The effect of self-directed virtual reality simulation on dissection training performance in mastoidectomy

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Objective: To establish the effect of self-directed virtual reality (VR) simulation training on cadaveric dissection training performance in mastoidectomy and the transferability of skills acquired in VR simulation training to the cadaveric dissection training setting.
Study Design: Prospective study.
Methods: 2x20 novice otorhinolaryngology residents received either self-directed VR simulation training before cadaveric dissection training or vice versa. Cadaveric and VR simulation performances were assessed using final-product analysis with three blinded expert raters.
Results: The group receiving VR simulation training before cadaveric dissection had a mean final-product score of 14.9 (95 % CI [12.9–16.9]) compared with 9.8 (95 % CI [8.4–11.1]) in the group not receiving VR simulation training before cadaveric dissection. This 52 % increase in performance was statistically significantly ($p<0.0001$). A single dissection mastoidectomy did not increase VR simulation performance ($p=0.22$).
Conclusions: Two hours of self-directed VR simulation training was effective in increasing cadaveric dissection mastoidectomy performance and suggests that mastoidectomy skills are transferable from VR simulation to the traditional dissection setting. VR simulation training can therefore be employed to optimize training and spare the use of donated material and instructional resources for more advanced training after basic competencies have been acquired in the VR simulation environment.
Key-words: temporal bone dissection, mastoidectomy, virtual reality simulation, surgical skills training
Level of evidence: NA

Introduction

Traditionally surgical training has been apprenticeship with direct supervision of the trainee in the operating room by an experienced surgeon and mentor.[1] However, this alone is untenable for high-quality training in a contemporary context of patient safety issues, constrained working hours and increasing productivity demands. In addition to apprenticeship, a multitude of training modalities has been used to supplement surgical skills training such as lectures, video demonstrations, cadaveric dissection, and physical box models.

In temporal bone surgery, the gold standard for skills training has for a long time been human cadaveric dissection because it closely mimics the real-life surgical conditions.[2] Human temporal bone specimens for training are becoming a scarce and expensive resource in addition to the costs of maintaining convenient dissection facilities. Therefore, temporal bone training is often limited to participation in a few temporal bone courses, each of which usually provides a once-instance opportunity for the resident to develop basic skills.

Recently, advances in computer technology have allowed virtual reality (VR) simulation training of surgery and VR surgical simulation is undergoing rapid development towards increased fidelity and realism supporting advanced procedural training in many surgical areas. VR simulation training has consistently proved to benefit the acquisition of surgical skills, and documented that the acquired skills are transferable.[3]

Altogether, this has sparked the development of different VR temporal bone surgical simulators.[4–8] Much effort has been used on gathering evidence for the validity of these simulators as a training tool[9–14] to corroborate that VR simulation training of mastoidectomy is effective and that the acquired skills are transferable: temporal bone surgery is complex and requires compound competencies in several domains including surgical technical skills with handling of instruments such as the operating microscope, a drill and suction/irrigation as well as an intricate understanding of the anatomical relationships of the temporal bone. Nonetheless, the hypothesis of this study was that basic mastoidectomy skills can be acquired with self-directed VR simulation training and are transferable to traditional dissection conditions.

Previous studies have explored the role of VR simulation training in improving dissection performance of trainees[11,12,15] but the training interventions in these studies have been multilayered. Consequently, the isolated effect of self-directed VR simulation training of mastoidectomy remains little researched and warrants further investigation. The aim of this study was to establish the effect of self-directed VR simulation training on cadaveric dissection training performance in mastoidectomy, and the transferability of skills acquired in VR simulation training to the traditional dissection setting.

Material and methods

Setting and participants

2x20 otorhinolaryngology residents participated in January 2014 and January 2015 in the national temporal bone course held annually at our institution. Participants were post-graduate year 2–5 and all novices regarding the procedure because the course is a prerequisite for commencing supervised temporal bone surgery. The temporal bone course is mandatory in Danish otorhinolaryngology resident training. Participants signed informed consent and completed a background questionnaire.

Study design

The study was conducted as a prospective study with the first course arranged with VR simulation training before cadaveric dissection training and the following course with cadaveric dissection training before VR simulation training (flowchart, Fig. 1). A class lecture on the mastoidectomy procedure and the surgical anatomy of the temporal bone was given the day before training.

VR simulation platform

The Visible Ear Simulator is a VR temporal bone surgical simulator [8,16] offered as academic freeware for download from the Internet.[17] The 3-D virtual temporal bone in the simulator is based on manual segmentation of high-resolution digital photos of cryo-sections from a fresh-frozen human temporal bone (the Visible Ear image library).[18] This gives a higher resolution and more details in the temporal bone and relevant anatomical structures than datasets post-processed from computerized tomography (CT). The Visible Ear Simulator runs on a standard PC with a GeForce GTX graphics card (Nvidia, Santa Clara, CA, USA) and supports force-feedback drilling with the 'Geomagic Touch™' or the the '3D Touch™ Haptic 3D stylus' (3D Systems, Rock Hill, SC, USA) haptic devices. The simulator also features optional 3-D stereo graphics and an integrated tutor-function. The simulator-integrated tutor-function option provides volumetric greenlighting of the volume to be drilled corresponding to an on-screen step-by-step guide with supporting text and illustration to a complete mastoidectomy (Fig. 2). In this study we used version 1.3 of the simulator in an experimental version that supported individual user logins and auto-save of the final-product after a predefined time as well as preset, fixed settings for simulator-integrated tutoring.

VR simulation training

Participants received a 5-minute hands-on introduction to the VR simulator in a non-mastoidectomy exercise after which they performed three virtual procedures consisting of a complete mastoidectomy to the point of posterior tympanotomy (flowchart, Fig. 2). The first session was simulator-tutored and the participants were allowed 60 minutes to learn the procedure and to study the temporal bone in depth. The second session was also simulator-tutored but shorter with only 30 minutes allowed. The last session was non-tutored with 30 minutes allowed. The final-product of this last session was auto-saved and later assessed. During all sessions, the participants had access to the on-screen guide but were otherwise completely self-directed and received no instructor guidance or feedback.

Cadaveric dissection training

The cadaveric dissection setup consisted of a formalin-prepared head of a cadaver in a dissection tray, an operating microscope, an otosurgical drill with a standard array of different drill bits, and suction/irrigation. Participants were allowed a total of 60 minutes to complete a similar mastoidectomy. The longer time allowed for cadaveric dissection compensated for the extra time needed for positioning of the cadaver head, handling of suction/irrigation and change of drill bits, which is not necessary or less time consuming in the VR simulator. Immediately after the time limit, the final-products were assessed before participants continued dissecting according to the general course curriculum. During cadaveric dissection training participants had access to a traditional table desk manual of the procedure but were otherwise self-directed and received no instructor feedback or guidance.

Outcome and statistics

Three expert raters assessed the virtual and cadaveric dissection final-products using a 25-item modified Welling Scale for final-product analysis. The use of the modified Welling

Scale for assessment of virtual and cadaveric dissection mastoidectomy performance has previously been detailed.[19] The assessment tool consists of binary items rated as complete (1 point) or incomplete/inadequate (0 point) adding to a maximal score of 25 points. Final-products were pseudonymized prior to assessment and raters were blinded to participant. The mean final-product score was calculated and used for the main analysis. Pearsons' r was used for analysis of correlation. A supplemental item analysis was performed to investigate which items in dissection were improved most by VR simulation training. Data were analyzed using ANOVA in SPSS (SPSS Inc., Chicago, IL, USA) version 22 for MacOS X.

Ethics

The regional ethics committee for the Capital Region of Denmark deemed this study to be exempt (H-4-2014-FSP 2).

Results

The two groups, 'VR simulation first' and 'cadaveric dissection first', had comparable age, sex, years of training, self-rated computer skills, and gaming frequency (Table I). Participants in the 'VR simulation first' group reported a significantly higher weekly average computer usage than the other group but computer usage was not found to be correlated with a better VR simulation final-product outcome. VR simulation and cadaveric dissection final-product scores were found to be correlated (Pearson's $r=0.21$, $p=0.02$).

A boxplot of the final-product performance scores in cadaveric dissection and VR simulation training is presented in Fig. 3.

For the cadaveric dissection performance, the group receiving VR simulation training before cadaveric dissection training significantly outperformed the group that performed cadaveric dissection first without prior VR simulation training ($p<0.0001$). The 'VR simulation first' group had a mean dissection final-product score of 14.9 (95 % CI [12.9–16.9]) whereas the group doing cadaveric dissection first achieved only a mean score of 9.8 in cadaveric dissection (95 % CI [8.4–11.1]).

The VR simulation performances of the two groups were found to be similar and without a statistically significant difference ($p=0.22$): the group doing VR simulation training first without prior training achieved a VR simulation final-product score of 15.5

(95 % CI [14.2–16.8]) and the group that had cadaveric dissection training before VR simulation training achieved a mean VR simulation final-product score of 14.4 (95 % CI [13.1–15.7]).

VR simulation training improved most aspects of the dissection performance (supplemental table I) but especially performance regarding the following items considered in the final-product assessment were significantly improved ($p<0.002$): 1) adequate sharpening and 2) complete removal of cells in the sinodural angle, 3) sufficient exposure of tegmen tympani, 4) not drilling into the ossicles, 5) not drilling holes in the external auditory canal wall and 6) identifying the vertical part of the facial nerve.

Discussion

In this prospective study on the effect of VR simulation training on cadaveric dissection performance in mastoidectomy, we found that mastoidectomy skills were transferable from VR simulation to the cadaveric dissection setting because two hours of self-directed VR simulation training increased cadaveric dissection final-product performance by 52 %. In contrast to this, a single unaided cadaveric dissection procedure before VR simulation did not improve the VR simulation performance. Several items considered in the final-product assessment of the dissection performance were significantly improved by having VR simulation training first.

VR simulation training of mastoidectomy has previously been studied in relation to improving the cadaveric dissection performance of novices: VR simulation training with human instructor supervision and guidance was found to improve cadaveric dissection final-product performance more than traditional teaching methods with small group tutorials, videos and models.[15] However, the effect of VR simulation training could not be isolated from the effect of the one-on-one tutoring by faculty. In a subsequent study, self-directed VR simulation training was investigated and a group receiving traditional training was also found to be outperformed by a group receiving self-directed VR simulation training.[11] The self-directed training included extensive simulator tutoring with instructional videos, computer-generated real-time feedback and final-product comparison with real-life videos and photos, and the relative contribution of each of these interventions could not be determined.[11]

In both these studies, VR simulation training was found to be superior to traditional training in improving cadaveric dissection performance. This was not the case in a multicenter study: residents with different levels of expertise practicing on either two cadaveric bones or as many VR simulations as possible during a two week period performed similarly on subsequent cadaveric dissections.[12]

The design of our study allowed us to establish the effect of self-directed VR simulation training, which was found to be substantial, supporting that skills acquired in VR simulation training transfers to dissection performance. Our results also suggest that the learning effect of dissecting a single cadaveric temporal bone is limited because cadaveric dissection training before VR simulation training did not improve the VR simulation performance. Different explanations for this can be suggested: a single repetition of the procedure in dissection training had limited effect on actual learning whereas the procedure was practiced three times during VR simulation training. The simulator-integrated tutor function and instructions could also be more useful in visually guiding and conveying the steps of the procedure than the conventional desk reference used during dissection. In addition, other factors such as the complexity of cadaveric dissection (i.e. handling several instruments, consulting a written manual, varying anatomy) could require more cognitive resources than VR simulation and thereby interfere with learning and integrating the necessary motor and cognitive skills. Repeated practice is essential for skills consolidation and retention in surgical skills training[20] and it is therefore not surprising that cadaveric dissection skills improve with repeated cadaveric dissection practice.[21] A similar dose-response relationship between increasing amounts of VR simulation training and cadaveric dissection performance remains unexplored.

VR simulation training improved cadaveric dissection performance on most items that is considered in the modified Welling Scale assessment tool for final-product analysis of mastoidectomy. However, it seemed that especially items concerning the final thinning of bone at the outer boundaries of the mastoidectomy were significantly improved by VR simulation training. This could suggest that participants acquired a better understanding of the anatomical relations of the temporal bone with the VR simulation training. In addition, on average participants scored low on items relating to not drilling holes in the sigmoid sinus, tegmen and external auditory canal during VR simulation while at the same time scoring high on these items during dissection. In other words, the participants seem to have learned from their mistakes in the VR simulation and proceeded more cautiously in the following cadaveric dissection, knowing and respecting the boundaries of the mastoidectomy.

Generally, it should be considered that performance evaluated by final-product analysis has limitations because final-product analysis only considers the end result and not the process. Moreover, final-product performance does not correlate well with performance on more process-related assessment tools.[22] Nonetheless, the assessment of process and technique is time consuming because it requires direct or videotaped observation of performances, making it a less feasible option for performance assessment in most clinical settings. Another limitation to this study was that the two groups were not individually randomized for order of training due to the practical organization of the course. However, the two cohorts were of equal size and had comparable background demographics and characteristics.

In our study, VR simulation training was self-directed in the sense that participants did not receive instructions or guidance by human instructors but the training was directed and self-regulated as participants were provided a VR training program with access to on-screen instructions of the procedure corresponding to a traditional table-desk dissection manual as well as additional simulator-integrated tutoring with greenlighting. It is very likely that the VR simulator and simulator-integrated tutor function may guide the participants with a more systematic approach than is accomplished when participants are guided by a traditional written manual during dissection training of the procedure, leading to a higher VR simulation performance. Guidance is crucial in surgical skills training but should be employed correctly to lead to the best learning outcome: individual guidance and tutoring by human instructors can benefit learning especially novice learners[23]; at the same time it has been demonstrated that feedback results in rapid skills acquisition but also rapid skill deterioration when feedback is unavailable.[24] Whether the instructional approach is direct instructional guidance or directed self-regulated learning, active learning is key in effective learning. VR simulation surgical skills training facilitate learner-centered and active learning and in the case of mastoidectomy skills training, we found that the training program provided sufficient guidance to improve cadaveric dissection performance. However, our study cannot separate the effect of having guidance by the simulator-integrated tutor function during the first two sessions from the effect of training in a simulator with haptic feedback alone.

Based on our findings, it is valuable to implement VR simulation training to improve cadaveric dissection, even if it is only of short duration, to make a more optimal use of donated temporal bones. This should be feasible in most settings especially because the hardware for the studied freeware simulator can be acquired for less than $5,000 whereas commercially available temporal bone simulators will cost 5–10 times as much.[13] Because VR simulation offers the opportunity for repeated practice and the possibility of self-directed training this could to some extent meet the trainees individual needs for inexpensive and unlimited practice at their own convenience and support progressive skills development and consolidation.

Conclusion

Two hours of self-directed VR simulation training is effective in increasing cadaveric dissection mastoidectomy performance of novice otorhinolaryngology residents. This makes VR simulation training an attractive and effective option for teaching novices basic skills and competencies in mastoidectomy that also transfers to cadaveric dissection conditions. The purpose of VR simulation training is not to replace cadaveric dissection or supervised surgery but rather to supplement it in acquiring basic competencies: VR simulation training could therefore be employed in training of novices to make better use of both donated material and instructional resources by reserving cadaveric dissection training for more advanced training after basic competencies has been acquired.

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Table I. Participant characteristics.

	'Cadaveric dissection first' group Means	**'VR simulation first' group** Means	Significance of difference
Age, years	35.6	36.7	ns
Sex			
Male, n (%)	9 (45 %)	10 (50 %)	ns
Female, n (%)	11 (55 %)	10 (50 %)	
Years of training			
Otorhinolaryngology, years	3.8	4.4	ns
Other surgical specialty, years	1.0	1.2	ns
Average computer usage, hours/week	5.6	8.9	p=0.02
Self-rated computer skills (1–7 Likert like scale)	4	4.8	ns
Gaming frequency (1–5 Likert like scale)	2.3	2.7	ns

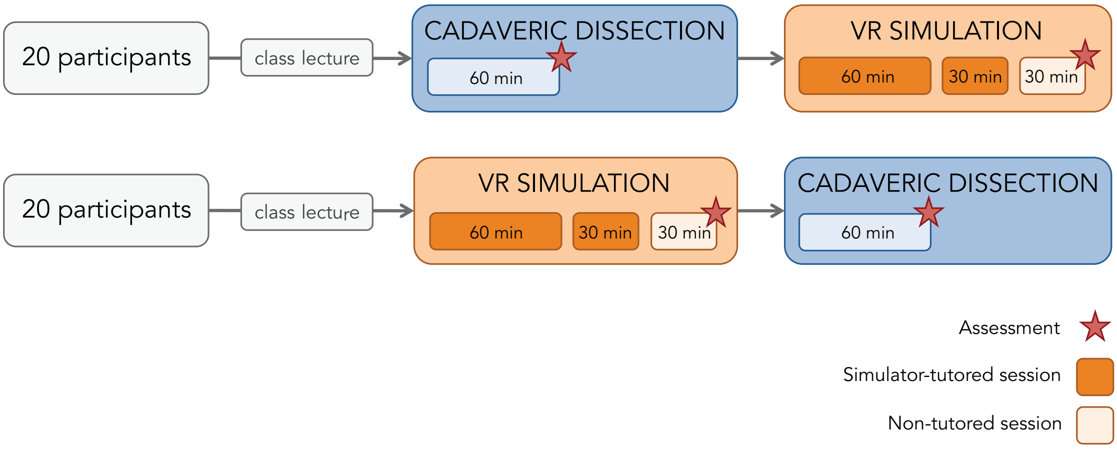

Fig. 1. Flowchart. A 'cadaveric dissection first' group completed a single cadaveric dissection mastoidectomy before VR simulation training of the procedure and a 'simulation first' group received VR simulation training before performing a cadaveric dissection mastoidectomy. Performances were assessed at the end of the final procedure in each training modality.

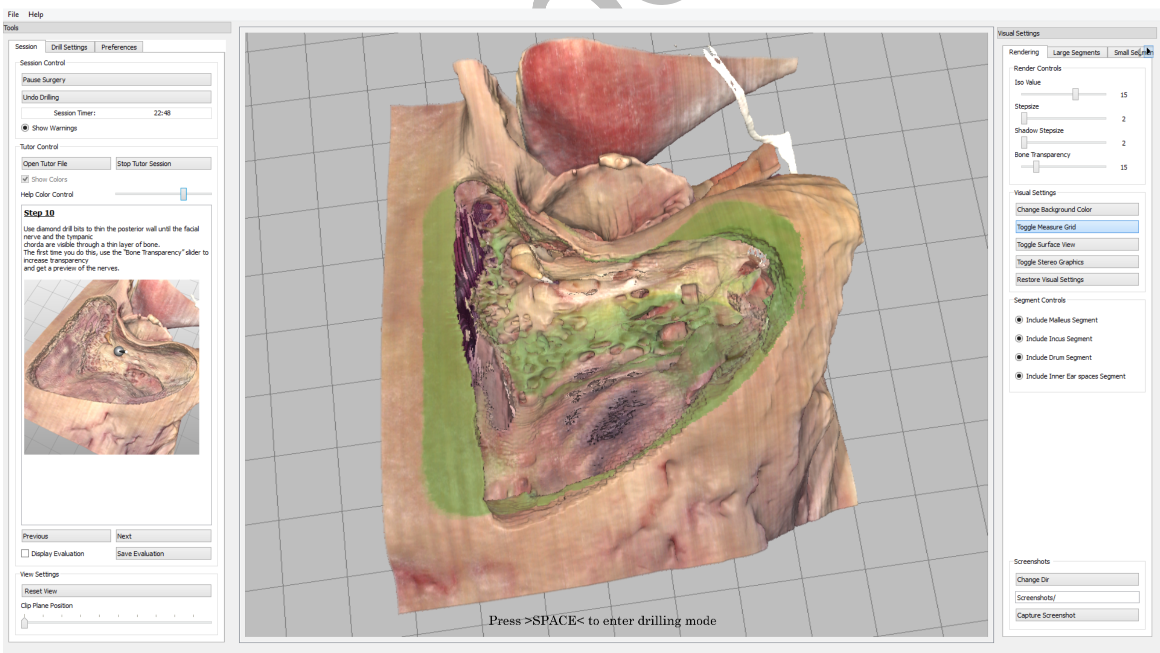

Fig. 2. Screenshot from the Visible Ear Simulator. The on-screen step-by-step instructions on mastoidectomy are found in the panel to the left and in this screenshot the simulator-integrated tutor-function is greenlighting the remaining volume to be drilled corresponding to the current step.

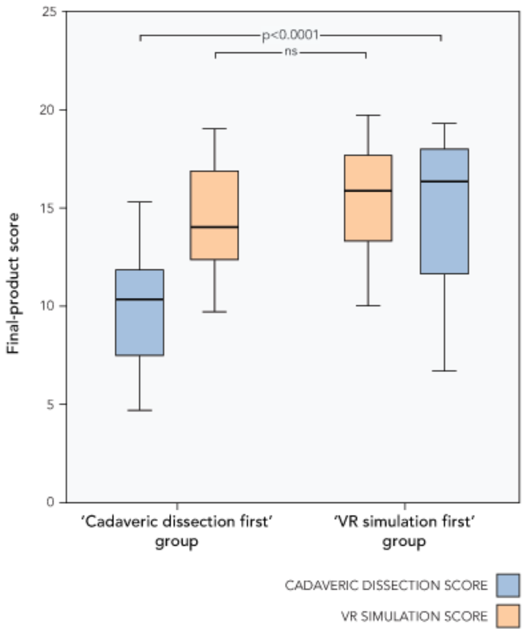

Fig. 3. Boxplot of final-product scores for the 'cadaveric dissection first' and 'VR simulation first' groups.