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Decentralized Virtual Reality Training of Mastoidectomy Improves Cadaver Dissection Performance: A Prospective, Controlled Cohort Study

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Abstract

Objective: Virtual reality (VR) simulation training can improve temporal bone (TB) cadaver dissection skills and distributed, self-regulated practice is optimal for skills consolidation. Decentralized training (DT) at the trainees' own department or home offers more convenient access compared with centralized VR simulation training where the simulators are localized at one facility. The effect of DT in TB surgical training is unknown. We investigated the effect of decentralized VR simulation training of TB surgery on subsequent cadaver dissection performance.

Study Design: Prospective, controlled cohort study.

Setting: Otorhinolaryngology (ORL) teaching hospitals and the Danish national TB course.

Participants: Thirty-eight ORL residents: 20 in the intervention cohort (decentralized training) and 18 in the control cohort (standard training during course).

Intervention: Three months of access to decentralized VR simulation training at the local ORL department or the trainee's home. A freeware VR simulator (the Visible Ear Simulator) was used, supplemented by a range of learning supports for directed, self-regulated learning.

Main Outcome Measure: Mastoidectomy final-product scores from the VR simulations and cadaver dissection were rated using a modified Welling Scale by blinded expert raters.

Results: Participants in the intervention cohort trained decentrally a median of 3.5 hours and performed significantly better than the control cohort during VR simulation ($p<0.01$), which importantly also transferred to a 76% higher performance score during subsequent cadaver training (mean scores: 8.8 vs. 5.0 points; $p<0.001$).

Conclusions: Decentralized VR simulation training of mastoidectomy improves subsequent cadaver dissection performance and can potentially improve implementation of VR simulation surgical training.

Introduction

Surgical skills have traditionally been taught through the apprenticeship method, whereby the trainee practices on patients in the operating room supervised by a senior colleague[1]. Patient safety concerns and work-hour restrictions have brought about the need for new ways of acquiring surgical skills. This is also the case for temporal bone (TB) surgery where the current gold standard training modality is cadaver dissection, which is an expensive and often scarcely available training resource[2]. Therefore, Virtual Reality (VR) simulators have been introduced to address the issue of limited training opportunity in TB surgery.

It has been demonstrated that VR simulation training of TB surgery improves cadaver dissection performance[3,4], but the distribution of training significantly affects the outcome: several shorter training sessions (distributed practice) are superior to few longer training sessions (massed practice)[5]. In a recent study, a 25% increase in dissection performance was demonstrated by distributed VR simulation training compared with massed practice during a temporal bone course[6].

Directed, self-regulated learning (DSRL) is a framework for self-directed learning whereby the trainee practices independently and self-regulates the learning process with the learning task being scaffolded by the educational designer through learning supports[7]. This aims to facilitate self-regulation and make learning effective without the need for instructor presence. DSRL has been found superior to instructor-led training for learning outcomes such as retention of skills[8].

Often, VR simulation training is conducted in a centralized setting, e.g. at a teaching department or a simulation center. Other examples of such centralized training is "boot camp" courses, where a large training effort is conducted in a short period of time (i.e. massed practice) using instructor-led training[9]. Centralization allows for access to expensive simulation systems and for simulation expertise and technical support[10]. However, centralization of training can at the same time make it inconvenient or infeasible to conduct many shorter training sessions for distributed practice, e.g. due to long distances to the simulation centers or infrequent courses. In contrast, decentralized training (DT) allows trainees to conduct distributed, self-regulated practice at their own convenience using local simulator systems[11]. We define DT as training at the local workplace or at home in a setting without access to direct instruction or in-person feedback. We hypothesize that this could improve training because participants would be able to train at any desired time without the constraints of access to centralized training.

Free academic VR simulation software for TB surgical training running on a laptop makes widespread implementation of VR TB simulation training affordable and feasible[12]. Nevertheless, there is an "implementation gap" in VR simulation training in otorhinolaryngology, and the use of VR simulation training in the surgical curriculum needs further dissemination[13]. For example, only 14% of major European training departments with in-house TB training reported access to an in-house VR simulator[14]. Clearly, novel and evidence-based strategies for the implementation of VR simulation training are needed.

In this study, we therefore aimed to explore the use of decentralized VR simulation training as a strategy to improve temporal bone surgical training. Consequently, we offered DT before a national TB course to investigate the effect of DT on cadaver dissection performance and compared this with regular simulation training during the TB course.

Materials and Methods

Study design and participants

We designed a prospective, controlled cohort study in relation to two consecutive, annual, national TB courses in Denmark. This 4-day course includes traditional lectures, three hours of hands-on VR simulation training, and cadaveric dissection (Figure 1). Participants were 38 ORL residents (PGY 2–5) attending the course. For the 2018 course, we offered structured DT training, resulting in an intervention cohort of 20 participants; at the 2019 course, we enrolled 18 participants as a control cohort (no structured DT). All participants received standard VR simulation training during the course. Participants were novices (i.e. generally without hands-on experience performing the procedure) in mastoidectomy because the TB course is a prerequisite for supervised surgery and mastoidectomy is typically performed only by sub-specialists in otology. Consequently, none of the participants had performed a live mastoidectomy prior to the course, but one participant in each cohort had completed a temporal bone dissection course.

VR simulation platform

The Visible Ear Simulator (VES) is a free software package for VR TB simulation[15,16] that runs on a standard gaming PC or laptop with a Geforce GTX graphics card (Nvidia, Santa Clara, CA, USA)[1]. In contrast to other VR TB simulators that are based on CT imaging data, the VES uses digital images of cryo-sections, resulting in high resolution and visual detail with natural colors[17,18]. A Geomagic Touch device (3D Systems, Rock Hill, SC, USA) provides haptic interaction and force feedback. A complete, fully portable VES setup (haptic device and gaming laptop for the free VES software) costs <3,500 USD.

Intervention

Three months before the 2018 TB course (Figure 1), participants were contacted by e-mail and encouraged to participate in DT of mastoidectomy on their local department's VES setup, which is available at most training departments in Denmark.

If their respective training department did not have a VES setup, the participant was offered to borrow a VES setup running on a laptop for DT at home. Trainees from all eight ORL training departments in Denmark were invited.

Several learning supports for self-directed training were offered to support DSRL. Two are built in to the VES as a standard: 1) an on-screen stepwise guide and 2) sequential green-lighting of the bone to be drilled. Four additional learning supports were made available: 1) a VR simulation mastoidectomy "dissection" manual with both technical advice and guide to the procedure[19]; 2) several short instructional videos relating to different aspects of the procedure[20]; 3) a tool for structured self-assessment of performance, and 4) external feedback on performance by sending a simulator save file for evaluation to one of the authors (SA). Monthly e-mails were sent to encourage DT and to remind trainees of the opportunity to train before the course. Study participation was voluntary and there were no training requirements or tests prior to the course, nor any compensation for practicing. Furthermore, the participants' departments did not offer protected time for training during work hours.

The 2019 cohort attended the regular TB course without specific encouragement to do DT. Nonetheless, some trainees had on their own initiative used the VR simulator at their department before the course but without the learning supports for directed, self-regulated learning or systematic training (Figure 2).

Data collection and outcomes
Data on demographics, previous surgical training and course participation, and an account of DT was collected via questionnaires before the course simulation training.

After the standard course lectures, all participants irrespective of cohort completed three hours of hands-on VR-training, with access to the step-by-step guide to the procedure and technical assistance. Participants were instructed to perform as many mastoidectomies as they could during the given time. On the following day, participants were instructed to perform a cortical mastoidectomy on a human cadaver in the Dissection Lab at the University of Copenhagen, using standard surgical tools and an operating microscope (Zeiss Pico, Zeiss, Oberkochen, Germany). After exposure of the temporal bone (i.e. removal of soft tissue), participants were given one hour to perform the mastoidectomy to the point of posterior tympanotomy. During the dissection, participants were only offered technical assistance with the equipment.

Dissection and simulation final-product performances were rated using a Welling Scale[21], modified to include only items 1–19, reflecting the procedure to the point of posterior tympanotomy[22] (maximum points): Definition of mastoidectomy margins (3 points), antrum mastoideum (3 points), sigmoid sinus (3 points), sinodural angle (2 points), tegmen mastoideum/tympani (5 points), and mastoid tip (3 points), resulting in a minimum score of 0 points and maximum score of 19 points. The measurement properties (e.g. reliability) of the Welling scale have previously been evaluated[23,24]. Three blinded expert raters (MDs with extensive research experience in temporal bone surgery; authors MS, PC and SA) independently rated the cadaver dissection performances; two of these (MS and SA) also rated the VR performances from simulator save files. The raters were blinded to participant identity and data (including whether the participant had done DT and the amount of training) and to the other raters' assessments, but not to cohort allocation as the year of the course could not be blinded (cadaver performances had to be rated during the specific course).

Data analysis and reporting

The statistical software SPSS version 25 for Mac (IBM, Chicago, IL, USA) was used. Linear mixed models were used to analyze performances due to repeated measurements (multiple raters and performance scores)[25]. For comparing categorical variables between groups, Fisher's exact test or Pearson's χ^2-test was used. Mann–Whitney *U* or Student's T-test was used for continuous variables.

Data were compared between cohorts using the intention-to-treat principle[26]: performance data for the intervention cohort were included irrespective of whether the participant had actually done any DT.

P-values <0.05 were considered statistically significant. There was no missing data.

The reporting in this paper is based on the *simulation-based research extension* to the *Consolidated Standards of Reporting Trials* (CONSORT) guidelines[27].

Ethics

The Capital Region of Denmark Ethics Committee deemed the study exempt (H-15011780). Participation was voluntary and thorough written and oral information was given prior to enrollment.

Results

All 2018 and 2019 TB course participants (n = 38) volunteered for participation and were included. Demographic and training data are presented in Table 1. There were no significant differences between cohorts with respect to demographic and background data, nor with respect to prior ORL experience (3.6 *vs*. 3.8 years; p = 0.67).

Overall, participants in the DT cohort (including five participants who did no DT) trained a median of 3.5 hours (range: 0–15 hours; Figure 2). Fifteen (75%) out of the 20 participants in the DT cohort chose to do DT before the course and among these, the median training time was five hours[28]. In the control cohort, three (17%) of the 18 participants had trained a median of two hours (range 1–4 hours; Figure 2); the remaining 15 were VR temporal bone simulation training-naïve before the temporal bone course.

The overall mean cadaver dissection score across cohorts was 7.0 points ranging from 2 to 16 points out of the maximum score of 19 points. The DT cohort performed significantly better than the control cohort (estimated marginal mean score: 8.8 points vs. 5.0 points, $p < 0.001$; Table 2), corresponding to a 76% higher mean performance score in the intervention cohort compared with the control cohort. The amount of time spent doing DT did not correlate to a better cadaver dissection performance ($p = 0.51$).

Similarly to cadaver performances, the DT cohort outperformed the control cohort in VR simulation surgery during the course (estimated marginal mean score 12.0 points vs. 9.2 points, $p < 0.01$; Table 2).

Discussion

In this prospective, controlled cohort study on the effect of decentralized VR simulation training, we found that decentralized training improved VR simulation performance during a temporal bone course and that this transferred to a 76% increase in cadaveric dissection performance.

Fifteen out of 20 participants in the intervention cohort chose to do DT despite no mandatory requirements, dedicated training time during work-hours or testing, suggesting that trainees had an intrinsic motivation to prepare for the course using VR simulation. Specific pre-course training requirements could potentially motivate trainees further for DT[11,28,29].

The intervention cohort outperformed the control cohort, suggesting that even in the absence of instructor-led training, decentralized VR simulation training with the principles of DSRL can substantially improve trainees' skills both in the VR simulator, but more importantly also in subsequent cadaveric dissection during a TB course. This supports that DT at the local department or private home is a feasible way to implement VR simulation training, allowing for self-regulated training without constraints of simulation center opening hours or simulation training only being available during formalized courses.

As cadaver TBs are a limited resource in many teaching hospitals[14], the initial part of the learning curve can be moved from training on cadavers to VR simulation, allowing the trainees to practice the procedure and consolidate basic skills before using expensive wet lab facilities. We propose that DT can narrow the "implementation gap"[13] in VR simulation training and potentially address the paradox that massed practice such as temporal bone courses and ”boot camps” are widely used although evidence suggests that it is inefficient compared with distributed and self-regulated practice[30–32].

Previous studies have found implementation of simulation-based training to be a challenge: in a study comprising 21 general surgery residents who were given access to a VR simulator for laparoscopy, only two residents (10%) trained and the introduction of a competitive element in the training had only a marginal effect on participation[33]. This demonstrates that mere access to VR surgical simulation equipment does not in itself lead to substantial training without attention to implementation. In contrast, we found a relatively high adoption rate of 75% in our study. This could be due the convenient, decentralized access to the VR equipment, and the range of learning supports allowing for DSRL
A study on decentralized training of basic laparoscopic skills using a “box trainer” for use at home, found a significant increase in performance from DT, despite a modest training amount[11]. In corroboration with our findings, this study demonstrated an effect of DT; however, it concerned basic skills and a “box trainer” whereas we used a high-fidelity VR setup for DT of an advanced procedure (mastoidectomy).

Using the framework of DSRL is central to successful DT because the absence of human instructors for conventional guidance and feedback is a potential challenge with DT. Consequently, DT requires a strong instructional design to support learning, to allow for DSRL, and provide real-time feedback on performance. The VES does not yet include automated feedback on performance that could potentially further improve learning outcomes.

To isolate the effect of the DT intervention, both cohorts received standard VR simulation training during the TB dissection course and we used the intention-to-treat principle to reduce bias. The study is, however, limited by its external validity: results from one educational system might not apply to all. The ORL curriculum in Denmark includes very limited training of sub-specialized surgery such as mastoidectomy during residency. This also affects participant motivation for training and could result in an underestimation of the general effect of DT for the mastoidectomy procedure compared with DT of other, mandatory procedures. Finally, raters were not blinded to cohort allocation in the assessment of dissection performances and this introduces bias. We elected to not pool data from the two cohorts on participants who had trained decentrally before the course because of the fundamentally different interventions: the three participants in the control cohort who had trained before the course had not received systematic DT with learning supports for effective and directed, self-regulated learning.

There are several possible explanations for the high adoption rate (75%) found in this study. To explore motivational aspects of DT, we recently conducted a qualitative study on implementation of DT and found that five main factors influenced the adoption of decentralized training: convenience, time for training, ease of use, evidence for training, and testing[28].

It is important to acknowledge that simulation systems (such as the VES) are merely tools for training, and their value depends on implementation into a well thought-out curriculum. Consequently, interventions addressing the implementation of surgical training and rigorous evaluation of such interventions are much needed. Future studies should investigate other specific implementation strategies that narrow the implementation gap in VR simulation training with outcomes that include effects on long-term skills retention.

Conclusion

Implementation of VR surgical simulation training into the surgical curriculum is a key issue with little research into different implementation strategies. We found that it was feasible to implement DT using a freeware VR TB surgical simulator for directed self-regulated learning. Furthermore, DT was a relevant strategy for VR simulation training of novices and could be used to improve the training outcome of costly cadaveric dissection because DT markedly improved cadaver dissection performance. Self-directed VR simulation training cannot substitute other training modalities in preparing the trainee for real-life surgery, but is a cost-effective supplement tool in the context of DT.

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Table 1

Table 1 Participant characteristics and training (*n* = 38)	DT[a] cohort (*n* = 20[b])	Control cohort (*n* = 18)	*p*[c]
Age, (years, mean (SD))	34.5 (3.0)	33 (3.0)	0.26
Sex, *n* (%)			
Female	7 (35)	7 (39)	0.80
Male	13 (65)	11 (62)	
ORL[d] experience (yrs; median)	3.5	3.5	
(min–max)	2–7	2–7	0.71
Other surgical experience (yrs; median)	0.4	0.5	0.12
(min–max)	0–2	0–5.5	
Previous temporal bone dissection course, n (%)	1 (5)	1 (5.6)	0.93
VR[e] simulation training conducted before course, *n* (%)	15 (75)	3 (17)	< 0.001
Total DT[a] time in those who trained (hours; median)	5	2	0.076
(min–max)	1.5–15	1–4	
Total DT[a] time, cohort[f] (hours; median)	3.5	0	<0.01
(min–max)	0–15	0–4	

a: DT = Decentralized Training; b: including five participants who did no decentralized training; c: p-value for difference between DT- and control cohort; d: ORL = otorhinolaryngology; e: VR = Virtual Reality; f: Including participants who did not train before the course

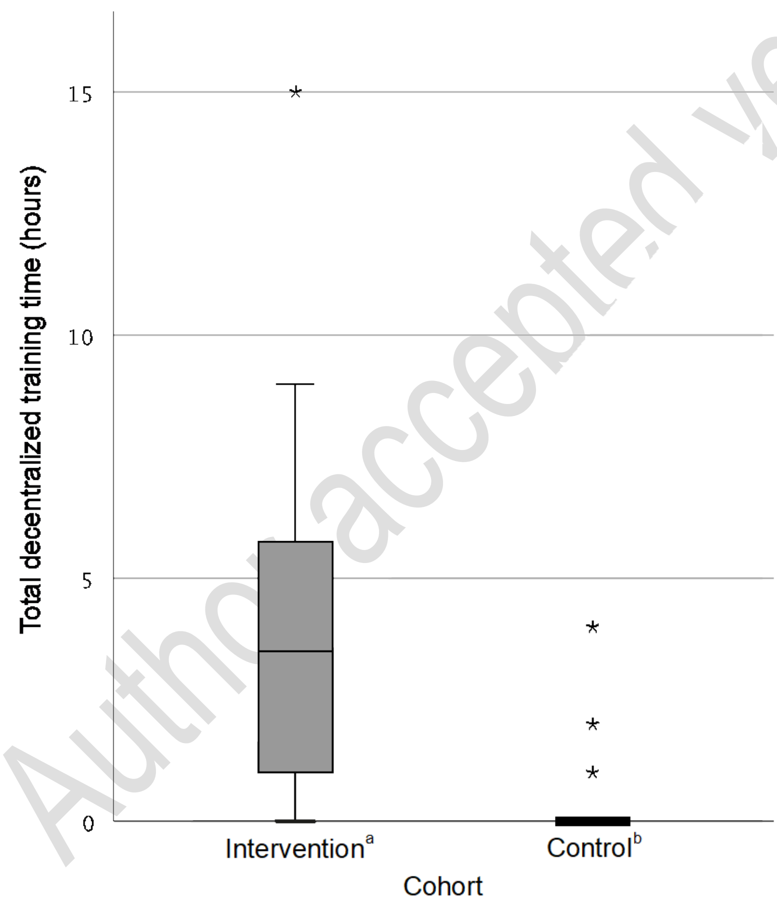
Table 2

Table 2 Mastoidectomy performance scores[a] (*n* = 38)	DT[b] cohort (*n* = 20)	Control cohort (*n* = 18)	*p*
Cadaver dissection, mean (95% CI[c])	8.8 (8.0–9.6)	5.0 (4.1–5.9)	<0.01
Virtual reality, mean (95% CI[c])	12.0 (11.2–12.8)	9.2 (8.6–9.7)	<0.01

a: Dissection performances were scored using a 19-item modified Welling scale (range 0–19 points); b: DT = Decentralized Training; c: CI = Confidence Interval

Figure 1 Study flowchart

Figure 2 Total decentralized training time



a: Fifteen of 20 participants (75%) trained decentrally
b: Three of 18 participants (17%) trained decentrally