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Decentralized virtual reality mastoidectomy simulation training: a prospective, mixed-methods study

Martin Frendø[1,2] · Ebbe Thingaard[2,3] · Lars Konge[2] · Mads Sølvsten Sørensen[1] · Steven A. W. Andersen[1,2]

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Abstract

Purpose Virtual reality (VR) training of mastoidectomy is effective in surgical training—particularly if organized as distributed practice. However, centralization of practice facilities is a barrier to implementation of distributed simulation training. Decentralized training could be a potential solution. Here, we aim to assess the feasibility, use, and barriers to decentralized VR mastoidectomy training using a freeware, high-fidelity temporal bone simulator.

Methods In a prospective, mixed-methods study, 20 otorhinolaryngology residents were given three months of local access to a VR mastoidectomy simulator. Additionally, trainees were provided a range of learning supports for directed, self-regulated learning. Questionnaire data were collected and focus group interviews conducted. The interviews were analyzed using thematic analysis and compared with quantitative findings.

Results Participants trained 48.5 h combined and mainly towards the end of the trial. Most participants used between two and four different learning supports. Qualitative analysis revealed five main themes regarding implementation of decentralized simulation training: convenience, time for training, ease of use, evidence for training, and testing.

Conclusions Decentralized VR training using a freeware, high-fidelity mastoidectomy simulator is feasible but did not lead to a high training volume or truly distributed practice. Evidence for training was found motivational. Access to training, educational designs, and the role of testing are important for participant motivation and require further evaluation.

Keywords Decentralized training · Simulation · Temporal bone dissection · Mastoidectomy · Virtual reality · Surgical training

Introduction

Virtual reality (VR) training of temporal bone surgery comprises virtual surgical procedures in a graphically realistic computer game environment (Fig. 1) and is effective for learning the mastoidectomy procedure: we reported a 52% increase in cadaver dissection performance after a brief VR simulator practice session [1]. Frequently, VR simulation training is organized as "boot camp" events comprising a large amount of training during a short period of time, resulting in massed practice [2, 3]. Massed practice leads to inferior learning outcomes compared with shorter periods of practice separated by breaks—distributed practice [4]. In mastoidectomy, a structured distributed VR simulation training program further increased dissection performance by 25% [5]. However, a major barrier to distributed practice is the availability of VR simulators, which are often centralized at simulation centers. Distance to such centers can make it difficult for trainees to conduct many individuals, shorter training sessions [5].

In contrast, decentralized training would give the trainee convenient access to simulation training. We define decentralized training as training at the workplace (i.e. local department) or at home. Free academic simulation software for VR temporal bone simulation running on a laptop makes decentralization of mastoidectomy simulation training possible [6]. Nonetheless, despite evidence that this simulation

✉ Martin Frendø
martin.frendoe-soerensen.01@regionh.dk

1 Department of Otorhinolaryngology-Head and Neck Surgery and Audiology, Rigshospitalet, Blegdamsvej 9, 2100 Copenhagen, Denmark

2 The Simulation Centre, Copenhagen Academy for Medical Education and Simulation (CAMES), The Capital Region of Denmark, Copenhagen, Denmark

3 Department of Gynecology and Obstetrics, University Hospital Hvidovre, Copenhagen, Denmark

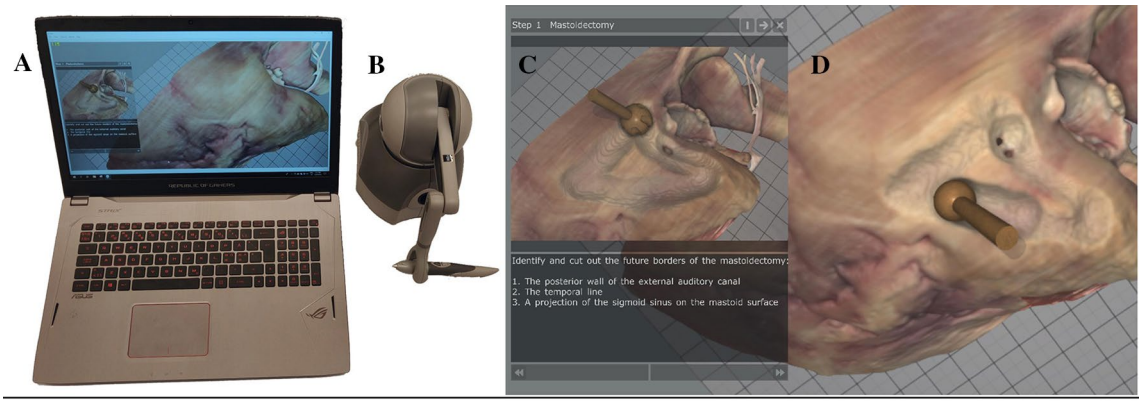

Fig. 1 Simulation setup and visual appearance during simulation surgery

training works, recent studies demonstrate that implementation into clinical practice is lacking—a fact that has been termed an "implementation gap" [7, 8]. This "implementation gap" exists in temporal bone VR training, and no previous studies have explored the implementation of decentralized simulation training of mastoidectomy.

Directed, self-regulated learning is a framework for independent learning without direct supervision. Consequently, directed, self-regulated learning is a key element in decentralized training, where the trainee has to train individually. Compared with instructor-led (i.e. directly supervised) learning, directed, self-regulated learning has been found favorable for retention of surgical skills [9].

In this mixed methods study using both quantitative and qualitative data, we aimed to investigate implementation, feasibility and barriers to decentralized VR simulation training of mastoidectomy using a freeware simulator and a range of learning supports.

Materials and methods

Participants

Participants were 20 otorhinolaryngology residents from eight different training departments throughout Denmark.

Intervention

At the start of the trial, participants were contacted by e-mail and encouraged to practice mastoidectomy on their local department's virtual reality (VR) temporal bone simulator setup; if none was available, they were offered to borrow a complete simulator setup running on a laptop for use at home. The mastoidectomy procedures comprised sequential drilling of the temporal bone in the virtual environment to achieve a complete cortical mastoidectomy. Training was supported by a range of optional learning supports: (1) a temporal bone simulation "dissection" manual; (2) several short instructional videos specifically designed for use with the Visible Ear Simulator; (3) a simulator-embedded, on-screen step-by-step guide; (4) simulator-integrated guidance through green-lighting of the volume to be drilled; (5) a tool for systematic self-assessment, and (6) remote feedback by sending a file to the study manager (SA) [10–12].

Participants were reminded by e-mail every four weeks to practice. Technical assistance by the study manager (SA) was available throughout the study. Although participants were encouraged to train during the trial, there were no formal requirements or tests, nor were participants offered any compensation for practicing.

VR simulation platform

The simulation setup consists of three parts: (1) a free software package (The Visible Ear Simulator) installed on (2) a gaming laptop and controlled via (3) a so-called haptic device—a special joystick mimicking a surgical instrument (Geomagic Touch, 3D Systems, Rock Hill, SC, USA), giving physical (haptic) feedback during surgery (Fig. 1). The Visible Ear Simulator is free academic software for high-fidelity temporal bone simulation and runs on a standard gaming computer or laptop with a GeForce GTX graphics card (Nvidia, Santa Clara, CA, USA) [6, 13]. Unlike other available temporal bone surgical simulators, the Visible Ear Simulator dataset is based on digital images of cryo-sections of a human temporal bone, resulting in ultra-high resolution and accurate visual detail (Fig. 1) [6, 14, 15]. A complete Visible Ear Simulator setup (haptic device and gaming laptop with free Visible Ear Simulator software) costs < 4000 USD.

Data collection

Participants filled out a questionnaire on background demographic data, previous surgical training and courses, and a structured account of their training and use of learning tools. This included data on number of VR procedures, number of training sessions and time spent per session and in total.

All 20 participants were invited and accepted to participate in semi-structured focus group interviews (four interviews with five participants per group) to explore the feasibility, implementation, use, and barriers to decentralized training. An interview guide based on the research questions was used and an interviewer with experience in clinical focus group interviews (author ET) conducted the interviews. The interviews were conducted in an educational setting at the University of Copenhagen and had a total duration of one hour and 38 min. Guiding questions included: How did you train? Which learning tools did you use? What makes you train? When did you train? Which obstacles to training did you experience? What motivated you to train? The interviewer encouraged participants to elaborate on their views.

The interviews were recorded digitally and transcribed verbatim by the first author (MF).

Statistics and data analysis

The statistical software package SPSS version 25 for Mac (IBM, Chicago, IL, USA) was used for quantitative analysis of the questionnaire data. Demographic and training data were extracted and tables and figures compiled using descriptive statistics. For comparison of categorical variables between groups, Fisher's exact test or Pearson's χ^2-test were used depending on minimum cell counts in contingency tables. To compare non-normally distributed variables between groups, Mann–Whitney *U* test was used.

The qualitative data (i.e. interviews) were analyzed using the qualitative method of directed content analysis whereby themes were derived: each sentence was paraphrased and the associated theme(s) noted (Table 1) [16]. After independent analysis of two interviews by two reviewers (authors MF and ET), the remaining two interviews were analyzed only by the first author (MF) due to agreement on the analysis and saturation of content. Finally, quotes for the analysis were selected and translated.

The qualitative reporting was based on the consolidated criteria for reporting qualitative research (COREQ) [17].

Ethics

The Copenhagen Capital Region Ethics Committee deemed the study exempt from requiring ethics committee approval (H-15011780). The study was conducted in accordance with the Helsinki declaration. Participation in the study was voluntary and all participants gave their written consent after thorough information.

Results

Quantitative data

All participants ($n = 20$) returned the background questionnaire; demographic data is presented in Table 2. Participants had a median duration of otorhinolaryngology training of 3.5 years (range 2–7 years; Table 2) but were all novices in temporal bone surgery. Fifteen participants had partaken in decentralized training while five had not trained. Among these, four attributed their lack of training to time constraints and one cited technical issues with the computer hardware running the simulation software.

Training and use of learning supports

Combined, the participants trained 48.5 h in the Visible Ear Simulator (Fig. 1). The median training time for all 20 participants was 3.5 h (range 0–15 h). For the 15 participants

Table 1 Examples of the analysis

Quotation	Paraphrase	Theme
If you know that we learn more […] by drilling at home, perhaps you should say -and this might be a bit dictatorial, but- that we should at least do two or something like that. I think, on my part, I would have done it. Off course	Knowing that it has an effect, training could be mandatory	Evidence based-training
Then there is the problem with time: When does one do it? Because you want to go home after a long day … So I mostly did it when I was on call at the hospital	Training time is a problem. Participant mainly trained during work-hours	Time for training
He showed us some graphs on how much better those who had simulated were. Perhaps that could be emphasized even more: If you haven't trained at home, you have fallen behind […]	Participant saw info on simulation training results and considers this relevant to stress to trainees	Evidence-based training

Table 2 Participant baseline characteristics ($n=20$)

Age (years; median)	35
(Min–max)	30–41
Sex, *n*	
Female	7
Male	13
Otorhinolaryngology experience (years; median)	3.5
(Min–max)	2–7
Other surgical experience (years; median)	0.4
(Min–max)	0–2

Including five participants who did no decentralized training

who had used decentralized training, the median training time was 5 h (range 1.5–15 h) corresponding to a median of three mastoidectomy procedures (range 2–7). There were no significant differences between female and male participants with respect to whether or not training was undertaken during the trial ($p=1.0$), nor to total training time ($p=0.36$). Participants mainly practiced at the end of the trial, as 32.5 h of total training for all participants combined were conducted during the final month, whereas a total of 10 and 6 h respectively were trained in the preceding 2 months (Fig. 2). One participant trained at home; the remaining 14 trained at their local department.

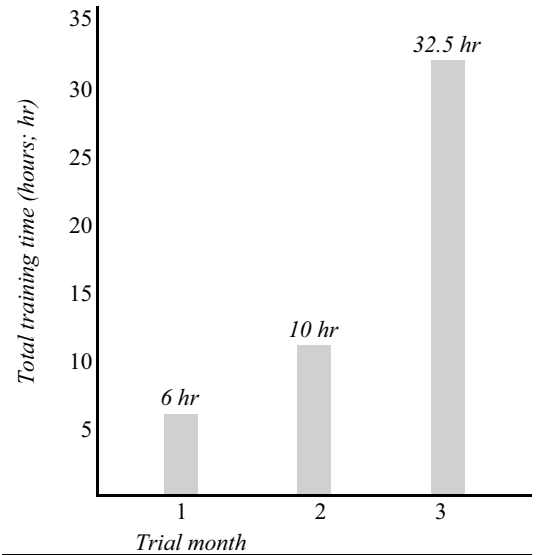

Fig. 2 Total duration of decentralized training during each of the three trial months

All 15 participants who did decentralized training used one or more of the available learning supports (Table 3); twelve used between two and four different supports whereas one participant used all six tools. Fourteen participants used the simulator-integrated step-by-step guide, whereas 11 used the simulator-integrated guidance through green-lighting. One participant used the written dissection manual and two opted to use the remote feedback (Table 3).

Qualitative data

In the analysis of the focus group interviews on feasibility, use, and barriers to decentralized training, five main themes were identified: convenience of training, time for training, ease of use, evidence for training, and testing.

Convenience

Participants generally considered convenient access to the simulator a central factor when training, and asked what makes participants train:

> "Availability. And that it just works. It is essential, during busy daily life, that you can do it without too much hassle." Participant 4B.

Time for training

The departments did not offer dedicated time for practice during clinical work hours and participants considered time constraints one of the biggest barriers to decentralized training:

> "If we could get three to four hours scheduled [training] (…). That would be brilliant because then you could start setting requirements. I do not know whether making demands is feasible when training is done outside of working hours." Participant 4C.

Table 3 Use of learning supports during decentralized training ($n=15$)

Learning support	*n* (%)[a]
Simulator-integrated step-by-step guide	14 (93)
Green lighting guide	11 (73)
Instructional videos	8 (53)
Systematic self-assessment	7 (47)
Remote feedback	2 (13)
Dissection manual	1 (7)

Five participants not included in table due to no decentralized training

[a]Number of participants who used the learning support

Training was mainly conducted directly after scheduled clinical work. Consequently, several participants felt fatigued when starting the training, which, to some, was a barrier:

> "You come in after a full day of work and spend your evening. And in that situation, I am not very patient." Participant 4E.

Ease of use

The ease of use of the simulator and learning supports was frequently mentioned. Some had high expectations about using the simulator for the first time without any learning supports:

> "I probably should have read the manual first. (…) I thought, 'I'll just turn on the simulator, then I'll figure it out'." Participant 1A.

Others took a systematic approach to start the training, preparing the familiarization process by using the learning supports, such as the dissection manual and videos designed for use with the simulator:

> "It took some time to figure out how the simulator worked and how to use it. But I watched the instructional videos including the one about self-assessment. I basically did what it said in the videos. And then I knew how to use the simulator." Participant 3C.

Evidence for training

Several sources of motivation were described. Specifically, knowing that the simulation training was evidence-based was identified as a motivating factor by the participants:

> "It actually said that research shows that if you have trained at home, you will benefit […]. So I thought 'Okay, there's probably something to it'." Participant 2E.

Also, the feeling of skill progression during simulation motivated participants:

> "I found it super motivating that I got better with each session. That I could see that there was an effect." Participant 2B.

Testing

Participants mentioned testing as both a potential motivator and source of stress. Specifically, participants found that they would train more if minimum requirements were part of the trial:

> "Laziness is human nature. Perhaps setting requirements is the only way." Participant 1F.

As one participant noted, requirements could be in the form of passing a test, which could lead to better preparation:

> "If there's something you're obliged to do and there is an assessment of performance, doctors *will* practice. (…) It's in our DNA after six ears of exams." Participant 3B.

Consequently, despite the availability of external assessment (systematic self-assessment or remote assessment; Table 3), the lack of compulsory testing was considered a motivational limitation.

Discussion

In this prospective mixed methods study on the implementation of and barriers to decentralized virtual reality (VR) simulation training in mastoidectomy, we found that without testing, mandatory training requirements or dedicated training time during work-hours, 15 out of the 20 participants trained. Despite reminders and a range of available learning supports for directed, self-regulated learning, the training volume was modest and was concentrated at the end of the trial rather than truly distributed. Second, the convenience of training, ease of use and work-hour constraints influenced training and were barriers to decentralized training. Third, participants had an individualized approach to the use of learning supports and mainly used the convenient simulator-embedded supports. Finally, we found that participants were motivated by the fact that the simulation training is supported by evidence and that testing could have increased motivation.

Our findings suggest that decentralized training is feasible, even in the absence of formal requirements or dedicated training time because 75% of the participants voluntarily trained a median of five hours during the trial. Convenient access to training in the simulator at the local department or at home was a key feature to participants. This is noteworthy as most VR simulators, regardless of specialty, are centralized at university hospitals, often due to costs of equipment. This results in simulation-based surgical skills training being organized in "boot camp" formats comprising a set amount of massed practice—i.e. a large training volume during a short period of time [18]. Despite the frequent use of this course design, massed practice, including of temporal bone surgery, is inefficient for both acquisition and retention of skills compared with the distribution of practice sessions over a longer period of time—distributed practice [3, 4, 19, 20]. For distributed practice to be possible for trainees, convenient access to training is required. Decentralized training

for directed, self-regulated learning is a feasible alternative when the distance to a simulation center would be a barrier to training.

The lack of protected training time was a major barrier to decentralized training (but also to centralized training [5]) and several participants noted that fatigue affected both performance and patience when training after working hours. Fatigue hampers skill acquisition and this stresses the need for protected training time during work hours [21]. The implementation of protected training time requires hospital stakeholders such as funding bodies to acknowledge the importance of surgical simulation training [22, 23].

A number of participants chose to start training on the simulator without using any learning supports, which some found challenging. Conversely, participants who used the learning supports before and during decentralized training reported to quickly learn to use the simulator. This suggests that a strong instructional design is needed for directed, self-regulated learning, where the lack of direct instructions or feedback by senior faculty is a potential barrier [24]. Lack of external feedback was not mentioned as a major concern by the participants and although a tool for structured self-assessment was an option, only about half of the participants used it. This was surprising, since "assessment drives learning": feedback on performance has been demonstrated to increase learning outcomes [25]. We hypothesize that because there was no *formal* or consequential assessment, participants had less interest in assessing their own performance and this absence of testing was demotivating. Correspondingly, a study on decentralized training of laparoscopy found testing to be the main driver of training [26]. In a cadaveric dissection course, meeting a minimum level in virtual surgery could be a requirement for participation in cadaver dissection which has limited availability and volume—a strategy that has been used in other surgical specialties [27, 28].

Supporting evidence for simulation training was considered imperative to participants and motivated them to train. This demonstrates that collecting evidence for the effect of training interventions is not only key for educational stakeholders but also for trainees: in order for them to invest time in training, they want evidence that it works. Indeed, evidence-based decision-making used in the clinical setting also applies to the educational setting.

To our knowledge, this is the first study on decentralized training of virtual temporal bone surgery. A strength of the study is the prospective, mixed-methods design where both quantitative and qualitative data are used to explore feasibility, use and barriers to decentralized VR simulation training. A limitation concerns the external validity of our findings: results from one educational system might not generalize to all. The otorhinolaryngology curriculum in Denmark includes practically no mandatory real-life training of specific sub-specialized surgeries during residency. If otosurgical training was imminent for all, participants might be more inclined to practice. As a result, our study could underestimate the usefulness of the proposed decentralized training design compared with curricula where temporal bone competencies are mandatory. Surprisingly, only a few participants mentioned this as having an effect on their motivation and we consider the 75% adoption rate to be high.

Even though virtual simulation training is established as a useful modality in temporal bone training, implementation into the surgical curriculum has further potential. Clearly, access to surgical simulation systems does not automatically lead to trainees practicing their skills [29]. Whereas much resource is used developing and purchasing advanced surgical simulators, our study emphasizes the need to allocate resources for successful implementation of simulation training, e.g. development of curricula, courses and learning supports. Virtual reality simulation training cannot replace cadaver or operating room training but novel educational designs that include decentralized simulation training can improve the learning value of cadaver-dissection and ultimately contribute to improved surgical quality.

This study proposes a new addition to future temporal bone surgical training: decentralized VR training at the local training department or at home. Nevertheless, successful implementation of decentralized training requires not only easy and convenient access to a simulator with a range of learning supports but also for this training to be part of a curriculum that includes testing and dedicated time for training.

Conclusion

Decentralized training of virtual reality mastoidectomy is feasible because it is inexpensive and easily accessible but did not lead to a large training volume or to truly distributed practice among unselected otorhinolaryngology residents. Our findings suggest that the educational design and understanding of participant motivations are central to successful implementation. Decentralized VR training, accompanied by relevant learning supports, might help overcome some of the barriers to distributed simulation training.

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Compliance with ethical standards

Conflict of interest The authors have no other funding or conflicts of interest to disclose.

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