Project Title: Importance of Stereoscopy in Novice Temporal Bone Surgical Training

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SUMMARY:

Knowledge of anatomical relationships forms the basis of any surgical procedure, and yet can be a difficult skill for both novice and advanced practitioners to master. Training through virtual models (VMs) is becoming increasingly prevalent in medical education, particularly for surgical residency programs. These VMs incorporate advanced technology to help simulate real-world procedures, and utilize 3D graphics that have already shown promising learning advantages over their 2D counterparts. Stereoscopy is an imaging technique used to simulate the third dimension that can be integrated into 3D anatomical simulations. Whether or not its inclusion enhances skill acquisition in a surgical setting is the topic of this research.

This study sought to assess the potential benefit of stereoscopy in training medical students (as surgical novices) in a well-defined procedure (canal wall up cortical mastoidectomy). Students were randomly divided into either the control (mono vision), or experimental (stereo vision) group, prior to being shown a training video explaining how to perform the operation. Following this, both groups practiced the surgery on a VM in their respective study categories, with the stereoscopic cohort experiencing a simulated third dimension. Lastly, all participants went on to perform the mastoidectomy on a rapid-prototyped printed bone model (PBM) replica of the VM. Drilled PBM specimens were collected and graded by three Otologic surgeons, and the scores from both groups were compared to look for a significant difference in performance.

[redacted]

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Introduction

Knowledge of anatomical relationships forms the basis of any surgical procedure, and yet can be a difficult skill for both novice and advanced practitioners to master. Regions of the body with inherently complex three-dimensional structures, such as the temporal bone, may be particularly difficult for students to appreciate [1]. In the past a variety of learning tools have been employed to help trainees gain an understanding of complex three-dimensional structures. With reference to the Temporal Bone, there exists manufactured/3D printed models (PBM), virtual models (VMs) and cadaveric materials. The latter of these is limited in both availability, and standardization for teaching as each specimen is anatomically unique. A large variety of 3D graphic simulators have been developed and tested in recent years; while in the past some illustrated problematic haptic fidelity, they are now generally cost effective, and permit a breadth of metric assessment tools, along with stereoscopic vision [2-7]. Printed Temporal Bone Models are not commercially available, but they present an exciting educational opportunity.

This study seeks to determine the significance of stereoscopy in learning a defined surgical skill through training in a 3D graphic VM. While generally accepted as superior to traditional 2D training [5, 8-10], 3D anatomy, and in particular stereoscopic display of 3D anatomy have not yet been demonstrated to affect learning of anatomically complex surgical procedures [11]. We elect to assess the significance of stereoscopy in learning via a Virtual Temporal Bone Surgery. Specifically, we will examine how a simulated three-dimensional display, using stereo glasses, affects the ability of novice trainees to learn a mastoidectomy procedure on a haptic and graphic simulation of the temporal bone. Although restricted to a single procedure in an isolated anatomical region, the study has the potential to guide the development of simulators and learning tools for a wide range of medical and surgical procedures.

The temporal bone is a highly complex structure and contains highly variable and sensitive anatomy, including the carotid artery, sigmoid sinus, facial and auditory nerves, vestibular and auditory apparatus, and lies in close proximity to the brain. The surgery is challenging and requires the ability to dissect structures of interest apart from vital structures from within an osseous framework. Temporal bone surgery is performed for a number of pathologic conditions; common indications include chronic inflammation, cholesteatoma, hearing loss, cochlear implantation, schwannoma and meningioma. Surgery is undertaken with use of a microscope with depth of field provided by true stereoscopy.

Current simulator designs incorporate multiple technologies to provide high levels of surgical fidelity. Simulators with haptic feedback employ a robotic system to apply forces through an end-effector (manipulandum). The user sees a graphical representation of the bone and feels virtual contact forces while holding the haptic manipulandum like an otic drill. Several of these multimodal simulators that combine graphic, auditory, and haptic cues are currently available and represent viable surgical education tools [12-21]. All temporal bone surgery simulators today display the surgical field in 3D, using a variety of visual cues such as lighting and shadow to simulate the third dimension on a 2D display. Additionally, several systems employ stereoscopic displays to provide users with additional 3D cues [13-17]. Our VM is similar to previous systems but uses a multicore architecture to accelerate graphic rendering and a distinct voxel-based collision detection and position-locking algorithm to improve drill-bone interaction [Figure 1]. This is in contrast to the commonly used virtual spring model. The apparent advantage of a VM is the ability to objectively monitor and assess trainee actions, providing a basis for formative and summative assessment. As an additional point, virtual simulation can be less expensive because costs are upfront without need for a drill system, microscope and disposables (PBM and drill burr(s)).

Printed temporal bone models (PBM) using 3D printing technologies have long been described in the literature. Initially they represented an accurate anatomic replica; however, the technology is now able to provide a functionally dissectible model that includes select post-processed soft tissues. Some initial laboratory focus was spent on improving internal anatomic fidelity with precise void space generation associated with realistic bone structure and mechanical properties [Figure 2].

Consequently, our research group had already generated both PBM and a VM for the purposes of resident education and pre-operative surgical rehearsal, with long-term goals of competency-based assessments, accreditation examinations and continuing medical education. Therefore it was already prepared for application into this student teaching study. Training with stereoscopy can easily be contrasted with ultimate grading of a standardized PBM with the previously validated Welling scale [36-39], and our study uses a modified version of this scale for grading. A canal wall up mastoidectomy was deemed a suitable surgical skill to evaluate as it is complex, yet still accessible to novice trainees and has a number of definable elements for grading.

While several commercially available VMs are available, the importance of training with the graphic addition of the third dimension (in this case with stereoscopy) is uncertain [11]. How the brain perceives stereoscopy has already been studied extensively [30-34]. Previous research has indicated that utilizing stereoscopy in virtual simulation technologies has an overall positive impact on learning in students; as mentioned, several simulators already incorporate it as an additional visual cue. Studies in the past have looked at examining simple geometric shapes, and these have shown some promise that stereo vision benefits the user in identifying or recognizing structures with the aid of stereo; others have also shown that it is possible to better infer novel portions of a structure with the inclusion of stereovision in the simulation [22-23].

A number of studies also suggest a possible benefit to procedural learning and increased retention of anatomy with stereoscopic modeling but are not definitive [24-26]; other studies seem to indicate that there is no benefit to its addition in a procedural learning setting [27-29]. Furthermore, some studies have found that participants were too experienced or familiar with a task, making it difficult to measure an appreciable difference in skill development [29]. Regardless, research has so far indicated that stereoscopic vision increases a user's immersion in a virtual model, and is preferred for most users, despite showing no statistical difference in scoring outcomes [28]. One particular study evaluated its effectiveness in a surgical procedure with medical students, and showed no benefit, but suggested further studies to be certain [35].

Methods

After approval by the University Research Ethics Board, 20 Medical Students from the University of Manitoba were recruited to participate. Recruitment was achieved via a generalized email to all potential graduates in the Faculty of Medicine Class of 2016. None had any prior experience with temporal surgery or exposure to the simulation software utilized in this research, and were considered to be novices for the purposes of this training study. Each student was randomly assigned [Research Randomizer, Asheville NC] to train with either a VM with graphic represented in 2D (control) or with the addition of the third dimension via stereoscopy (experimental group).

All participants viewed a training video specifically created for the project (13:28 min.) that was intended to teach the procedure at a level suitable to second year medical students. Focus was spent on local anatomy and vital structures, along with the requisite steps in a canal wall up cortical mastoidectomy, and featured the dissection of a PBM by an in-house Otologist for reference. Furthermore, the specific features to be graded [modified Welling scale, Columbus Ohio], dissection techniques, and common errors that may occur, were highlighted in the media.

Subsequent to the training video, participants randomized into the stereo group were subjected to an nVidia [SantaClara CA] program in order to ensure that they were able to visualize stereoscopic 3D images. Following a 5 minute period of familiarization with the VM controls, all participants underwent forty minutes of training on our VM in their respective randomized condition [10 per group]. All subjects were required to wear stereoscopic active shutter glasses regardless of whether or not they were selected for stereoscopic training. The ability to manipulate or adjust the view of the model, as well as the size of the drill, was allowed for both participant groups. A total of three simulated cortical mastoidectomy surgeries were allowed per user for this stage of the study.

Following their training and VM practice sessions, subjects then performed the same procedure in a mock-surgery setup [Figure 3] on a PBM [20 minute duration]. Participants were allowed to request a change in size of the drilling burr to achieve better precision during the procedure and maintain consistency with the VM. A single PBM was granted per student, leading to a total of 10 specimens per study group, or 20 in total. These models were then graded by 3 Otologic Surgeons employing a modified Welling scale, who were blinded as to participant training graphic [Figure 4].

To create each cadaveric template, a human CTB specimen underwent microCT using a SkyScan 1176 microtomograph (Bruker-microCT, Billerica, MA). Image resolution was initially 35 μm but down-sampled to 140 μm to match 3D printer resolution. MicroCT data was then segmented using Mimics 14.0.1.7 (Materalize, Leuven, Belgium) into separate structural features. Bone was segmented semi-automatically using Hounsfield unit thresholds. Soft tissue features including carotid artery, sigmoid sinus, dural plates, endolyphatic sac, endolymphatic duct, otic capsule contents, greater superficial petrosal nerve, chordae tympani and facial nerve were manually segmented. Segmented features were stored as an individual polygon mesh.

Concerning the preparation of the virtual haptic models, the data was generated from cadaveric specimens by recombining individual polygon mesh models into a single voxellated model. The simulation used a haptic device (Geomagic Touch - SC, USA) to control a virtual drill during interaction with the voxellated model. The model was visually displayed on a 165 cm plasma screen (Panasonic TCP65VT30, Panasonic, Osaka, Japan) mounted above and behind the haptic device (1280x720 pixel resolution). The drill was activated using an on-off foot-pedal (Scythe – Tokyo, Japan).

The stereoscopic display was achieved through nVidia technology shutter glasses that when activated, displayed alternating images to either eye piece, providing with user with the illusion of a three-dimensional interface.

Utilizing the same cadaveric data used in the VM, a PBM was generated. To create the requisite void spaces multiple polygon meshes, representing soft tissue and bone, are combined into one voxellated model. Utilizing a proprietary algorithm, the computer model is manually sliced into layers. Alignment fiducials are digitally added for post-print reassembly. The slices were outputted as a series of triangular meshes created by the Marching Cubes algorithm. Each slice was then printed separately. The void spaces are cleared of remnant material using compressed air and the slices are infiltrated with a binding agent (Cyanoacrylate with hydroquinone) and then recombined to produce a final physical model. The PBMs were anatomically identical to the virtual haptic bone, being based on the same microCT data. Internal soft tissue structures are preserved and coloured as they are in the virtual bone.

The PBM was dissected with an otic drill (Stryker, Kalamazoo, MI) and stereo microscope (Zeiss, Jena, Germany). The otic drill was activated via a foot-pedal mechanism that can obtain up to 20,000 RPM at max function.

Analysis & Results

Following the completion of all participant studies, the printed bone models were collected and graded using the previously mentioned modified Welling scale and were assessed on seven points, leading to an averaged score of up to 7 for each model. The three Otologists responsible for grading were blinded as to which method students were trained in, and analysis resulted in two groups of data: stereoscopy-trained vs mono vision VM. Statistical analysis in the form of a t-test was performed comparing the mean values of the two sample groups, and the results were as follows: 2D mono vision (M=4.4, SD=1.5), and 3D stereoscopic vision (M=3.8, SD=1.1), t(11) = 2.18, p = 0.163 [Figures 5-6]. There were no outliers associated with the data, and all PBMs were considered viable.

With the results of the statistical analysis performed showing p=0.163, we can conclude that there was no significant difference in the scores of those who were trained with the addition of stereoscopy compared to those in the control group (mono). This suggests that stereoscopic vision provides no added performance benefit in the learning of a canal wall up cortical mastoidectomy using our training VM. An analysis of variance was also performed, and was consistent with the above data.

In the seven attributes assessed during grading through the modified Welling scale, the stereoscopically-trained group did not outperform the mono group on any mean value calculated. The data does not suggest however that the addition of stereoscopy imparted a negative effect on learners, and may be explained by the sample size and nature of this study. No particular analysis was made in looking at right or left-handedness or gender in this study. Entrance or exit surveys were not performed with participants with regards to the procedure.

Discussion

The results of this study suggest that the stereoscopy imparted no benefit in effecting improvement of surgical skill translation from a VM to PBM in learners. This is a unique study combining two user learning models that has not been examined elsewhere at this time. A review of study limitations indicates that while a definitive answer may seem to appear, there was a potentially inadequate sample size to say for certain as to the effects of this teaching method on a population-wide scale. Further research calls for more participants in order ensure these results are statistically significant for the study group that was looked at.

While VMs in general for temporal bone surgery have been previously validated, this particular model was not approved on a national level for usage, and this might have played a factor in skill acquisition to the learner. The amount of time given for students to familiarize themselves with the equipment and to experience the effects of mono vision, or stereoscopy also may not have been sufficient for the sake of the study, but was justified by real-world limitations and availability of the population for study participation. A more ideal scenario may involve training sessions over a more prolonged period of time to be allotted in order to accurately determine if stereoscopic vision can impart any skillset improvement.

The modified Welling scale that was used for the study may also not have looked at appropriate traits that might be improved through the stereo learning program, and could perhaps have been problematically oversimplified in order to facilitate a generalized grading scheme for these bone models. The selected surgical task itself could have been an issue, since it potentially does not represent a reasonable procedure to be taught over a brief time period for purposes of analysis. A curious outcome of the study is the seeming trend towards lower scores for the majority of participants in the stereoscopy group, which cannot be explained by any one factor at this time. One hypothesis is that users of stereoscopy required additional time to become accustomed to the effect, which might have hampered their ability to practice effectively on the VM. No participants of our system expressed any particular discomfort or difficulty with regards to the depth effect created by utilizing the nVidia display glasses.

The strengths of this study include the fact that despite the results, this study does indeed seem to be in line with some previous research regarding the validity and role of stereoscopy in training scenarios, and its role in the translation of skill onto real-world procedures. Being that the nature of 3D training in general has not be proven to be beneficial with certainty, this could have led to a confounding variable that further exacerbated attempts to train students using stereo vision. A great benefit of our study design is that manages to fit a comprehensive learning situation into an easily replicable training program that in further studies can be applied on a larger scale, with training tools already available for use; the protocol is highly flexible in this regard.

The study's materials and technology are reproducible in the laboratory and facilities at the University of Manitoba, and the nature of a virtual model and the translational abilities of microCT scans and their synergy with 3D printing with our research allow for the particular procedure itself, or the target model, to be modified with relative simplicity. It is possible to shift the focus of this study to incorporate any number of other anatomical regions to apply the experiment's general principles through this inventive design. This university is the only site in the world to have looked at the application of a virtual model coupled to the development of a PBM with the added variable of stereoscopy, and it is nonetheless a pioneer study that has the potential to help elucidate the role of stereoscopy as a learning tool on a larger scale in the future.

Conclusion

There does not appear to be any benefit in training for a canal wall up mastoidectomy with stereoscopic graphic display with this particular virtual model. This research presents a novel idea that combines multiple training modalities, and cannot alone provide a generalized statement on the role of stereoscopy in education. Nonetheless, it does support some evidence from previous research showing stereoscopy may have no effect on learning. Future studies will require a larger sample size and will need to examine this question from other viewpoints, and an adjustment of protocol is called for in order to determine how best to analyze and incorporate stereoscopy in a VM to definitively study this topic. Stereoscopy cannot yet be discarded as a training tool before this occurs, and will continue to be a focus of research interest for some time ahead. Considering the enormous resources currently being invested in training and in the generation of adjunctive tools, it is imperative that a holistic review of temporal bone simulation technologies be undertaken.

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Tables and Graphs

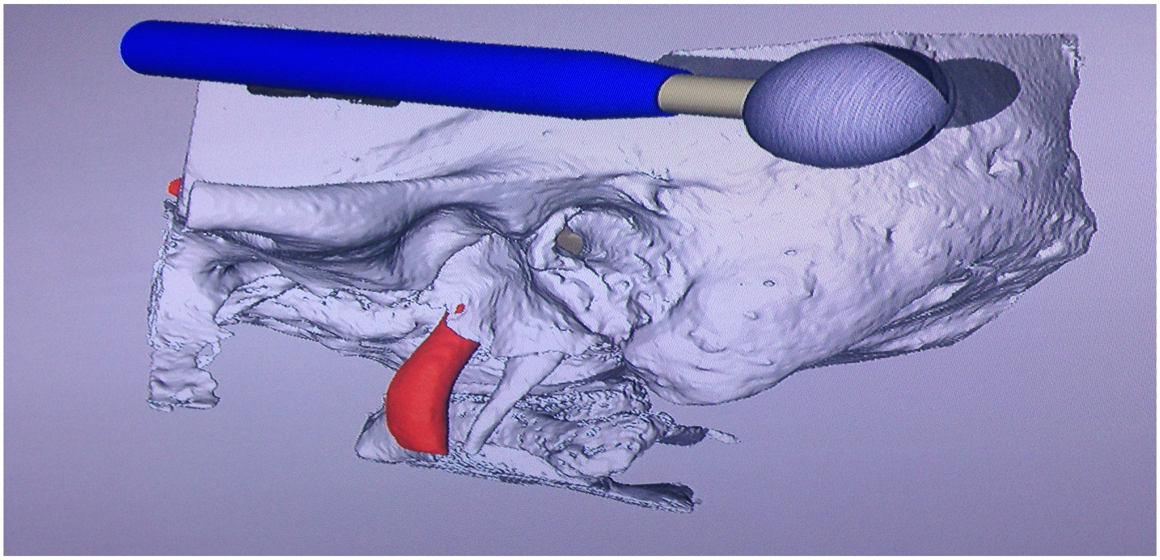

Figure 1 – *This image showcases the virtual graphic model that participants trained on; the ability to perform the procedure in stereoscopy is built into the program. Pictured is the microCT-derived temporal bone segment utilized in the study, as well as the drilling tool operated via manipulandum*

Figure 2 – *Seen above is the rapid-prototyped printed bone model (PBM) that was used to assess surgical skill acquisition in novices for this study. It is derived from the same microCT data used in the virtual model (VM), and created using an in-house 3D Printing device. Note the colourization of the model, indicating vital structures.*

Figure 3 – *The mock-surgery setup where participants performed the drilling of their printed bone model (PBM) specimens that were used in the grading and assessment of surgical ability for the study.*

Grading of Mastoidectomy 1 – Not successful in task, 4 – Partially successful, 7 - Successful in task		
Attribute	Score	Comment
Thin posterior canal wall		
Thin middle fossa dural plate		
Entered zygomatic root		
Opened sino-dural angle		
Exposure without violation of sigmoid sinus		
Exposure of antrum		
Opening of all aircells		

Figure 4 – *A representation of the modified Welling scale used for grading each of the twenty (20) PBM that were generated during the study.*

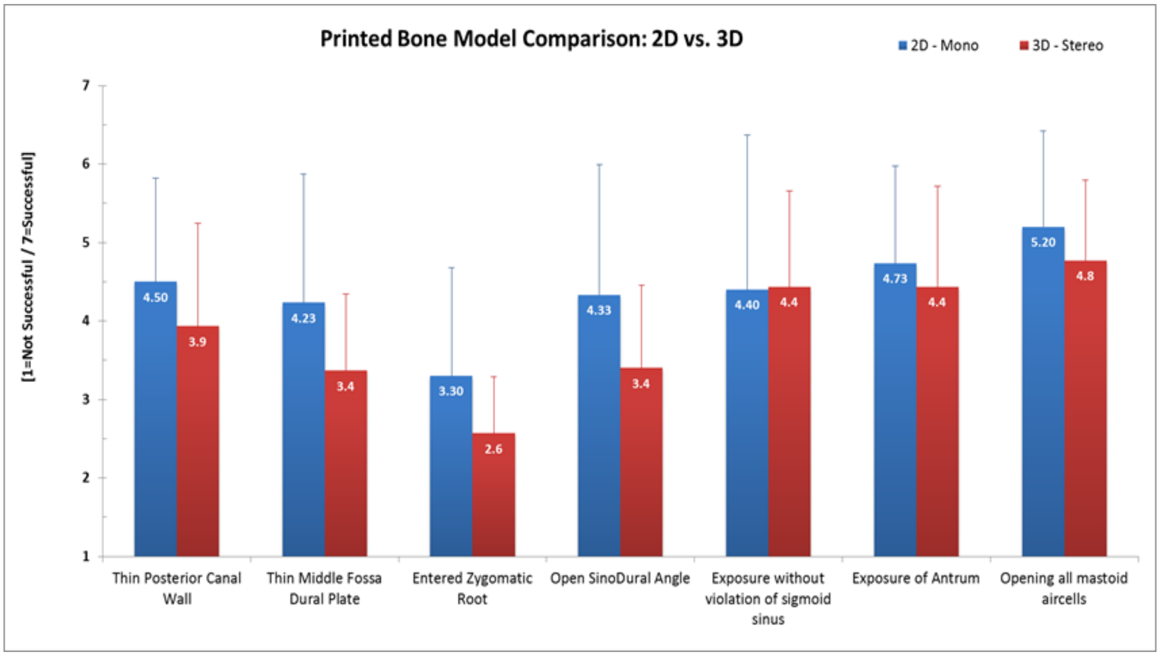

Figure 5 – *This figure summarizes the mean scores (M) along with standard deviation (SD) for each attribute assessed by the three Otologists with the modified Welling scale used in the grading of printed bone models (PBMs) for the study.*

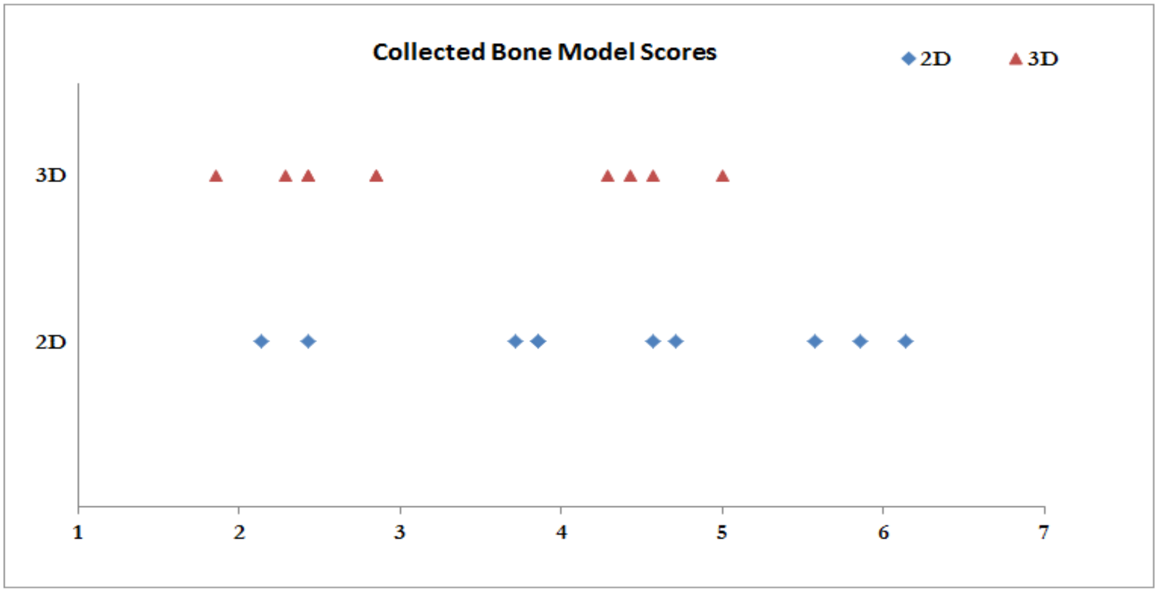

Figure 6 – *This graph showcases the individualized scores of the ten PBM samples performed in either research group, along the modified Welling scale. They are comprised of the averaged values of the three Otologists responsible for grading in this study.*