Clinical techniques and technology

Assessment of skills using a virtual reality temporal bone surgery simulator

Valutazione delle competenze nella chirurgia dell'osso temporale con un simulatore della realtà virtuale

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SUMMARY

Surgery on the temporal bone is technically challenging due to its complex anatomy. Precise anatomical dissection of the human temporal bone is essential and is fundamental for middle ear surgery. We assessed the possible application of a virtual reality temporal bone surgery simulator to the education of ear surgeons. Seventeen ENT physicians with different levels of surgical training and 20 medical students performed an antrotomy with a computer-based virtual temporal bone surgery simulator. The ease, accuracy and timing of the simulated temporal bone surgery were assessed using the automatic assessment software provided by the simulator device and additionally with a modified Final Product Analysis Scale. Trained ENT surgeons, physicians without temporal bone surgical training and medical students were all able to perform the antrotomy. However, the highly trained ENT surgeons were able to complete the surgery in approximately half the time, with better handling and accuracy as assessed by the significant reduction in injury to important middle ear structures. Trained ENT surgeons achieved significantly higher scores using both dissection analysis methods. Surprisingly, there were no significant differences in the results between medical students and physicians without experience in ear surgery. The virtual temporal bone training system can stratify users of known levels of experience. This system can be used not only to improve the surgical skills of trained ENT surgeons for more successful and injury-free surgeries, but also to train inexperienced physicians/medical students in developing their surgical skills for the ear.

KEY WORDS: Virtual reality operation simulator • Temporal bone laboratory • Ear surgery • Skills lab

RIASSUNTO

La chirurgia dell'osso temporale è difficile dal punto di vista tecnico a causa della sua complessa anatomia. La precisa dissezione anatomica è però essenziale e fondamentale per la chirurgia dell'orecchio medio. Nel nostro studio abbiamo valutato il possibile utilizzo di un simulatore virtuale nella chirurgia dell'osso temporale per la formazione di chirurghi in questo campo. Diciassette medici ORL con diversi livelli di formazione chirurgica e venti studenti di medicina hanno eseguito una antrotomia con un simulatore virtuale di chirurgia temporale ossea collegato ad un PC. La leggerezza, l'accuratezza e il tempo impiegato per l'intervento simulato all'osso temporale sono stati valutati utilizzando sia un software automatico di valutazione collegato al dispositivo simulatore sia una scala modificata per l'analisi finale del prodotto. I chirurghi ORL esperti, i medici senza esperienza chirurgica dell'osso temporale ma anche gli studenti di medicina sono stati tutti in grado di eseguire l'antrotomia. Tuttavia i chirurghi ORL altamente qualificati erano in grado di completare l'intervento in circa la metà del tempo, con una migliore maneggevolezza del trapano e una maggiore precisione, come dimostrato dalla significativa riduzione di lesioni a importanti strutture dell'orecchio medio. I chirurghi ORL con maggiore esperienza hanno ottenuto punteggi significativamente più alti con entrambi i metodi di analisi. Sorprendentemente non sono state trovate differenze significative nei risultati ottenuti dagli studenti di medicina e dai medici senza esperienza nella chirurgia dell'orecchio. L'utilizzo del sistema virtuale per interventi all'osso temporale è in grado di stratificare gli utenti in base ai livelli noti di esperienza. Questo sistema può essere utilizzato non solo per migliorare le competenze chirurgiche di operatori esperti per interventi di maggior successo e senza lesioni, ma anche per aiutare i medici senza esperienza e gli studenti di medicina a sviluppare le loro competenze chirurgiche all'orecchio.

PAROLE CHIAVE: *Simulatore operativo di realtà virtuale • Laboratorio dell'osso temporale • Chirurgia dell'orecchio • Competenze di laboratorio*

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Introduction

Surgery of the middle ear and the temporal bone remains challenging for otologists due to the complex anatomy and inherent anatomical variability between individuals. The greatest difficulty for beginners is in understanding the three-dimensional positional relationship of the middle ear and the ossicles to the facial nerve, carotid artery, sigmoid sinus and the dura of the middle and posterior fossa. Even under favourable conditions, the rate of complications for intra-operative injury to the facial nerve, sigmoid sinus, labyrinth, cochlea and dura is reported to be from 2-6% [1-4]. This rate is even higher in third world countries [5]. Therefore, surgery on the temporal bone requires a consistently high degree of technical skill and usually requires specialized ENT surgeons. As a result, intermediate and advanced otosurgical training programmes exist and are essential for the training of ENT physicians in most hospitals.

Traditionally, anatomical knowledge was gained by studying standard surgical anatomical diagrams; however, this alone does not provide sufficient information to prepare a physician for ear surgery. Therefore, otology training begins with temporal bone dissection labs involving cadaveric temporal bones prior to any surgery on human patients. This training allows the physician to practice his surgical skills and gain knowledge of the temporal bone anatomy. If temporal bone dissection labs are not available in a hospital, then knowledge of the ear anatomy and the surgical landmarks of the temporal bone can be gained through temporal bone drilling courses, but these courses have limited availability. In fact, in some areas of the world, barriers imposed by religion, policy and law make it impossible to obtain human bones for these drilling courses [6].

Virtual simulators have been used increasingly in recent years for education and training purposes in all fields of surgery [7-9]. Simulators are currently used as successful training tools in many high performance fields not only to provide specialized training, but also to prevent rare and hazardous events [10-12]. Therefore, application of virtual simulators to the field of ear surgery is of tremendous interest to ENT surgeons because of its potential to accelerate training and increase physicians' skill level in temporal bone surgery even prior to entering a temporal bone dissection lab or the operating theatre.

The principles of evaluating surgical simulators are well established. Common benchmarks on which simulators are judged include reliability, face, content, construct, concurrent and predictive validities. Construct validity is a mandatory, and one of the most valuable, assessments of a simulator before its acceptance as a competency-developing device. In this regard, a simulator must be able to distinguish the experienced from the inexperienced surgeon [13]. Given this interest, our goal in this work was to assess if the simulation can stratify users of known levels of experience, which explores construct validity.

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Virtual temporal bone laboratory

The VOXEL-MAN TempoSurg® simulator is a commercially available three-dimensional virtual reality simulator that was developed for teaching temporal bone anatomy and surgery (Fig. 1). The simulator is a tool for training and planning classical and navigated surgical access to the middle ear. The system is based on virtual 3D models of the skull base derived from high-resolution CT data.

The trainee observes the virtual surgical site using the display on the stereoscopic mode (Fig. 2) and controls the drill with a force feedback device. Thus, the simulated

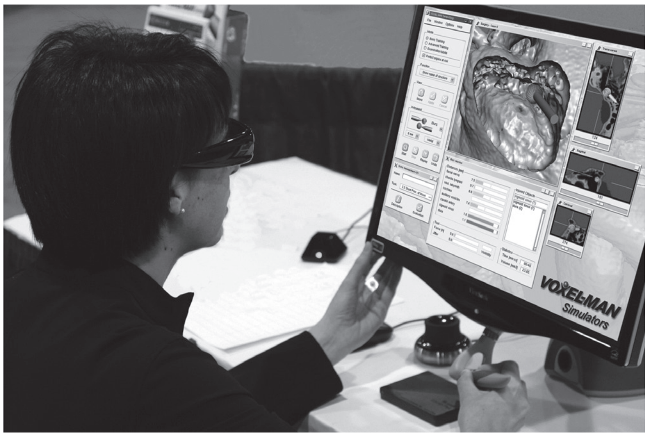


Fig. 1. A view of the virtual temporal bone laboratory. The subject sits with the stylized drill in the hand in front of the screen and dissects the virtual mastoid.

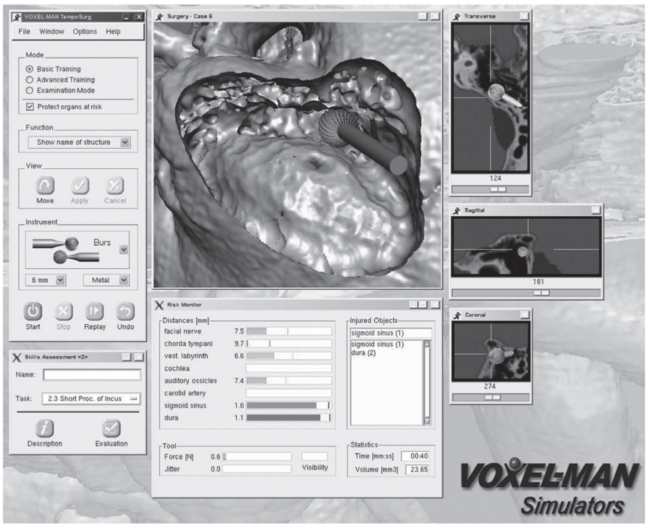


Fig. 2. The VOXEL MAN TempoSurg® user interface. In this case, the sigmoid sinus (blue) and the dura (brown) are injured. The surgeon is on the way to the antrum which is not opened. This is the mode for beginners. The risk monitor, which shows the distance to vital structures, can be seen at the bottom. A 3-D-navigation is displayed on the right side. An interactive menu to choose the level, the view and the instrument is on the left side.

procedure closely mimics the real procedure with respect to the patient's orientation and the surgeon's view, working direction and haptic feedback. The trainee can choose the view angle and magnification as well as the type, size and rotation speed of the drill. In addition, the user can navigate with three orthogonal cross-sectional views. A set of models derived from individualized patient cases with labelled organs at risk are provided for surgical training. During the early training phase, the organs at risk are coloured both in the 3D surgical site and the cross-sectional views, and alarms can be set to indicate when organs at risk are injured. These functions enable different levels of training support. It is also possible to record the dissection procedure, and the unit can create an error log and measure various parameters.

Study design

We performed a validation study using the computer-based virtual ear surgery simulator in an academic training programme. Seventeen physicians from the ENT department and 20 medical students consented to perform an antrotomy using the simulator. Of the physicians, 10 were residents without any experience in ear surgery, while seven (six consultants and one resident) had varying levels of experience and had previously performed mastoidectomies and tympanoplasties. Residents without experience in ear (temporal bone) surgery did have at least two years of prior experience in other forms of ENT surgery (e.g. tonsillectomy, surgery of the nasal septum or the paranasal sinuses, surgery of tumours of the neck, insertion of grommets).

The task was first explained to all subjects in the same manner. Subjects were told that they could try the simulator programme in a task referred to as the first step. Subjects were asked to write their names with metal and diamond burrs of two different sizes on an animation of a plane face.

The pathogenesis of otitis media and mastoiditis was explained to the students. All subjects without experience in ear surgery were shown a model of the middle ear and the temporal bone. The antrotomy and mastoidectomy procedures were explained. The landmarks, delicate ear structures and surgical procedure were illustrated by a three dimensional model. All subjects without experience in ear surgery were shown two images. The first image illustrated the human temporal bone, which was dissected without corticalis and gave the view of partially opened mastoid cells. The second image illustrated the aim of the procedure by showing a completed antrotomy with a wide open antrum and a view of the short process of the incus, dura, sinus with a thinned out bony hull, labyrinth and angle of Citelli.

The principles of the techniques of ear surgery were explained to all subjects without experience in temporal bone surgery. Special instructions were given including a discussion of the differences between diamond and metal burrs, and advice was provided to always choose the largest possible burr, to avoid drilling without seeing the top of the instrument and to always use the maximum burr rotation speed. All subjects without experience in ear surgery were instructed in the anatomy of the area again immediately prior to drilling, including the linea temporalis, Henle's spine, tympanic membrane, dorsal wall of the outer ear canal, position of the approximated antrum and sigmoid sinus as well as the dura.

All subjects were also instructed that credit would be given for smooth and steady drill action, avoidance of damage to important ear structures and progress made in the task. A film of the drilling procedure was recorded on the computer as well as an electronic record of the preparation.

Assessment of the preparation

The performance of subjects was measured using two different methods; a newly developed custom rating scale for the special situation of a virtual dissection that is based on the Final Product Analysis Scale as well as the automatic assessment software provided by the computer-based simulator.

Modified Final Product Analysis Scale

The easiest way to assess surgical skills is, in addition to the surgical time, to assess the surgical outcome. This is, ultimately, essential for the patient. The Final Product Analysis Scale is a method to assess the outcome of an operation or a dissection, which was first described for a GI procedure [14]. We modified this scale for the conditions set by an ear operation and especially for the virtual reality operation simulator. The score was designed to rate the subject's achievement of the basic objective of the operation rather than perfect completion.

We awarded points for the presentation of important structures and restricted the operation time to 20 min (Table I). Points were deducted when subjects injured important structures.

Distinctions were made as to whether the violation took place during the dissection when using a metal or diamond burr. This distinction was made because there is a big difference if an injury takes place with the metal or the diamond burr. If someone touches the ossicles, for example, with the diamond burr, the patient gets a sensorineural hearing loss of about 40 dB. Touching the chain with the cutting burr leads to deafness as a rule. In the case of injury of the dura, the tympanic membrane or the sigmoid sinus, the damage is much smaller if the injury is performed with the diamond. Opening of the cochlea is a major error; if the facial nerve is cut, the patient has a facial palsy for life. It makes no difference if this happens by dissection with a diamond or a metal cutting burr. Therefore, no distinction was made for these items.

Table I. Points awarded for prepared structures (Modified Final Product Analysis Scale).

Prepared structure	Points
Compacta of the temporal bone	1
Cancellous bone of the temporal bone / opening of the first cells	2
Reaching Koerner´s septum	3
Opening the bulla of the antrum	10
Removal of the walls of the bulla	12
Preparation of the incus	15
Preparation of the labyrinth block	2
Preparation of the dura	2
Thinning the bony coverage of the sigmoid sinus	2
Operating time < 20 min, reaching all operating objectives and preparing all structures listed above	10

Table II. Point deductions for drilling defects (Modified Final Product Analysis Scale).

Injured structure	Penalty / diamond burr	Penalty / metal burr
Ossicles	5	10
Dura	3	5
Sigmoid sinus	3	5
Tympanic membrane	2	5
Perforation of the posterior canal wall	1	2
Cochlea	10	10
Semicircular canals	3	6
Facial nerve	10	10
Chorda tympani	2	2

In the end, the participants were asked to complete a questionnaire. Injured structures should be marked with a cross and the instrument with which the injury happened should be denominated. If the subject noted structural damage, one less point was deducted than if the subject did not take note (Table II).
The procedures were videotaped. Based on these criteria, the question whether landmarks were exposed or not, were established by two experienced ENT surgeons, using the taped video material, by consensus. The experts were blinded to the user's skill level**.** Both surgeons have more than 15 years of experience in otorhinolaryngology. Collisions with vital structures were identified automatically by the software of the device as described below.

Feedback on the software protocol

Objective parameters of the training were measured from the software protocol scheme. One hundred points could be achieved for the complete removal of the mastoid cells on the way to the antrum. The reference volume was defined by a virtual antrotomy done by a highly trained ear surgeon. This expert performed the procedure three times. From this, the voxels were extracted, which he has removed each time (intersection). This defined the reference volume. The percentage indicates how much a candidate has removed, always referring to the voxels in the reference volume; 100% was reached by removing the reference volume completely.
Again, injury of delicate structures was penalized with point deduction. Injury was defined as the penetration of the drill into a risk structure. These risk structures were segmented as separate items, i.e. they were described by a set of voxels. Furthermore, it was worked with subvoxel accuracy. The risk structures (soft tissue) were first defined by thresholding (threshold intensity).
In a subsequent processing stage, these were adjusted and smoothed interactively with the assistance of an expert using a volume editor. Therefore, they were independently segmented objects, and not only the bone cavities. Any violation in one motion (as defined by the penetration depth, approximately 0.1 mm) was counted as an error. The device noted whether the violation was made with a metal or diamond burr, but no distinctions were made with reference to point deductions.
The dissection time was calculated, and the reference time for the virtual operation was set to seven min. Subjects were penalized if the operation time exceeded these limitations and rewarded if they completed the operation in less time (one point per 5 sec).
A special feature of the virtual temporal bone laboratory is that it can calculate and register changes in pressures in the vicinity of delicate structures, particularly in the area of the facial nerve and the chorda tympani. Sewell et al. showed that an expert works in the field of about 25 mm to the facial nerve with a force of 0.2-0.1 N; a beginner, however, works with a force of more than 0.2 N [15]. In this system, only significantly higher forces are counted as errors, in order to avoid "false positives." The threshold here for excessive force is 0.8 N. High pressures noted in the proximity of delicate ear structures would lead to point deductions. This particular feature of the virtual simulator is of significant interest and is valid in the training of ear surgeons to perform temporal bone surgeries as high pressures are known to lead to non-functional facial nerves in patients. In addition, one point was deducted for each second that the rotating burr did not remain visible (Table III).
Furthermore, all actions of the subject were recorded and evaluated including the "drill path", which is the total length of the path of the drill during drilling without accounting for movements in air. Furthermore, the aver-

Table III. Points deducted for drilling errors (automatic assessment).

Injured structure	Penalty
Injuring the ossicles	10
Injuring the dura	1
Injuring the sigmoid sinus	5
High pressure near the facial nerve or the chorda tympani	5
Rotating burr not properly visible (per sec)	1
Preparation time longer than 7 min (each 5 sec)	1

age volume removed in an internal time step of 20 msec was also measured. The device also recorded the angle of drilling. These metrics have not been validated previously and, therefore, are not included in the evaluation scheme, except for output as a measured value. It was assumed that they could be meaningful, as (i) experienced surgeons will be more targeted and operate with less movement in the air, (ii) they are goal orientated, (iii) and they bit more with the equator than grow with the tip as inexperienced colleagues.

Our experience

The study was approved by the human ethics committee of the University of Luebeck (AZ-12-021). There are no objections to the participation of medical students and qualified doctors in a virtual temporal bone lab. Data were analyzed with a one- and two-way ANOVA followed by Fisher's Exact Test using Stat View 5.0 software. Differences between groups were considered significant when $p < 0.05$.

The results show that all experienced ENT surgeons were able to complete the aim of the operation and open the antrum and to intraoperatively dissect both the dura and the sigmoid sinus. Nine of ten residents succeeded in entering the antrum. Eight residents (80%) explored the sigmoid sinus, but only three (30%) explored the dura. Additionally, 18 (90%) students explored the sigmoid sinus, but only 11 (55%) explored the dura. It should be noted that none of the subjects injured the cochlea, semicircular canals, facial nerve or chorda tympani. In addition, no injury was observed to the ossicles when the surgical procedure was performed by the experienced ENT surgeons. However, the rate of injury to the ossicles was 50% in residents and 60% in students. This suggests that the experienced ENT surgeons performed significantly better than the residents ($p < 0.05$) and students ($p < 0.01$). In contrast to the students, a majority of the residents immediately before entering the antrum changed to the diamond burr to avoid injuring the ossicles. While only one experienced ENT surgeon injured the sigmoid sinus, 50% of residents and 45% of students damaged the sigmoid sinus. Interestingly, there was a high rate of injury to the dura, with 70% of the experienced ENT surgeons inducing injury compared with 20% and 45% by residents and students, respectively. In addition, no experienced ENT surgeon perforated the posterior wall of the outer ear canal. However, two residents (20%) and nine students (45%, Table IV) did perforate the posterior wall of the outer ear canal. Excessive force near delicate ear structures was observed in 60% of residents and 55% of students, but in none of the experienced ENT surgeons. This parameter further illustrated that the experienced ENT surgeons were significantly better at handling the drill compared to residents ($p < 0.05$) and students ($p < 0.05$).

Our results further show that dissection times significantly differed between subject groups. Experienced ENT surgeons required half the time for the surgical procedure when compared to residents without ear surgery experience and students. Differences in procedure times between the experienced ENT surgeons and both students and residents were highly significant ($p < 0.001$), while no significant variability was detected between residents and students.

A significant difference was observed between groups in the automatic score assigned by the software provided with the virtual device. The difference between the experienced ENT surgeons and both the students and residents was again highly significant ($p < 0.001$), but no significant difference was noted between residents and students. Scores measured by the Modified Final Product Analysis Scale further validated that the more experienced ENT surgeons scored significantly higher than residents and students ($p < 0.05$). Again, there were no differences in scores between residents and students.

We also show that there was no difference in the removal of temporal bone volume ($p > 0.15$), length of the drill path ($p > 0.45$) or drill angle ($p > 0.5$) between subject

Table IV. Preparation of landmarks and damage to the posterior wall of the outer ear canal.

	Experienced ear surgeons (n = 7)	Residents without experience in ear surgery (n = 10)	Students (n = 20)
Preparation of the dura*	7 (100%)	3 (30%)	11 (55%)
Thinning of the bony hull of the sigmoid sinus*	7(100%)	8 (80%)	18 (90%)
Entry to the antrum*	7(100%)	9 (90%)	20 (100%)
Damage to the posterior wall of the outer ear canal*	0 (0%)	2 (20%)	9 (45%)
Injury of the auditory ossicles*	0 (0%)	5 (50%)	12 (60%)
Injury of the auditory ossicles with metal burr*	0 (0%)	1 (10%)	9 (45%)
Injury of the sigmoid sinus*	1 (10%)	5 (50%)	9 (45%)
Injury of the dura*	5 (70%)	2 (20%)	9 (45%)
Luebeck-Score**	51.0 (± 2.9)	41.5 (± 8.7)	43.7 (± 7.8)

** number of incidences (percentage); ** mean (standard deviation)*

Table V. Parameters recorded by the device.

	Experienced ear surgeons (n = 7)	Residents without experience in ear surgery (n = 10)	Students (n = 20)
Preparation time (min:sec)**	06:36 (± 0:38)	14:55 (± 8:47)	15:05 (± 6:27)
Automatic score**	68.7 (± 30.5)	-80.4 (± 82.0)	-52.7 (± 61.8)
Injury of the auditory ossicles*	0 (0%)	5 (50%)	12 (60%)
Injury of the auditory ossicles with metal burr*	0 (0%)	1 (10%)	9 (45%)
Injury of the sigmoid sinus*	1 (10%)	5 (50%)	9 (45%)
Injury of the dura	5 (70%)	2 (20%)	9 (45%)
Removed volume (ml)**	1.35 (± 0.30)	1.11 (± 0.22)	1.38 (± 0.24)
Excessive force near delicate structures*	0 (0%)	6 (60%)	11 (55%)
Rotating burr not properly visible (sec)**	0.4 (± 0.8)	4.1 (± 5.4)	1.4 (± 2.8)
Length of the drill path (mm)**	2542 (± 1270)	2439 (± 1682)	3170 (± 1944)
Drill angle (°)**	46.0 (± 5.5)	47.7 (± 6.9)	46.3 (± 6.6)
Volume per strike (mm^3)**	0.77 (± 0.19)	0.39 (± 0.26)	0.43 (± 0.20)

** number (percentage); ** mean (standard deviation)*

groups. However, the volume per strike was significantly higher in experienced ENT surgeons when compared to residents and students ($p < 0.001$). In addition, it should be noted that the rotating burr was not properly visible for a significantly longer period of time when used by residents compared to experienced ENT surgeons and students ($p < 0.01$). Otherwise, no significant differences were found between ENT specialists and students (Table V). Figures 3 and 4 show representative examples of the electronic protocol of the completed antrotomy performed by an experienced ENT surgeon and by an advanced resident without experience in ear surgery, respectively.

Subjects were also asked about their impressions of the virtual device for training. Students expressed appreciation for the possibility of self-assessment and thought that the system was suitable for use in surgical specialization and was valuable as an initial training tool to prepare for surgical skills. Experienced ENT surgeons found the model to be similar to human temporal bone and suitable for training purposes.

Discussion

Temporal bone surgery is complex and requires extensive surgical skills. The first step in acquiring the credentials for ear surgery is the dissection of cadaver temporal bones in a temporal bone lab. Human temporal bone specimens naturally provide an excellent resemblance to the anatomic details of the human temporal bone in living people. In fact, post-mortem defects in these bone specimens are almost negligible and can be advantageous since they also provide a breadth of anatomical variability between individual specimens, reflecting the inherent variability between individuals. On the other hand, disadvantages of using these cadaver preparations include the inability to study pathological changes to the ear, the lack of anatomical reproducibility in the specimens, and the lack of specimen availability.

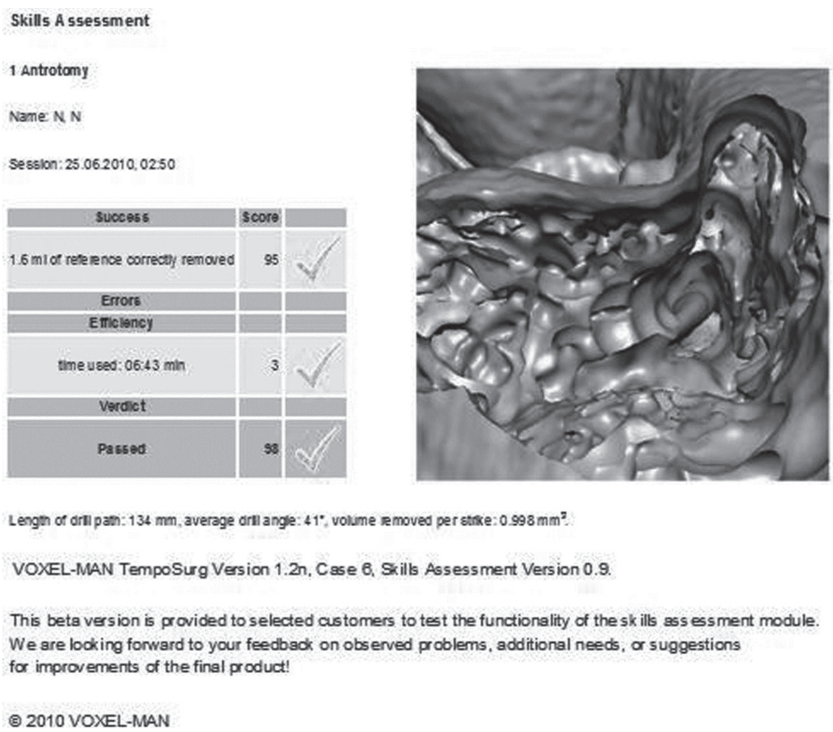


Fig. 3. Example of an electronic protocol of a completed antrotomy performed by an experienced ear surgeon. The major part (95%) of the reference volume is removed. The sigmoid sinus and the dura are explored. The antrum is wide open with a free view of the incus (brown). The virtual operation was finished within the time limit. The verdict on the procedure in general is "passed".

Artificial temporal bone models have been developed over the last two decades in Europe, especially in Germany [16-19]. A number of virtual temporal bone models have been developed over the last several years [15 20-24]. The VOXEL MAN Tempo Surg® simulator is a commercially available system for training on bone drilling interventions in middle ear surgery and offers the possibility to learn about temporal bone anatomy as well as to perform procedures with relatively realistic visual and haptic feedback. The system is based on a volumetric, high-resolution model of the temporal bone derived from a CT. Interactive volume-cutting methods are performed using a multivolume scheme cut where regions are modelled independently. Data volumes can also be measured using voxelization techniques. The so-generated temporal bone model shows all anatomical landmarks and organs of risk such as the sigmoid sinus, dura, posterior wall of the outer ear canal, labyrinth block, facial nerve and incus [20].

Compared to classical methods and artificial temporal bones, training using a virtual temporal bone lab provides a number of major advantages. It allows physicians to train with temporal bones, which exhibit normal and pathological conditions, and the system can adapt to the user's existing skill level. Another advantage of the electronic simulation is the ability to infinitely repeat the procedure. It also allows the user to correct for mistakes by undoing a step and starting over again from a point before the error was committed. The system can also be used by many trainees and provides the possibility of self-assessment. Because users can record procedures, it allows for correction or evaluation at a later time. This virtual simulator can also decrease the required investment in bone drilling labs and the consumption of cadaveric material can be substantially reduced or even omitted.

Results achieved from temporal bone dissection labs can be difficult to recapitulate in human specimens [18 25 26]. We developed a "Modified Final Product Analysis Scale" to assess performance. The software included with the VOXEL MAN Tempo Surg® simulator can provide automatic assessment of the user's surgical skills. A limitation of the automatic evaluation is that it only determines the ratio of the volume removed from the mastoid to the reference volume. The device does not note whether the antrum is in fact open at the end of the procedure. In this study, the experienced ENT surgeons never injured the chain of ossicles, injured the sigmoid sinus less frequently than other subjects and needed only half the operation time compared with other subjects to perform the temporal surgery. This is also reflected in a significantly better score calculated using both the self-developed Modified Final Product Analysis Scale as well as the automatic analysis software provided by the device. These results further validate that the performance in the virtual surgery closely resembles the level of skill and performance observed in the operating room.

Interestingly, the more experienced ENT surgeons injured the dura more often. This could be due to the lack of an increase in the intensity of blood flow in this region in the simulator, which is characteristic for the bone in the vicinity of the dura. More importantly, the experienced ear surgeon is looking for the dura as a landmark. In reality, the dura does not disrupt immediately if it comes in contact with the drill. The drill pushes the dura in front of it; the dura is not liable to be fixed to the bone. Thus, these

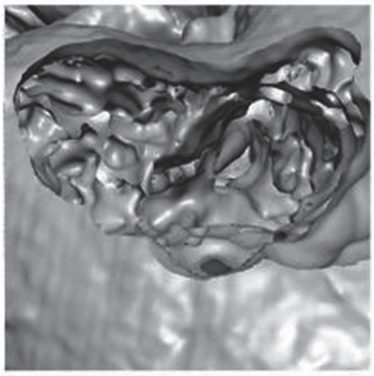
Skills Assessment

1 Antrotomy

Name: N. N

Session: 18.06.2010, 01:27

Success	Score
1.2 ml of reference correctly removed	74
Errors	
excessive force of 0.2 N near the facial nerve	-18
excessive force of 0.4 N near the chorda tympani	-42
2 injuries of the auditory ossicles	-20
1 injuries of the sigmoid sinus	-5
rotating bur 17.1 s not properly visible	-17
Efficiency	
time used: 08:35 min	-16
Verdict	
Failed	-43



Length of drill path: 241 mm, average drill angle: 50°, volume removed per strike: 0.507 mm³.

VOXEL-MAN TempoSurg Version 1.2n, Case 6, Skills Assessment Version 0.9.

This beta version is provided to selected customers to test the functionality of the skills assessment module. We are looking forward to your feedback on observed problems, additional needs, or suggestions for improvements of the final product!

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Fig. 4. Example of an electronic protocol of a completed antrotomy performed by a resident. Two-thirds (74%) of the reference volume is removed. Points were deducted because excessive force was applied in the area of the facial nerve and of the chorda tympani. The antrum is wide open, but the auditory ossicles were injured twice and the sigmoid sinus once. The rotating burr was not properly visible for 17 sec. The virtual operation was not finished within the time limit. The verdict on the procedure in general is "failed".

models should be further developed to account for these observed differences between the simulator and real operations.

Experienced ENT surgeons did not apply a high pressure with the drill near delicate ear structures, unlike half of the residents and students. These results suggest that the virtual device is very sensitive to major technical errors in drilling, which is also a good indicator of the level of surgical skill of the prospective ENT surgeon.

Operating room training often consists of guidance and supervision of a theoretically highly educated but more or less inexperienced surgeon (trainee) by a more experienced colleague. Even when a supervisor is present, there is always a high risk when a surgical trainee operates on a patient requiring complex surgery. Operation time is becoming increasingly important as medicine becomes commercialized. The atmosphere in the operating room is accompanied by a time limitation and a high level of expense. It has been calculated that surgical residents cost the operating room $1,000 per training hour in addition to the regular cost of the operation [27]. In addition, individual surgical steps cannot be practiced repeatedly prior to surgery. Thus, the virtual surgery simulator offers the possibility of partial replacement of expensive operation room time and supervision by an expensive academic teacher with electronic supervision. One option for the future is preoperative simulation of the operation of selected and particularly difficult patient cases on a personal computer [28]. In this way, even experienced ear surgeons could simulate complex procedures before the real intervention, saving time and avoiding complications. In line with these thoughts, a training model for paranasal sinus surgery is currently in development [29].

Surprisingly, no significant difference was noted between the residents without experience in middle ear surgery and the medical students. In Germany, a classical education in ENT surgery begins with adenotomy and tonsillectomy. Middle ear surgeries are the pinnacle of ENT surgeries and are performed by especially committed medical specialists during the culmination and height of their ENT training. It is obvious that ear surgery occupies a special position in ENT surgery and we show that surgical education in other sub-specializations has no influence on the physician's performance at the beginning of ear surgery training.

In our study we observed a dichotomic distribution separating skilled and non-skilled surgeons. This first evaluation of the virtual temporal bone laboratory by means of a standard operation revealed its construct validity and its suitability as a training model for temporal bone surgery in principle. Surgery training is a continuous process where different intermediate skill levels are observed. Therefore further studies on construct validity are required. These should include surgeons of different levels, e.g. completely inexperienced surgeons, inexperienced physicians who just had a temporal bone dissection course, surgeons with intermediate experience (< 200 operations), experienced surgeons (> 200 and < 1000 operations) and experts (> 1000 operations).

The next step is to assess the efficacy of the system as a learning tool. Future work should investigate the learning curves on the simulator with single-subject repeated measure design. One possibility is to study whether there is a significant difference between the first and subsequent sessions of the inexperienced subjects in terms of operating time and surgical outcome. Furthermore, every attempt of the inexperienced surgeons could be compared with the data from the group of experienced surgeons to determine the point at which there is no significant difference between the two groups. Another experiment might assess the performance of trainees over time to see if the simulator performance improves with increasing clinical experience, as confirmed by the scores.

Finally, studies are needed to assess whether skills acquired in the virtual environment can be transferred to the operating room in order to translate the effect of learning on the simulator to real-life ear surgery; it would then be possible to demonstrate a transfer-effectiveness ratio.

Work completed in the temporal bone laboratory is and will remain "conditio sine qua non" for the start of training in ear surgery on patients. Virtual learning programs of the anatomy of the temporal bone and interactive programs for dissection may display the anatomical characteristics of this difficult anatomical region and serve as a good baseline for the dissection exercises in the temporal bone lab. The technology of virtual reality simulators can be expected to improve. It should be noted that a virtual surgical simulator cannot replace the traditional temporal bone laboratory, but the virtual temporal bone laboratory supplements the traditional training path of the prospective ear surgeon.

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