

Development and Validation of a Virtual Reality Simulator for Thyroid Surgery Training: A High-Fidelity System Featuring CT-Derived Deformable Tissues and Photorealistic Volumetric Operating Room Environment

Karl Eisenträger, Eva Maria Dobrindt, Moritz Queisner, Christopher Remde, Igor Sauer, Johann Pratschke, Martina Mogl, Frederike Butz, Charlotte Müller-Debus

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Abstract

Background: Thyroid surgery entails significant challenges due to the intricate anatomical structure of the region, including the recurrent laryngeal nerve and the parathyroids.

Objective: To support the training of resident surgeons through the development of a virtual reality simulator for thyroid surgery.

Methods: We created an anatomical model integrating structures segmented from CT data with manually inserted elements not clearly visible in CT scans (e.g., nerves, parathyroids). The model was integrated into a photorealistic operating room environment created using photogrammetry. The simulation incorporates organ and tissue deformation consistent with clinical observations and surgical exploration.

Results: The prototype simulator enables users to manipulate key anatomical components and explore the positioning of parathyroids, nerves (e.g., the recurrent laryngeal nerve), and relevant vascular structures, creating an immersive learning experience.

Conclusions: We have developed a proof-of-concept virtual reality simulator for thyroid surgery training that has received initial qualitative validation and feedback from experienced thyroid surgeons. Clinical Trial: This study primarily involved the development and qualitative assessment of an immersive virtual reality simulator for thyroid surgery training. The anatomical models were created using anonymized publicly available CT scan data, ensuring no identifiable patient information was utilized. For simulator validation, three surgeons, who are also co-authors of this paper, with varying levels of experience participated in the evaluation after receiving a brief explanation of the simulator functionality. Written informed consent was obtained from all participating surgeons prior to their involvement. The photogrammetry process for creating the virtual operating room environment and patient positioning utilized a surgical training mannequin rather than actual patients. No experimental procedures were performed on human subjects or animals, and no sensitive personal data was collected during the research process. This type of technological development and simulator validation research does not typically require formal institutional review board approval according to our institutional guidelines. All research activities were conducted in compliance with the principles outlined in the Declaration of Helsinki and adhered to the institutional regulations for educational technology development and evaluation. The surgeons' feedback was documented and analyzed with their consent, with responses presented in an anonymized format to maintain confidentiality while preserving the educational value of their expert

assessment.

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Original Manuscript

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Keywords: virtual reality, immersive virtual reality, thyroid surgery, training, deformable organ models

Introduction

Motivation for This Research

Thyroid surgery requires precise navigation of delicate structures within a confined space. The recurrent laryngeal nerve and parathyroid glands must be identified and preserved to prevent complications^{1,4}. The recurrent laryngeal nerve can follow unpredictable courses, while parathyroid glands can be difficult to distinguish from surrounding tissue and may occupy variable or ectopic positions. If these challenges are not mastered the result can be hoarseness and shortness of breath due to damaged nerves or severe cramps because of an hypoparathyroidism^{5,6}.

The restricted surgical field typically allows direct visualization only to the primary surgeon, limiting hands-on learning opportunities for trainees. Surgical education represents a complex medical training, requiring the integration of theoretical knowledge with practical skills, decision making and teamwork in a high-stakes environment⁷. The education often takes place in a taxing, stressful and unpredictable work environment. Acquisition of surgical proficiency requires repeated exposure to the same procedure^{8,9}. To guarantee optimal surgical outcomes, even experienced surgeons need to perform the same procedures regularly to preserve and refine their skills¹⁰.

The conventional surgical training paradigm encounters notable limitations. Hands-on practice opportunities are restricted by safety imperatives, supervisory availability, and case variation. Surgical proficiency demands repeated procedural execution to cultivate technical accuracy and adaptive judgment, as practitioners must become adept at managing diverse anatomical presentations. This combination of repetition and exposure to variability cultivates the expertise necessary for addressing both standard procedures and unexpected complications. Translating knowledge from static educational materials and imaging to the fluid surgical environment represents a substantial perceptual hurdle.

Mapping spatial relationships from images to actual patients requires skilled interpretation and mental effort. Anatomical recognition during operative procedures remains a capability requiring dedicated development.

Challenges in Surgical Training

The lack of opportunities to practice without putting patients at risk is one of the major challenges in surgical training. An ideal situation in which trainees operate under supervision in high-volume centers, allowing for high levels of exposure, is rare⁴. Current supplemental training solutions have limitations. The use of photographs and videos are helpful to acquire theoretical knowledge, yet they are inherently two-dimensional, lack interactivity and are passive ways of learning. Physical anatomical models also have limitations since they typically represent simplified versions of anatomy, lack anatomical variation, require regular maintenance, lack visual authenticity, don't replicate the surrounding operating room and usually require supervision during use^{12,31}. Similarly, the effectiveness of cadaveric training beyond basic surgical skills has been questioned^{14,35}. At the same time, cadaveric training is associated with logistical challenges, ethical concerns, high costs, limited availability, and potential health risks^{36,39}. Cadavers generally lack living, perfused tissue turgor. Animal models have similar limitations, raise ethical concerns, and may not fully replicate human anatomy, which limits their educational value⁴. Supplementing hands-on experience working on patients with simulation training would be ideal to minimize potential patient harm and to provide the best possible preparation for resident surgeons. Specifically, a need for open procedure and thyroid surgery training in virtual reality using head-mounted displays (also known as immersive virtual reality) is recognized as an effective and economic solution for educational purposes^{12,30}. The potential of virtual reality viewed in head-mounted displays to simulate complex situations and anatomical variations is considerable when compared to physical models or cadavers⁴. However, there is a recognized need for further development to ensure that these simulators can adequately replicate the handling of real surgical instruments and provide realistic and accurate haptic feedback.

Contribution of the Current Work

Virtual reality can provide immersive, repeatable training experiences that overcome many traditional limitations such as variability, high realism and interaction. Here, we present the prototype of an innovative virtual reality simulator that combines a highly realistic operating room environment with anatomically accurate, deformable organs derived from computer tomography (CT) segmentation. The simulator offers interactive capabilities that allow trainees to explore and manipulate anatomical structures from perspectives typically available during surgery. The simulator aims to bridge the gap between theoretical knowledge and practical surgical experience, providing a safe, repeatable environment for surgical training that complements traditional educational methods. We validate the prototype with qualitative feedback from thyroid surgeons with different levels of experience and synthesize potential solutions to shortcomings of the current implementation and potential routes of further development. Our aim is to advance virtual reality simulators towards maximum realism, reproducing real anatomy and surgical settings.

Related Work on Immersive Virtual Reality in Thyroid Surgical Training

Studies have demonstrated that virtual reality and non-immersive virtual reality (2D simulators on monoscopic screens) training significantly improve surgical performance metrics, with meta-analyses showing faster procedure times, improved technical accuracy compared to traditional training methods, and lower complication rates making it an effective tool for preparing trainee surgeons for their operative experiences^{2,22-25}. While virtual reality and non-immersive virtual reality differ, we believe that the benefits derived from non-immersive virtual reality simulators should carry over to virtual reality simulators as well.

Specifically for neck and thyroid surgery there exist some virtual reality, non-immersive virtual reality, and augmented reality simulators. A virtual reality trainer has been developed for bilateral axillo-breast approach robotic thyroidectomy²⁶, for endoscopic transoral thyroidectomy with a physical tool², and for training of needle biopsy of thyroid gland nodules²⁸. Furthermore, an augmented reality simulator has been designed for recurrent laryngeal nerve identification during thyroid surgery²⁹ and a commercially developed virtual reality simulator exists for neuromonitoring during thyroid surgery³⁰.

These simulators use artificially crafted models that are not derived from real patient data and often place users in cartoon-like environments, which do not resemble clinical situations. To our knowledge, no thyroid surgery simulator currently exists that combines CT-derived deformable anatomical structures with an authentic operating room

environment for thyroid exploration.

Method

The simulator leverages CT data to create anatomically detailed models, achieving a high level of structural fidelity, deformability, allowing for visual exploration closely mirroring actual surgery, though the interaction does not replicate actual surgical techniques. Additionally, the immersive volumetric operating room environment replicates the real-world surgical experience and spatial context. In doing so, the system provides a high-fidelity training tool that aims to make an effort to bridge the divide between current simplified simulators and the complex realities of thyroid surgery. In the following sections, we describe the creation of the prototype and the qualitative validation testing we conducted to assess its feasibility and realism.

Imaging Data and Segmentation

We used an anonymized publicly available CT scan as the basis for our anatomy model³¹. We imported the CT scan into Slicer 3D³², an advanced open source DICOM platform and performed segmentation using TotalSegmentator³³. We used the total, headneck_bones, and headneck_muscles tasks³⁴ to segment the relevant anatomy. We removed unnecessary segments and anatomy that was segmented multiple times.

Virtual Reality Environment Creation

The prototype for our virtual reality thyroid surgery training simulator was developed using Unity Pro (Version 6000.0.29, Unity Technologies, San Francisco, Ca, USA)³⁵. The environment recreates a fully-equipped modern operating room, featuring a centrally positioned operating table with a patient prepared for thyroid surgery, complete with appropriate surgical draping and neck positioning. The scene is based on a photogrammetric reconstruction of an operating room at Charité – Universitätsmedizin Berlin, Campus Mitte, and includes essential medical monitoring equipment, overhead surgical lighting systems, and standard operating room fixtures³⁶. The specific surgical setup, including the thyroid procedure preparation, was designed in collaboration with surgeons experienced in the field of thyroid surgery to ensure authentic training conditions.

The patient model was created through high-resolution photogrammetry, utilizing a Fuji XT-4 camera³⁷ mounted on a tripod with controlled settings (ISO 160, f/8 aperture, 1/4 second shutter speed). Under consistent LED lighting conditions, we systematically captured over 300 photographs of a surgical training mannequin positioned on a standard operating table, with proper surgical positioning and draping. The photographic dataset was processed using Agisoft Metashape software (Agisoft Metashape Standard, Version 2.1.0 build 17532 (64 bit), Agisoft LLC, St. Petersburg, Russia)³⁸ to generate a detailed point cloud, which was then converted into a textured 3D model. The final model accurately represents a thyroid surgery setup, featuring the characteristic hyperextended neck position and standard surgical draping protocols.

Medical Data Processing and Organ Deformation

The segmentations described under Image Data and Segmentation were exported as OBJ files to Blender (Version 3.0.0, Blender Foundation, Amsterdam, Netherlands)³⁹, a free and open source 3D computer graphics tool to manually insert the parathyroids as well as the recurrent laryngeal nerve and to apply UV mapping to all OBJ-files. To mirror the effect of hyperextension of the neck, as is customary during thyroid surgery, we manually adjusted the positioning and tilt of the segments. The enhanced OBJ-files were then imported into Unity³⁵. Textures were created using FLUX (FLUX1.1 [pro] ultra, Black Forest Labs, Wilmington, DE, USA) through the fal.ai API (fal, San Francisco, Ca, USA)^{40,41}.

Example prompt for texture generation: *“Hyper-realistic thyroid gland surface texture as viewed intraoperatively. Slightly moist organic surface with Base color variations from deep crimson (vascular zones) to burgundy-red (parenchyma). Delicate fibrous capsule texture with faint follicle patterns. Branching arteriole networks (bright scarlet) and thrombosed veins (darker maroon). Semi-transparent areas revealing subsurface vasculature Subtle collagenous striations and adipose tissue inclusions Near-flat surface topography (0.1-0.3 mm variance) with minimal specularly Surgical field lighting creating subtle moisture sheen (0.2 roughness) Microscopic blood spots and capillary leakage details Seamless tileability for 3D model UV mapping PBR-ready format (Albedo/ORM/Normal maps) for Unity URP.”*

After exporting the OBJ-files from Blender and importing them into Unity, plausible tissue deformation was achieved using a realtime particle physics engine called Obi Softbody (Obi Softbody Version 7.0, Virtual Method Studio, Madrid, Spain)⁴². Deformability was applied to select segmentations using the Obi package. Through Obi we employ a particle-

based method where organs are discretized into clusters of particles. A shape-matching constraint system updates these particles' positions in real time to model soft-tissue deformation, with each cluster defining how its local region can deform through bending, stretching, and compression. A physics solver continuously computes the forces and constraints, adjusting particle positions while maintaining the organ's overall shape, while plasticity parameters regulate permanent deformations to ensure realistic effects such as tissue stretch and recovery. These parameters were set by the primary developer trying to approximate real tissue behaviour. Custom C# scripts were developed to enable VR interaction with the deformable segmentations.

Interaction and User Interface

We developed the interaction system on top of the XR Interaction Toolkit (XRI Toolkit 3.0.7, Unity Technologies, San Francisco, Ca, USA)⁴⁹. Navigation utilizes the standard XRI implementation for passive directional movement controlled by the left controller's joystick and snap turning via the right controller's joystick. The remaining interactions are customized. When the trigger button of the right controller is pressed, the first particle from the anatomical models that collides with the controller's emitted visible ray will be subject to force. The deformation correlates to the movement transform of the controller. Upon release of the trigger the deformation persists. The system maintains a sequential history of all deformations in memory. By pressing a dedicated button on the right controller, users can undo the last manipulation and revert the tissues to their previous state. This straightforward interaction design facilitates comprehensive exploration of the virtual model.

Simulator Workflow

The simulator enables users to navigate freely within the virtual operating room. The implemented interaction focuses on deformable tissue anatomy at the surgery site. Here, the users can prepare the neck muscles to gain sight of the thyroid, the parathyroids, and vascularization. It is possible to move and twist the thyroid. All deformations can be undone with a single button press. The workflow was designed to ensure intuitive usability and to enable a first qualitative validation. This first implementation simulates an advanced stage of thyroid surgery where the gland has already been fully exposed and mobilized. At this stage, the surgeon's primary objective is to identify and preserve critical structures like the recurrent laryngeal nerve and the parathyroid glands prior to resection.

Qualitative Validation Setup

After a brief introductory session explaining the use of controllers for navigation and interaction within the immersive virtual reality environment, three surgeons with varying levels of experience explored the simulator. The qualitative questionnaire targeted the following topics: general impression, immersion and realism, anatomical accuracy, tissue behavior and haptics, interaction and controls, learning and training effectiveness, user interface and workflow, additional features and future enhancements, and overall evaluation and feedback (**Appendix 1**).

The simulation was tested on a Quest 3 tethered with a USB C 3.1 cable to a high-performance workstation equipped with an NVIDIA RTX 3090 graphics card with 24GB GDDR6X (Nvidia Corporation, Santa Clara, Ca, USA), 64GB DDR RAM, and an AMD Ryzen 9 3900 12 core 3.80ghz processor (Advanced Micro Devices, Inc., Santa Clara, Ca, USA). In the scene, there were approximately 6 million vertices and the program was running at about 70 frames per second.

Ethical Considerations

This study primarily involved the development and qualitative assessment of an immersive virtual reality simulator for thyroid surgery training. The anatomical models were created using anonymized publicly available CT scan data, ensuring no identifiable patient information was utilized. For simulator validation, three surgeons, who are also co-authors of this paper, with varying levels of experience participated in the evaluation after receiving a brief explanation of the simulator functionality. Written informed consent was obtained from all participating surgeons prior to their involvement. The photogrammetry process for creating the virtual operating room environment and patient positioning utilized a surgical training mannequin rather than actual patients. No experimental procedures were performed on human subjects or animals, and no sensitive personal data was collected during the research process. This type of technological development and simulator validation research does not typically require formal institutional review board approval according to our institutional guidelines. All research activities were conducted in compliance with the principles outlined in the Declaration of Helsinki and adhered to the institutional regulations for educational technology development and evaluation. The surgeons' feedback was documented and analyzed with their consent, with responses

presented in an anonymized format to maintain confidentiality while preserving the educational value of their expert assessment.

Results

The following section presents the surgeon's responses, which have been organised thematically and aligned with the order of the questionnaire. Relevant aspects were the sense of immersion, the realism of tissue response to manipulation and educational value. The surgeons provided written responses. The surgeons agreed that the highly realistic experience delivered by the virtual reality tool would provide effective operating practice and learning. Suggestions for improvement included ensuring more realistic reactions of organs and adding the instruments that would normally be used at the operating table.

Initial Impression

All three participants agreed that the simulation provided an immediately convincing operating room environment. They described feeling as if they were stepping directly into a real surgical scenario, with one participant noting, *"The operating room felt impressively realistic, and I instantly found myself in the role of the surgeon, wanting to move right up to the table"* (surgeon 1). Another emphasized the vividness of both the environment and the patient's position, stating, *"The position of the 'patient' on the operating table was so authentic that I really felt like I was in an actual operating room situation"* (surgeon 3).

Sense of Immersion

There was a strong consensus that the sense of being "immersed" in the virtual operating room was highly effective. One participant remarked, *"I almost forgot that I was actually standing in my office; the setting felt entirely convincing"* (surgeon 2). Others noted that minor anomalies, such as a floating anatomy model, briefly reminded them of the virtual nature of the scenario, yet did not significantly break their engagement with the simulated surgery.

Factors Enhancing Immersion and Areas for Improvement

All participants felt that realistic visuals, along with environment-specific audio, would further enhance immersion. One person suggested, *"Adding the beeping of monitors or the sounds of a ventilator would recreate a typical operating room atmosphere, especially if one could also hear the noise of neuromonitoring when checking a nerve"* (surgeon 3). Another participant observed that starting the scenario directly at the operating table could reduce the need for joystick navigation, noting, *"I wanted to step right up to the table, so maybe it would be more intuitive to have the user start at the right distance"* (surgeon 1).

Anatomical Realism

The group agreed that the thyroid gland, major blood vessels, and musculature were depicted with a high degree of realism, although the absence of connective and fat tissue made the surgical site appear "naked." One participant stated, *"The thyroid surface appears very authentic, but the vagus nerve is placed too superficially, since in reality it is hidden between the artery and vein"* (surgeon 1). Another recommended revising the color and location of the nerve, noting, *"the vagus nerve should run deeper between the carotid artery and jugular vein; it would be more realistic if it appeared yellowish rather than greenish"* (surgeon 2).

Plausibility of Tissue Deformation

All participants noted that the thyroid gland appeared more pliable than in real surgery, as if it could be displaced too easily. One participant commented, *"The thyroid felt super flexible, softer than in reality; it shouldn't be so easy to luxate"* (surgeon 1). Despite this, there was agreement that other structures, such as the muscles, had a reasonably lifelike range of motion.

Improving the Plausibility of Tissue Interaction

Suggestions included refining how the tissues move together, particularly when pulling on the thyroid gland. One participant recalled: *"It was unrealistic that the thyroid alone was pulled up while the overlying muscle remained unchanged"* (surgeon 3). Another noted that repositioning the fixation point to reflect a later surgical stage, where the recurrent laryngeal nerve is actually exposed, would enhance authenticity (surgeon 1).

Current Interaction Possibilities (Grabbing, Moving)

There was widespread agreement that—despite not perfectly replicating genuine surgical maneuvers—the interactions became intuitive and accessible following a brief period of familiarization. *“It might not replicate an actual operation perfectly, but it feels intuitive enough for the purposes of navigating and manipulating tissue.”* one participant observed (surgeon 1).

Desired Additional Interaction Forms

Most suggestions focused on integrating a wider range of surgical instruments and adding a neuromonitoring probe. One participant stated, *“It would be fantastic to have a force-feedback mechanism so you can sense when you’re applying too much tension on the thyroid or risking nerve damage”* (surgeon 2). Another emphasized the utility of tools such as hooks or forceps, explaining, *“In reality, we hold muscle aside with a retractor rather than simply ‘pushing it away,’ so the option to use instruments would feel more natural”* (surgeon 1).

Educational Value

The simulator was unanimously regarded as a valuable tool for teaching anatomical landmarks, especially nerve tracts and location of parathyroid gland. One participant emphasized its potential for novice learners, saying, *“For students, it’s already highly beneficial in showing relationships between the recurrent laryngeal nerve, vagus nerve, thyroid, and vessels”* (surgeon 1). Another looked to the future development, suggesting, *“Ultimately, I’d like to train the complete workflow of a thyroidectomy, including identifying critical structures and performing the standard sequence of steps”* (surgeon 3).

Navigation and Clinical Workflow

The overall impression was that the navigation and menu controls were clear enough that only minimal training was required. One participant mentioned, *“A short introduction was all I needed, and I believe it fits into a typical clinical routine without much extra time”* (surgeon 1). Another recommended a simpler method for adjusting the table height, remarking, *“Clearer prompts, like ‘pull yourself toward the operating table with your left hand,’ would make the learning curve even smoother”* (surgeon 2).

Comfort and Possible Strain (Motion Sickness)

None of the participants reported discomfort, visual strain, or motion sickness while wearing the headset.

Additional Features and Long-Term Engagement

The participants were enthusiastic about the addition of different pathologic scenarios, such as an enlarged or nodular thyroid, anatomical variations in nerve positions, and the potential for simulated complications such as bleeding. One participant commented, *“It would be great to have warnings if you pull the gland too aggressively, putting stress on the recurrent laryngeal nerve”* (surgeon 1). Another envisioned a gamified approach, remarking, *“I would love to see a points-based system where you lose points for injuring a nerve or causing excessive bleeding”* (surgeon 2).

Overall Assessment and Further Suggestions

All participants praised the simulator’s immersive operating room environment and felt that the surface realism of the structures shown was already high. One participant summarized, *“I loved the instantly immersive atmosphere and how naturally I could interact with the thyroid and surrounding muscles”* (surgeon 2). Another pointed to areas needing attention, explaining, *“A more lifelike arrangement of fat tissue, plus more coherent deformation when pulling on the thyroid, would really enhance the experience”* (surgeon 3).

Discussion

The aim of the current undertaking was to qualitatively assess the first prototype of our thyroid surgery simulator. Based on expert feedback, future iterations will incorporate suggested refinements and expand the range of surgical cases with the goal to conduct a quantitative evaluation. The surgeons’ appraisal confirmed that a photorealistic operating room and well-defined anatomical structures are crucial for creating a credible and immersive training experience. They reported a strong sense of immersion, emphasizing that the accurate representation of key landmarks, such as the recurrent laryngeal nerve and parathyroid glands, fostered engagement. However, they noted that the lack of simulation of connective tissue made the model appear *“naked,”* emphasizing the need for additional soft-tissue detail to match the complexity of real

surgery. This consideration is particularly relevant for parathyroid identification, as normal-sized parathyroid glands may be hard to detect when embedded within adipose tissue matrices.

Participants also highlighted that the thyroid gland appears overly pliable, which reduced the authenticity of tissue handling. To address this, they recommended refining the elasticity of the organ and introducing surgical instruments, including retractors and neuromonitoring probes, to more closely replicate standard surgical procedures. Despite these shortcomings, all surgeons emphasized the educational potential of the simulator, particularly for teaching anatomical relationships critical to safe thyroid surgery.

From a usability perspective, they found the interaction and movement intuitive and user-friendly, requiring minimal onboarding. Notably, none of the participants experienced motion sickness. Although the evaluation was limited to three participants, their comments provide valuable information for future improvements: adding realistic tissue layers, refining tissue deformation, and integrating surgical workflows. Addressing these limitations could make the simulator a more comprehensive training tool for aspiring thyroid surgeons.

Contextualization of the results

Historical surgical data indicates that mortality rates in thyroidectomies can decrease dramatically with increased surgeon experience. Evidence shows that as surgeons perform more procedures, patient outcomes improve significantly, with documented cases of mortality rates falling from over 12% to less than 1% after thousands of operations⁴⁴. This underscores the critical importance of regular practice for achieving effective surgical outcomes. Despite this understanding, current research reveals significant knowledge gaps regarding the training protocols for surgical residents and fellows specializing in neck endocrine surgery throughout Europe⁴⁵. Gimm et al. suggest that proper training requires experience in medical units that conduct a minimum annual volume of 100 thyroid and 50 parathyroid surgical procedures to ensure adequate skill development⁴⁵.

There is limited research on learning curves in conventional thyroidectomy. Interestingly, even though endoscopic and robotic surgical approaches emerged only recently, there exists a more structured understanding of how practitioners can attain mastery in these techniques⁴⁴. Providing better access to training for surgeons through a tool as proposed in this paper can therefore potentially add to a more thorough understanding of the learning curves in conventional thyroidectomy. The literature shows that there are different types of learning tools. Simulator training on physical models and cadavers has long been a central component of surgical education, bridging the gap between theoretical knowledge and hands-on patient care⁴⁶. For example Graham-Stephensen et al.⁴⁷ argue how important it is to use simulators in order to gain the necessary practice for performing thyroidectomy. Specifically, they assessed the learning effectiveness of a 3D-printed model with silicone components. Highlighting the importance of practice for students of anatomy Bartikian et al. 2018 draw on a 3D printer to develop models of the skull bones⁴⁸. Kennel et al 2017 assess dissection experience with cadavers. Thiel-embalmed cadavers, according to the authors, “show greater flexibility and color retention compared to formalin-embalmed cadavers, properties which might be considered advantageous for anatomy teaching”⁴⁹. Rajasekhar and Kumar highlight the health risk to staff and students handling cadavers, particularly in the context of the COVID pandemic⁴⁶.

Finally, there is also research on alternative teaching methods. Technological developments are constantly creating new opportunities, particularly, in the area of VR, as Reinhold et al.⁴⁸ point out. VR training allows transferring technical skills to the real world environment of the operating room⁴⁹. In a meta-analysis, Humm et al. show the positive effect VR simulation training has on time and surgical performance in minimally invasive cholecystectomy⁵⁰. Assessing the impact virtual reality simulators (VRS) can have for teaching neurosurgical skills Intekhab Alam et al. argue “*this technology investment can enhance the learning curve while maintaining patient safety*”⁵⁰.

Limitations of this Study

We have described the development of an early prototype for a virtual reality thyroid surgery trainer and its initial validation by a small group of surgeons. Inherently there is room for improvement, but we think it is interesting to describe the development process and illustrate the interdisciplinary work necessary to achieve a simulator that meets the needs of professionals. Since the simulator is still under development, we deemed it sufficient to assess it qualitatively.

Future Work

Based on surgeon feedback and in continuation of our collaboration, we plan to enhance the simulator. We are

planning to add interaction through surgical instruments, nerve monitoring, ambient sounds, and more cases for our next development sprint. We are committed to evaluating the next prototype quantitatively with medical students and/or surgical residents.

Conclusion

Main Contributions

This paper aims to contribute to the discussion of making the education and practice of endocrine surgeons more efficient and effective. In particular, we present the prototype of a virtual reality simulator for thyroid surgery. The traditional surgical training model faces several constraints. The opportunity for hands-on experience is limited by patient safety considerations, the availability of expert supervision, and the inherent variability of surgical cases. Test subjects found that the tool can meet training needs through a realistic immersive experience, while being readily available, unlike other more traditional methods.

Key Takeaways

Our prototype demonstrates that a virtual reality thyroid surgery simulator combining CT-based anatomical models with a photorealistic operating environment can provide an effective and readily available training tool, as validated by experienced surgeons. While improvements in tissue mechanics and the addition of surgical instruments are needed, the simulator shows promise in addressing the critical need for safe, repeatable surgical training opportunities that complement traditional methods.

Abbreviations

CT – computer tomography

Multimedia Appendix 1, 2, 3

Screenshots of the simulator (1+2)

First Person Video Capture of an user of the simulator (3)

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Supplementary Files

Multimedia Appendixes

Liv Capture of a user in the simulator.

URL: <http://asset.jmir.pub/assets/cdcfb5ee246a60475e53b5a22def772a.png>

Liv Capture of a user interacting with the deformable anatomy.

URL: <http://asset.jmir.pub/assets/0a0d09042aaa5c6260b237c0b31e4f74.png>

First person perspective of user moving and interacting in the simulator.

URL: <http://asset.jmir.pub/assets/68701048b40f0adaea2a80947600079f.mov>