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ORIGINAL ARTICLE

Novices perform better in virtual reality simulation than in traditional cadaveric dissection training of mastoidectomy

Steven Arild Wuyts Andersen,* Per Cayé-Thomasen and Mads Sølvsten Sørensen

Department of Otorhinolaryngology—Head & Neck Surgery, Rigshospitalet, Copenhagen, Denmark

**Corresponding author at: Department of Otorhinolaryngology—Head & Neck Surgery, Rigshospitalet, Blegdamsvej 9, DK-2100 Copenhagen Ø, Denmark. Email: stevenarild@gmail.com*

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Abstract

Background: Temporal bone surgery requires integration of complex knowledge and technical skills. This can be difficult to accomplish with traditional cadaveric dissection training, which is often organized as single-instance participation in a temporal bone course. Simulator-integrated tutoring in virtual reality (VR) surgical simulators can visually guide the procedure and facilitate self-directed surgical skills acquisition. This study aims to explore the performances of novice otorhinolaryngology residents in a freeware VR simulator and in cadaveric dissection training of mastoidectomy. **Methods:** Thirty-four novice otorhinolaryngology residents performed a single and self-directed mastoidectomy procedure in a freeware VR temporal bone simulator before performing a similar procedure on a cadaveric temporal bone. VR simulation and cadaveric dissection performances were assessed by two blinded expert raters using final product analysis. **Results:** Participants achieved a higher mean final product score in VR simulation compared with cadaveric dissection (14.9 and 13.2, respectively; $P = 0.02$). Significantly more of the participants had their best performance in VR simulation ($P = 0.04$). No differences in computer experience and interest were found between the group that performed better in VR simulation and the group that performed better in cadaveric dissection. **Conclusions:** Novice performance in a freeware VR temporal bone simulator was significantly better than in cadaveric dissection. The simulator-integrated tutor function and reduced complexity of the procedure in VR simulation could be possible explanations for this finding. VR simulation training could be used in the initial training of novices, reserving dissection training for more advanced training after basic competencies have been acquired with VR simulation.

Keywords: *virtual reality simulation; technical skills training; self-directed learning; mastoidectomy; temporal bone surgery; surgical simulation*

Introduction

The classic apprenticeship model with direct supervision in the operating room for training surgical skills is under pressure from constrained working hours, productivity demands and patient safety issues. A range of other teaching methods has therefore been used in basic surgical technical skills training including lectures and videotaped demonstrations, and simulation-based methods such as cadaveric dissection training, animal models, box models, simulated patients, and more recently virtual reality (VR) simulation.[1] Simulation-based training can help the trainee gain technical proficiency and provide tailored feedback in a situational learning context.[2]

In temporal bone surgery, key surgical skills include precise motor skills in handling the otosurgical drill and suction/irrigation, microsurgical skills with the use of the operating microscope and a detailed three-dimensional understanding of the complex anatomical relationships of the temporal bone. The drilling of cadaveric temporal bones is currently considered the gold standard training method for acquiring basic temporal bone skills. Traditional temporal bone drilling exercises can be organized as formalized temporal bone courses or as access to an open temporal bone laboratory. Often participation in a temporal bone course offers a single-instance opportunity for the trainee. In contrast to this, it is well established that repeated and deliberate practice is essential to support both the consolidation of acquired skills and further skills development and progression.[3]

VR surgical simulation training can provide repeated skills training based on the individual trainee's needs without the organizational, financial and time constraints relating to working hours of instructors and trainees. In temporal bone surgery, several VR simulators have been developed using different approaches[1,4,5] and there is a growing body of evidence for their efficacy and validity.[6–14] Uniquely, an advanced and fully functional VR temporal bone simulator is offered as academic freeware for mastoidectomy training on a standard PC with a high-end graphics card and a haptic device.[15,16] This simulator also features an integrated tutor function, allowing for self-directed training of the procedure.

Hypothesizing that simulator-integrated tutoring and reduced complexity in the freeware VR simulation environment would entail higher initial mastoidectomy performance of novices, we set out to explore the mastoidectomy performances of novices in VR simulation and in traditional cadaveric dissection.

Methods

Ethical considerations

Virtual and dissection final products as well as questionnaire data were pseudonymized before analysis. Ethics committee approval was not required because educational research is exempt under national legislation in Denmark. This study complies with the Helsinki Declaration and the cadaveric specimens used for dissection were donated to the University of Copenhagen, Denmark, for educational purposes.

Participants and setting

Thirty-four otorhinolaryngology residents (postgraduate year 2–5) participated in the annual, national temporal bone course held at our institution in January 2012 (17 participants) and 2013 (17 participants) and were included in the study. One participant experienced a computer crash during VR simulation and the final product performance could not be saved for analysis; this participant was therefore excluded from the study. The participants were novices regarding the procedure: 90% were complete novices and 10% had previously participated once in a different temporal bone course. The participants had no hands-on operating room experience with mastoidectomy because the national temporal bone course is a prerequisite for supervised temporal bone surgery. The participants completed a questionnaire on background, computer experience and interest.

The VR temporal bone simulator

The Visible Ear Simulator (VES) version 1.2 is based on the Visible Ear image library, which consists of high-resolution digital photos of cryosections of a fresh-frozen human temporal bone.[17] After manual segmentation of the important anatomical structures, a solid three-dimensional voxel model with natural colours was rendered[15,16] and made available as a free download.[18] The simulator uses a Geomagic Touch (3D Systems, USA) haptic device for interaction and real-time force-feedback drilling, features stereographic 3D, and runs on a standard PC with a GeForce GTX graphics card. The simulator has an integrated tutor function with step-by-step volumetric green lighting of the bone to be removed (the so-called reference volume) (Fig. 1). The simulator simultaneously provides an on-screen step-by-step guide to the procedure with text and simulator illustrations.

Study design

This study used a single-subject design in which participants served as their own control. The participants performed a single virtual mastoidectomy in the VES and on the following day a similar mastoidectomy on a cadaveric temporal bone. Participants were asked to perform a complete mastoidectomy with entry into the antrum but without posterior tympanotomy. The participants were teamed in pairs during both simulation (80 min of training) and dissection training (120 min of training) and divided the allowed time between them. During the virtual training, participants were provided with simulator-integrated written instructions and visual tutoring, but were not given feedback or instructions by human instructors. During dissection training, participants received individual and plenary instruction and feedback from four senior otologists and had access to a written temporal bone dissection manual.

Outcomes

Performances were assessed using a final product assessment tool based on the Welling Scale[19] and assessors were blinded to participant and temporal bone. The modified Welling Scale consists of 25 items scored dichotomously as complete (1 point) or incomplete/inadequate (0 points), totalling a maximum score of 25, which is the expected level of experts. The items reflect the procedural steps of the mastoidectomy, for example, defining the mastoidectomy at the correct margins, entering the antrum etc. (see Appendix 1). The assessment tool is applicable for the assessment of mastoidectomy performance on both cadaveric and virtual temporal bones with a moderate and substantial inter-rater reliability, respectively.[20] In cadaveric dissection, the physical specimens were examined immediately after dissection and in VR simulation, the saved final products were later opened in the simulator and examined with all degrees of freedom. The participants' final product score was calculated as an average between the score

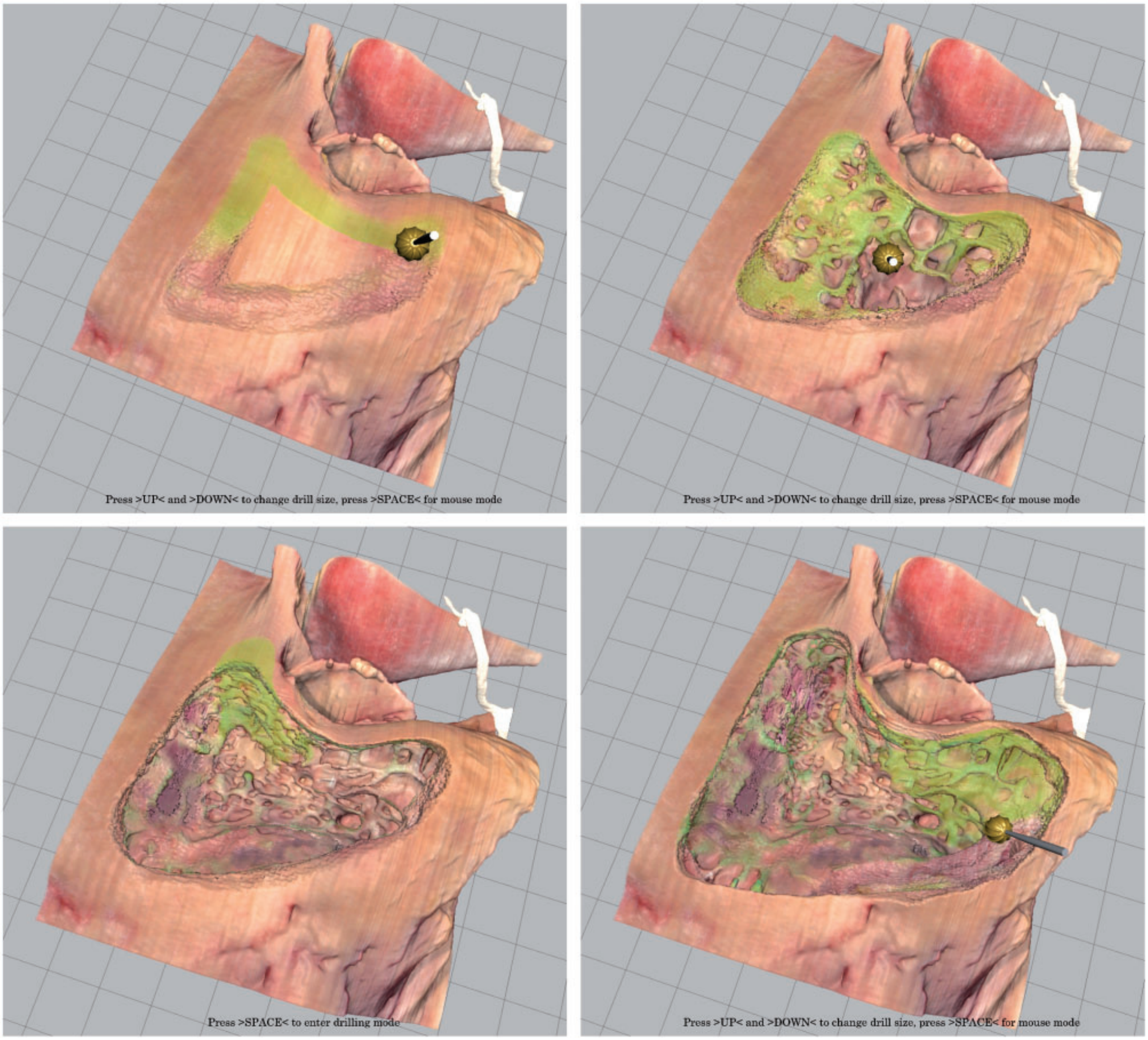

Figure 1 The simulator-integrated tutor function with step-by-step volumetric green lighting of the bone to be drilled and removed.

assigned by the two raters. Participants were divided into groups according to whether they performed best in cadaveric dissection (group A) or in simulation (group B) for further analysis.

Statistics

The collected data were analysed with SPSS (SPSS Inc., Chicago, IL) version 20 for MacOS X using paired-samples *t*-test and analysis of variance.

Results

The participants achieved a higher mean final product score in VR simulation compared with cadaveric dissection (14.9 and 13.2, respectively; $P = 0.02$) (Table 1). An example of a cadaveric dissection and VR simulation performance is illustrated in Fig. 2.

Significantly more participants performed better in VR simulation than in cadaveric dissection (21 and 10 respectively, $P = 0.04$) and participants were divided into a group that performed best in cadaveric dissection (group A) or in VR simulation (group B) (Fig. 3). Two participants had equal performances in both modalities and were not assigned a group.

The two groups had comparable mean final product performance scores in the modality in which they had the better and worse final product performance (Table 1). The two groups had comparable means with regard to background, experience related to computers and information technology and interest except for self-reported computer skills that were reported to be significantly higher in the group that performed better in cadaveric dissection (Table 2).

Discussion

In this blinded prospective trial on novice mastoidectomy performance in VR simulation with simulator-integrated tutoring and traditional cadaveric dissection, we found that participants performed significantly better in the VR simulator and that the majority of participants had their best performance in VR simulation. The group that performed better in cadaveric dissection and the group that performed better in VR simulation had comparable background and computer experience and interest.

One of the possible explanations for the higher performance in the VR simulation setting is the simulator-integrated

Table 1 Mean final product scores in VR simulation and cadaveric dissection

	Mean score	SD	95% CI
Overall (*n* = 33)			
Cadaveric dissection	13.2*	3.47	11.9–14.4
VR simulation	14.9*	3.42	13.7–16.1
Group A: Better dissection performance (*n* = 10)			
Cadaveric dissection	15.8	1.81	14.5–17.1
VR simulation	12.9	2.07	11.4–14.3
Group B: Better simulation performance (*n* = 21)			
Cadaveric dissection	12.0	3.55	10.3–13.6
VR simulation	16.1	3.54	14.5–17.7

**P* = 0.02.

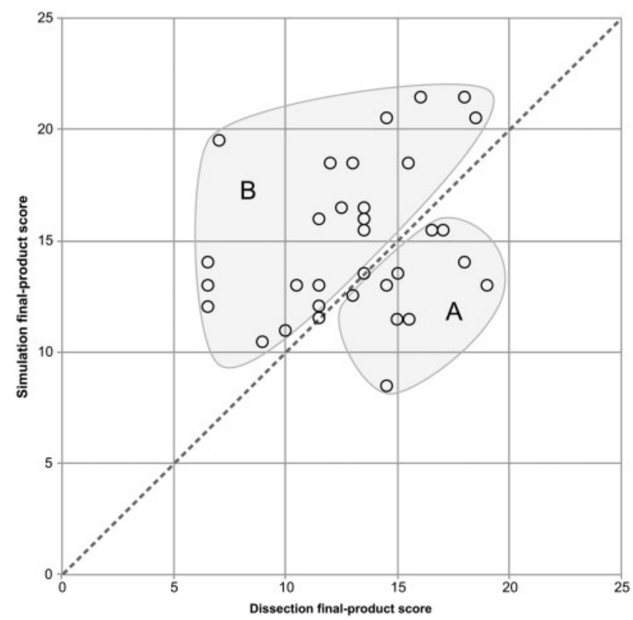

Figure 3 The average VR simulation and cadaveric dissection final product scores grouped according to (A) a better score in cadaveric dissection and (B) a better score in VR simulation.

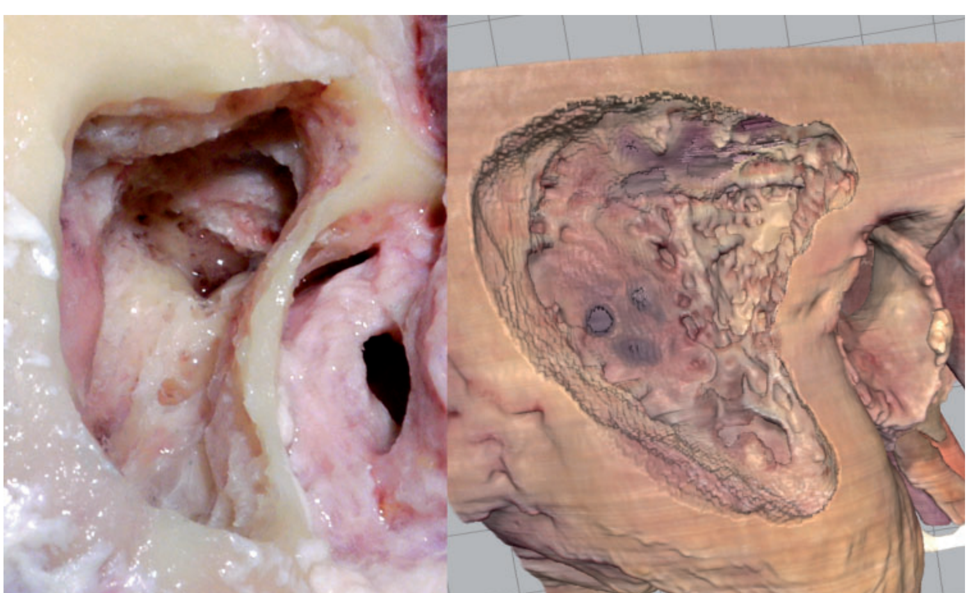

Figure 2 An example of a cadaveric dissection (left) and virtual mastoidectomy performance (right).

Table 2 Group comparison

Factor	Mean/count		Significance
	Group A (cadaveric dissection performance best) ($n = 10$)	Group B (VR simulation performance best) ($n = 21$)	
Age, years	36.7	34.8	ns
Sex	3 women, 7 men	9 women, 12 men	ns
Handedness	7 right-handed, 2 left-handed, 1 ambidextrous	19 right-handed, 2 left-handed	ns
Experience in ENT, years (range)	3.8 (2–6)	3.6 (1.4–6)	ns
Experience in other surgical specialties, years (range)	0.7 (0–2)	0.9 (0–3.5)	ns
Previous participation in a mastoidectomy course, n (%)	1 (10)	2 (10)	ns
No. of mastoidectomy manuals studied beforehand	0.8	0.7	ns
Experience with surgical simulation, n (%)			
Have tried VES before	1 (10)	3 (14)	ns
Have tried other virtual surgical simulators	6 (60)	9 (43)	ns
Have participated in other surgical simulation training	7 (70)	17 (81)	ns
Computer and technology interest			
Time spent on a computer, hours	12.2	12.5	ns
Interest in computers and technology[a]	4.9	3.8	ns
Self-reported computer skills[b]	5	3.9	0.016
No. of IT items in the household[c]	3.2	2.9	ns
Frequency of reading websites on computers or technology[d]	3	2.1	ns
Current frequency of gaming[d]	2.9	2.0	ns
Previous frequency of gaming[d]	3.5	3	ns

[a]**On** a 7-item Likert-like scale (1 = none; 7 = much).
[b]**On** a 7-item Likert-like scale (1 = none; 4 = average; 7 = expert).
[c]**From** following items: PC, laptop, smartphone, PDA/iPad and Playstation/X-box.
[d]**On** a 5-item Likert-like scale (1 = never, 2 = yearly, 3 = monthly, 4 = weekly, 5 = daily).

tutor function. This tutor function can provide self-directed training with real-time green lighting of the volume of each procedural step corresponding to on-screen instructions with text and simulator images. In other words, the simulator-integrated tutor function can visually demonstrate key elements of difficulty to the novice; for example, the skeletonization of the dura and the sharpening of the sino-dural angle. These crucial steps are usually difficult to comprehend simply from two-dimensional illustrations and text in traditional dissection manuals. The visual guidance of the simulator-integrated tutor function seemed to particularly improve the novices' performance on items relating to achieving proper exposure of key anatomical landmarks. On the other hand, it also seemed to entice some participants to overexpose especially the sigmoid sinus and the external auditory canal, which, however, could also be related to technical aspects of the simulator in the transition between bone and other tissues or a combination of both. This should be considered in future instructions and technical developments of the simulator.

In the literature, self-directed training with automatic guidance has previously been demonstrated to increase performance in another VR temporal bone simulator for a group receiving repeated, self-directed VR simulation training; the simulator provided structured training tasks with computer-generated feedback, as well as final product comparison and real-life operative videos and photos.[12] However, further studies are needed to establish the end level of competency in mastoidectomy that can be acquired exclusively with repeated, self-directed virtual training of novices. Nonetheless, tutoring plays an important role for the novice in technical skills training and ongoing, positive, constructive, and timely feedback is key.[2,21] The surgical trainee is an adult learner and according to learning theory, the optimal learning environment is learner-centred, self-directed, and problem- or task-based.[21] VR simulation platforms with integrated tutoring can provide all of these elements.

The surgical procedure studied here is complex and requires the integration of many different skills such as handling of advanced instruments, navigation, and a visuospatial understanding of the surgical anatomy. These skills are all required immediately in traditional (cadaveric dissection or apprenticeship) training modalities, whereas the VR simulation environment is less complex. In the VR model, the physical interaction is dependent on only one instrument (the haptic device) and it is simpler in the sense that bone dust and bleeding are not visualized. At the same time, all relevant information on the procedure is presented in real time on the screen. This reduced complexity could also be an important explanation for the higher performance in VR simulation.

However, both the haptic interactions such as force and the translation of hand movements as well as the visual cues might be different from the cadaveric dissection and real-life surgery. This could provide a different learning experience for the novice and could be considered a weakness of the VR simulation platform. On the other hand, and from an educational point of view, this reduced complexity could potentially be an advantage; according to the well-established cognitive load theory, a highly complex learning task such as the mastoidectomy procedure can challenge and inhibit actual learning. Cognitive resources should be allocated for the integration of relevant information rather than novel and unorganized information that provides a cognitive overload, preventing learning.[22]

Only a few studies have investigated the relationships between cognitive load and VR surgical simulation training. Cao et al.[23] found that novice surgeons had relatively limited spare cognitive resources available to process additional haptic feedback information and the haptic feedback enhanced performance particularly for the expert group. They found that haptics were beneficial in improving accuracy and task speed thereby countering the detrimental effect of cognitive load on performance. Even though the haptic device might affect cognitive load in virtual training, there have been no studies on cognitive load in traditional dissection training. There is a gap of knowledge on the role of cognitive load in temporal bone surgery and it remains to be explored whether cognitive load lowering interventions can be used to improve technical surgical skills performance.

We found that, on average, participants performed significantly better in the VR simulator even though several factors could have been expected to increase cadaveric dissection performance over VR simulation performance. First, all the participants received virtual training before receiving dissection training. A learning effect from having simulator training first would have improved the dissection performance. Such a learning effect was found by Zhao et al.[11] who demonstrated that a simulator-trained group had a better final product performance in cadaveric dissection than a group receiving traditional instructions. Second, participants were allowed more time for the procedure during cadaveric dissection training to compensate for time-consuming drill changes, navigating the operating microscope and handling of suction/irrigation, which is not needed during VR simulation. We believe that the additional time led participants to complete comparable steps in the two training modalities and any extra time in cadaveric dissection would have contributed to a better cadaveric dissection performance. Third, participants received individual and plenary instruction and feedback by faculty during cadaveric dissection in contrast to being self-directed with only the simulator-integrated tutor function and on-screen guide in the VR simulator. The participants were teamed in the same pairs for VR simulation and cadaveric dissection training, which was course tradition. Participants thereby had peer feedback in both training modalities. Teaming could have an effect on performance through being observer first; however, a recent large and randomized study has demonstrated no effect on performance of peer feedback in VR technical skills training.[24] These factors would have have contributed to a better cadaveric dissection performance. Nonetheless, we still found that participants outperformed themselves in VR simulation training. In general, the present study was limited by being both non-randomized and non-interventional but, at this point, we were not allowed to make changes to the original course curriculum before demonstrating an effect of VR simulation training.

VR temporal bone simulation seems to result in a higher initial performance by novices, which most likely can be explained by a combination of less complexity and by intuitive simulator-integrated tutoring. The VR simulator used in this study is freeware and runs on standard PC hardware, which could facilitate widespread adoption. The required hardware (a PC with a newer GeForce graphics card and a Geomagic Touch haptic device) is relatively inexpensive and can be acquired for about $5000, whereas a commercially available VR temporal bone surgical simulator is reported to be 5 times more expensive.[9]

In conclusion, novice performance in a freeware VR temporal bone simulator was found to be significantly better than in cadaveric dissection. We therefore recommend that access to VR simulation should be provided to all trainees in otorhinolaryngology for basic technical skills training as an adjunct to traditional training including cadaveric dissection training. Based on our other published research, we also recommend that repeated VR simulation training is organized as time-distributed practice to provide a superior learning experience.[25]

Conflict of interest

Dr Andersen has received a grant from the Oticon Foundation for PhD studies on virtual temporal bone surgery. The foundation played no role in the design or conduct of the study. The development of the Visible Ear Simulator has been financially supported by the Oticon Foundation. The authors have no conflicts of interest.

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Appendix 1: The modified Welling Scale for final product analysis of mastoidectomy performance

Each item is graded with: 0 = incomplete/inadequate dissection, 1 = complete/adequate dissection

Mastoidectomy margins defined at:		
1. Temporal line	0	1
2. Posterior canal wall	0	1
3. Sigmoid sinus	0	1
Antrum mastoideum		
4. Antrum entered	0	1
5. Lateral semicircular canal exposed	0	1
6. Lateral semicircular canal intact	0	1
Sigmoid sinus		
7. Exposed, no overhang	0	1
8. No cells remain	0	1
9. No holes	0	1
Sinodural angle		
10. Sharp	0	1
11. No cells remain	0	1
Tegmen mastoideum/tympani		
12. Attic/tegmen tympany exposed	0	1
13. Ossicles intact (untouched)	0	1
14. Tegmen mastoideum exposed	0	1
15. No cells remain	0	1
16. No holes	0	1
Mastoid tip		
17. Digastric ridge exposed	0	1
18. Digastric ridge followed towards stylomastoid foramen	0	1
19. No cells remain	0	1
External auditory canal		
20. Thinning of the posterior canal wall	0	1
21. No cells remain	0	1
22. No holes	0	1
Facial nerve		
23. Facial nerve identified (vertical part)	0	1
24. No exposed nerve sheath	0	1
25. Tympanic chorda exposed	0	1