA simulators than can be used both for initial skill acquisition as well as continued skill refinement. This is particularly true for robotic-assisted remote-access thyroidectomy and TVA techniques, where the learning curves have been demonstrated to be steeper than the respective endoscopic approaches (17-19).

Characteristics of effective simulators

The ideal simulator is both high-fidelity and low cost. Prior studies examining robotic surgery simulators have suggested that virtual reality systems alone may not be adequate (38). As such, the ideal simulator would contain both virtual reality and physical components to allow for training in both operative decisions making (appropriate instrument selection, management of hemorrhage, etc.) and technical performance (instrument haptics, fluidity of motion). This is of particular importance as nontechnical skill simulation has been found to be lacking both in our review, as well a larger review examining simulation within OHNS as a whole (13).

Although surgical training can often focus on development of technical skill, operative decision-making and situational awareness may be of greater value when maintaining patient safety in the operating theatre (41). In fact, development of these nontechnical skills can often foster appropriate surgical technique and mitigate technical errors (42). Other surgical subspecialties have successfully integrated nontechnical skill training within their simulators (43). As such, a system combining physical aspects of the silicone model for the bilateral axillary breast approach by Yu *et al.* and the augmented reality structural overlay by Lee *et al.* may be of greatest benefit as it would allow for both technical and nontechnical skill acquisition (29,31). High-fidelity simulation involving physical and augmented reality components would allow trainees to directly exercise and improve on operative technique and decision-making. Physical models provide the benefit of haptic feedback whereas augmented reality facilitates visualization of anatomic targets. Further, the ability to simulate an entire operation or key steps of a procedure allows trainees to be observed and evaluated on communication skills, teamwork, and situational awareness.

Conclusions

There is a need for high-fidelity low-cost simulation in head and neck endocrine surgery. The value of such simulation is even greater in remote-access thyroidectomy approaches, particularly the newer robotic and endoscopic TVA techniques. Given that the majority of remote-access thyroidectomy adopters have already completed their residency training, these simulators may play a vital role in surgeon education, and ultimately better prepare the surgeon prior to his/her first case.

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