Distance Control and Virtual Drilling Improves Anatomical Orientation During Anterior Petrosectomy

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Received, October 4, 2018.
Accepted, December 25, 2018.

BACKGROUND: A combined drill distance control and virtual drilling image guidance feedback method was developed.

OBJECTIVE: To investigate whether first-time usage of the proposed method, during anterior petrosectomy (AP), improves surgical orientation and surgical performance. The accuracy of virtual drilling and the clinical practicability of the method were also investigated.

METHODS: In a simulated surgical setting using human cadavers, a trial was conducted with 5 expert skull base surgeons from 3 different hospitals. They performed 10 AP approaches, using either the feedback method or standard image guidance. Damage to critical structures was assessed. Operating time, drill cavity sizes, and proximity of postoperative drill cavities to the cochlea and the acoustic meatus, were measured. Questionnaires were obtained postoperatively. Errors in the virtual drill cavities as compared with actual postoperative cavities were calculated. In a clinical setup, the method was used during AP.

RESULTS: Surgeons rated their intraoperative orientation significantly better with the feedback method compared with standard image guidance. During the cadaver trial, the cochlea was harmed on 1 occasion in the control group, while surgeons drilled closer to the cochlea and meatus without injuring them in the group using feedback. Virtual drilling under- and overestimation errors were 2.2 ± 0.2 and −3.0 ± 0.6 mm on average. The method functioned properly during the clinical setup.

CONCLUSION: The proposed feedback method improves orientation and surgical performance in an experimental setting. Errors in virtual drilling reflect spatial errors of the image guidance system. The feedback method is clinically practicable during AP.

KEY WORDS: Skull base, Petrous bone, Neuronavigation, Feedback

Operative Neurosurgery 18:83–91, 2020 DOI: 10.1093/ons/opz064

Open microscopic anterior petrosectomy (AP) has become a standard neurosurgical procedure to approach intradural lesions such as brainstem cavernous malformations, petroclival meningiomas, posterior circulation aneurysms, and extradural lesions of the petrous apex.[1] AP requires drilling of the petrous bone in Kawase's triangle (or quadrangle).[2,3] One of its major complications is hearing loss caused by iatrogenic damage to the cochlea during the drilling part of the procedure.[4-7] Gross et al[8] reported a 12% incidence of hearing loss after AP to approach brainstem cavernous malformations. This rate may be higher for other types of lesions and is probably dependent on the extent of exposure required.[6]

ABBREVIATIONS: AP, anterior petrosectomy; **CT,** computed tomography; **EVADE,** exposure visualization and distance emission; **MIP,** maximum intensity projection; **3D,** 3-dimensional

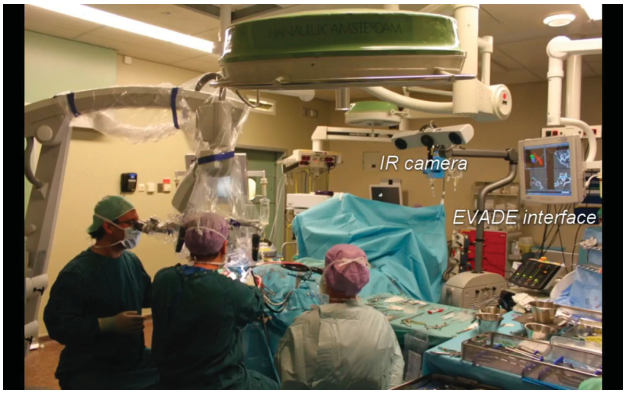
Several methods that aid in protection of the cochlea during AP have been described previously.[4,7,9-11] Neurosurgical literature recommends to use anatomic landmarks (such as topographic features or anatomical extrapolations like the cochlear line and cochlear safety line) to localize the cochlea.[6,7,12] However, other studies show there is significant anatomic variability in the temporal bone, which potentially limits the applicability of these methods.[13,14] Therefore, a more reliable method, specified to the individual patient's anatomy, is needed.

Moreover, demand for good clinical outcomes after skull base surgery is currently increasing because of the effectiveness of less-invasive techniques such as radiosurgery. Therefore, aside from having an extensive anatomical knowledge gained from cadaver dissections and surgical experience, modern skull base surgeons need to be optimally informed about each individual patient's anatomical variations during surgery.

Preoperative imaging combined with intraoperative image guidance potentially provides an anatomically individualized method for designating the cochlea and other anatomical structures during AP. However, standard image guidance is as of yet unable to provide (real-time) feedback to indicate the location of these structures, while the surgeon is drilling the petrous apex.

Therefore, we developed a special software module (called exposure visualization and distance emission (EVADE)) for this purpose.[15] The software augments image guided drilling during AP with 'distance control' and 'virtual drilling' feedback. Distance control continuously computes the distance between the drill tip and important structures (eg, the cochlea, internal acoustic meatus, and internal carotid artery) and emits audio-visual warnings when the drill tip comes within a protective perimeter set at a certain distance around these structures.[16,17]

The system can supply audio feedback through 1 of 2 modes. Mode 1 is a beep followed by a human voice stating the name of the structure approached. Mode 2 consists of a beep, with different tones for each structure (similar to a neuromonitoring device). The surgeon can adjust the system's sensitivity per individual structure (by adjusting that structure's protective perimeter distance, which can be set to any value ≥ 1.0 mm), the warning mode and the audio volume, at any time during surgery (Video).



VIDEO. *This video showcases the 2 different distance control warning modes of the EVADE system. Mode 1 is a beep followed by a human voice stating the name of the structure approached. Mode 2 consists of a beep, with different tones for each structure. Furthermore, it shows the employed experimental and clinical setups.*

Virtual drilling updates the preoperative computed tomography (CT) scan in (near) real time to show virtual bone drilling, enabling the surgeon to see the current extent of the drill cavity during surgery (see Figure 1).

Our hypothesis was that usage of the presented software improves the anatomical orientation of surgeons, thus reducing the risk of drill damage to anatomical structures during AP, while maintaining, or even improving surgical performance. The aim of this article was to investigate this hypothesis, and furthermore evaluate the accuracy and clinical feasibility of the software during AP. Efficacy was evaluated in a trial comparing surgical performance in a population of skull base surgeons performing AP either with standard image guidance and EVADE, or with just standard image guidance, in a cadaveric simulated surgical setting. Second, we researched whether virtual drilling feedback was accurate. Third, we investigated the clinical feasibility of the software during AP in a case of petroclival meningeoma.

METHODS

Cadaver Heads

Five formalin fixed human cadaveric heads supplied by our institute's pathology department were prepared as described in Voormolen et al 2018.[15]

Preoperative Scans

CT scans were acquired as described in Voormolen et al 2018.[15]

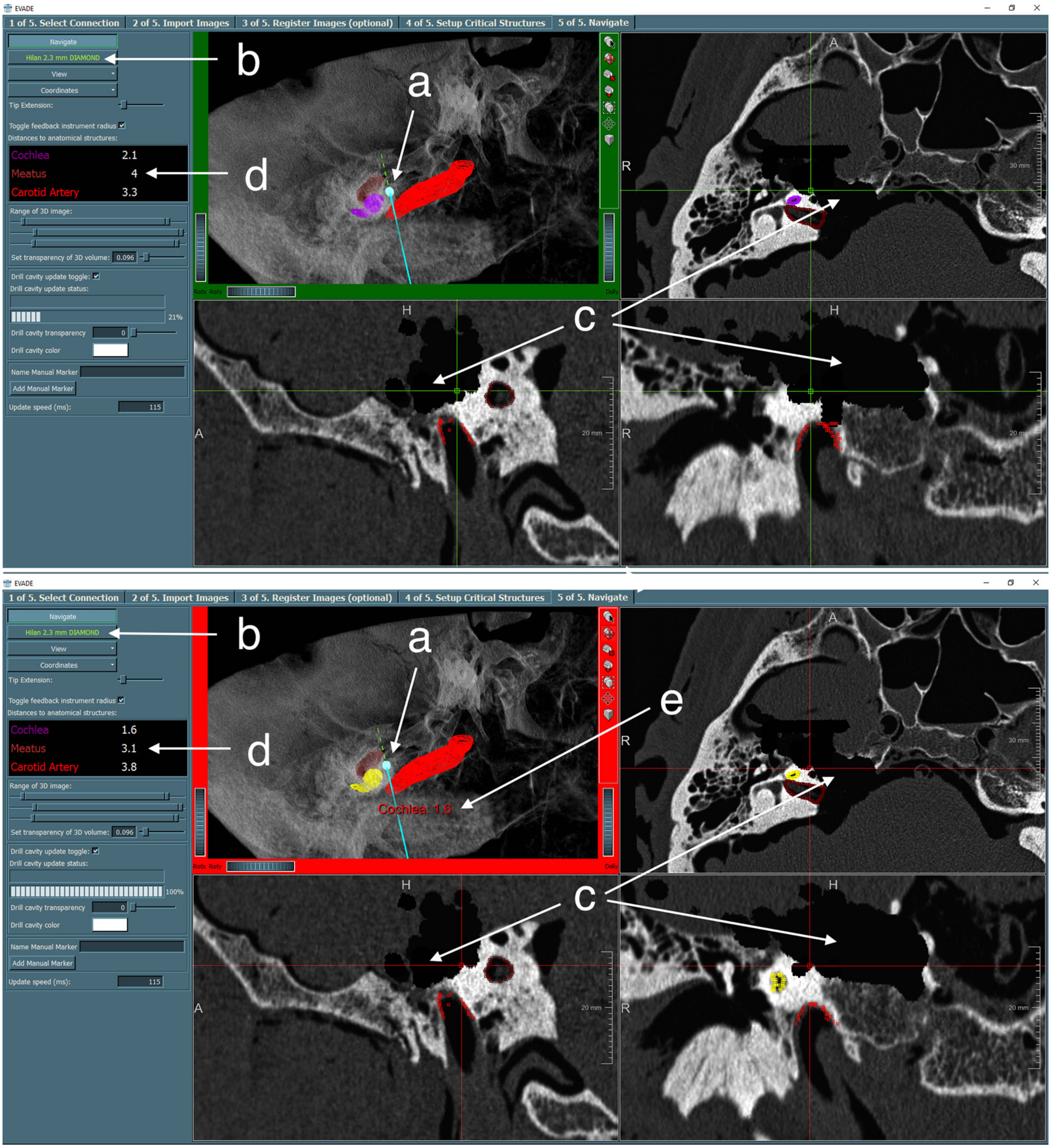
Experimental Set-up

Preoperatively, the cochlea, internal acoustic meatus, and carotid artery were manually segmented (contours were drawn in the axial plane and subsequently checked in the sagittal and coronal planes) on the left and right sides by one of the researchers with extensive knowledge of radiological temporal bone anatomy. It took approximately 30 min to perform the segmentation per side. Next, the cadaver heads were fixed to the table using 4 table-mounted screws. A reference frame (Medtronic Inc) was attached to the table. Each head was registered using 4 skull-fixed fiducial points (screws) to the preoperatively acquired image guidance CT-scan. A SureTrak tracking frame (Medtronic Inc) was fixed to the drill and it was calibrated for image guidance. Figure 2 illustrates the laboratory setup.

Before the surgeons started their task, the heads were prepared in a standardized fashion; a curved skin incision over the ear, followed by a 5 by 5 cm temporal bone craniotomy was performed. Subsequently, the dura was peeled from the middle fossa and the middle meningeal artery was cut, exposing the greater superficial petrosal nerve, foramen ovale, and mandibular nerve. A spatula was positioned behind the petrous ridge to retract the temporal lobe from the skull base and expose the petrous apex.

Study Population

Five experienced right-handed skull base surgeons participated in the trial on a voluntary basis upon receiving an oral and/or written invitation by the main author (E.V.). Each surgeon had at least 5 yr of experience in skull base surgery. The surgeons were based in 3 different university medical centers in the Netherlands with skull base reference clinics, and



Hilan 2.3 mm DIAMOND
Tip Extension:
Toggle feedback instrument radius ☑
Distances to anatomical structures:

Cochlea	2.1
Meatus	4
Carotid Artery	3.3

Set transparency of 3D volume: 0.096
Drill cavity update toggle: ☑
Drill cavity update status: 21%
Drill cavity transparency 0
Update speed (ms): 115

Hilan 2.3 mm DIAMOND
Tip Extension:
Toggle feedback instrument radius ☑
Distances to anatomical structures:

Cochlea	1.6
Meatus	3.1
Carotid Artery	3.8

Cochlea: 1.8
Set transparency of 3D volume: 0.096
Drill cavity update toggle: ☑
Drill cavity update status: 100%
Drill cavity transparency 0
Update speed (ms): 115

FIGURE 1. *The EVADE feedback interface is shown twice. The top image shows the interface under 'normal' conditions. The bottom frame shows the interface when it gives an audiovisual warning because the drill entered the protective perimeter of critical structures. Figure annotations (a–d) are displayed in white and are not part of the software. The cross designates the current position of the drill tip. The light blue shape at (a) represents the drill bit on the tip of the drill. The type and size of the drill bit can be selected at (b). The cochlea is shown in purple, the internal acoustic meatus in brown, and the carotid artery is outlined in red. The virtually drilled cavity is shown on the anatomical images in black (c). The current distances to anatomical structures are displayed in the textual information panel at (d). The bottom panel shows a moment during surgery when the distance to the cochlea is 1.8 mm from the drill bit which is below the set protective perimeter of 2.0 mm. Therefore, the system gives the surgeon a visual warning changing colors of the interface from green to red. Additionally, a text is displayed over the 3D rendering stating the name(s) of the structure(s) and the distance to this/these structure(s). Moreover, an audio warning is given at the same time.*

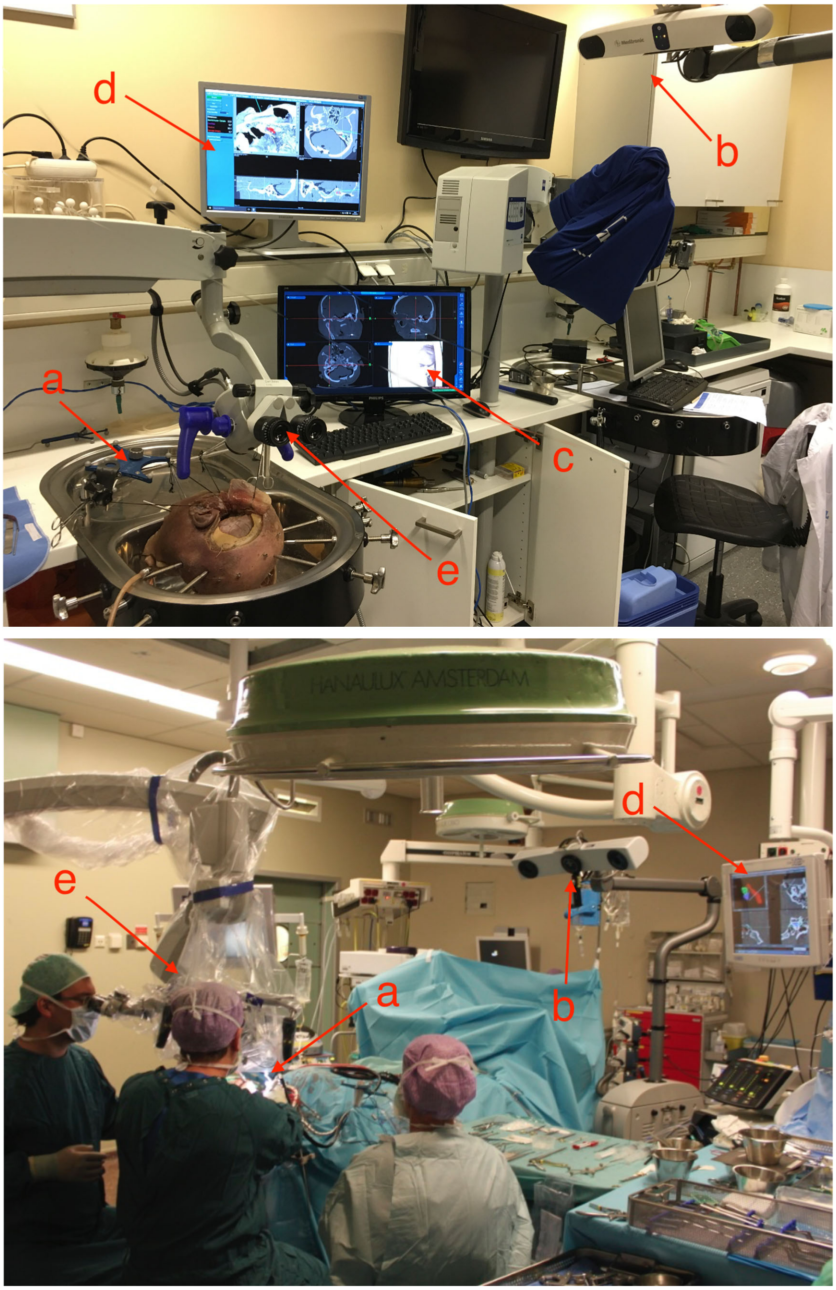


FIGURE 2. *Illustration of the experimental and clinical setup. The upper frame shows the setup in the cadaver laboratory where (a) designates the reference frame, (b) the infrared camera of the image guidance system, (c) the monitor displaying the standard image guidance interface, (d) the monitor displaying the EVADE feedback software, (e) the prepared cadaver head (start of the experiment), and (f) the operating microscope. The lower frame shows the setup in the operating room where (a) designates the reference frame, (b) the infrared camera of the image guidance system, (c) the drill with attached SureTrak frame, (d) the monitor displaying the EVADE feedback software, and (e) the operating microscope.*

did not receive any financial or material compensation for participating in this study. A sixth separate skull base surgeon, and author of this manuscript, (L.R.) performed the clinical AP.

Instructions and Task

All surgeons were introduced to the feedback functions of the EVADE image guidance software module via a standardized presentation before the start of the experiment. The presentation instructed the surgeons about the experimental task. Their task was to make the largest possible bony exposure through the petrous apex, drilling as close as possible to the cochlea and meatus without injuring these structures. Surgeons were free to expand their exposures laterally. However, they were instructed to maintain the same kind of expansion for both approaches (on both sides). Moreover, surgeons were allowed to vary the protective perimeter value during the experiment. Completion of the task was defined as follows: the experiment ended when the surgeon believed that no more bone in the petrous apex could be drilled without injuring the cochlea or meatus.

Trial Protocol

Ten AP approaches were performed by 5 different skull base surgeons. Each surgeon performed 2 approaches on the same cadaver head on the same day. The first approach was performed using EVADE image guidance and standard image guidance and the second approach using standard image guidance. The anatomical side of the first approach (right or left) was decided by coin-toss. Two researchers (E.V. and S.D./H.C.) were present during the experiments. Two digital stopwatches were used to measure the total operating time and the drill-on time. When the experiment finished, both researchers assessed drill cavities for iatrogenic damage to the meatus and cochlea. In addition, standardized questionnaires in which surgeons evaluated the presented feedback methods were obtained from the participants.

Hardware and Software

The hardware and software setup utilized in this study are described in detail in Voormolen et al 2018.[15] With this setup, the position update speed of EVADE's image guidance system varies between 6 to 15 Hz.

AP Trial Outcome Measure Definitions

Postoperatively, the cadaver heads were rescanned using high resolution temporal bone CT. Subsequently, the postoperatively acquired temporal bone scans were registered to the corresponding preoperative temporal bone scans. The drilled cavities were then delineated semiautomatically by an inhouse algorithm developed and validated (data not shown) for this purpose. The relevant anatomical structures, being the cochlea, the internal acoustic meatus, the carotid artery, and the semicircular canals were delineated manually slice-by-slice on axial scans, and subsequently checked in 3 orthogonal directions and through 3-dimensional (3D) rendering. The drill cavity and anatomical structure segmentations were converted to 3D surface meshes without loss of resolution. For each of the 10 approaches performed, the minimal unsigned Euclidian point-to-point distances between the meshes of the postoperative cavities and the anatomical structures were calculated. Furthermore, an axial maximum intensity projection (MIP) image, projecting the drill cavities and the segmented critical structures along the Z-direction, was computed for each AP. In each MIP image, the area between the cochlea, meatus, and drill cavity was calculated. This measure was called 'underused area'. We assume that a smaller underused area reflects a better surgical approach, because it means that more petrous bone has been removed close to the cochlea and meatus, thereby creating a larger exposure to the petroclival area. Figure 3 shows an example of how the underused area was calculated.

The following outcome measures were acquired to assess surgical performance: total operating time, drill-on time, drill speed, cavity volume, iatrogenic damage to the cochlea/meatus, minimum and mean distance to cochlea/meatus, underused area, and standardized questionnaires.

Total operating time is defined as the time taken from the first moment the surgeons looked through the microscope until the time the surgeon completed the task. Drill-on time is defined as the time the drill was used to drill bone during the experiment. Drill speed is defined as the drill-on time divided by the drill cavity volume. Iatrogenic damage to the cochlea was defined as compromise of the structural integrity of the cochlea visible under the microscope and/or on the postoperative CT-scan. Iatrogenic damage to the meatus was defined as unintentional opening of the dura of the meatus with the drill visible under the microscope. Statistical analysis was conducted with student's t-tests.

Questionnaires

Standardized paper-and-pencil questionnaires were administered directly after experiments ended. A questionnaire contained 5 questions, and required answers to be given on a 5-point scale. The surgeons received instructions about the meaning of the scale.

Accuracy of Virtual Drilling

Over- and underestimation errors of the virtual drill cavities were assessed as compared with real postoperative drill cavities. Mean and signed maximum Euclidian surface-to-surface distances between both cavities were calculated. Virtual drilling error results from these surface-to-surface distances. A distance of zero, means there is perfect overlap between cavities. If the distance is nonzero, the virtual cavity was either underestimated or overestimated by EVADE compared. Per approach, we calculated the mean distance, standard deviation, maximum overestimation error, and maximum underestimation error.

Clinical Case

AP was performed in the operating room. Patient consent and ethics approval from the hospital's medical review board to conduct this study was obtained.

RESULTS

AP Trial Results

Three right-sided APs and 2 left-sided APs were performed with EVADE. Vice versa for the control group. The total time needed to complete the AP task was on average 7 min longer (on a total of 74 min) in the group using EVADE compared with the control group ($P = .69$). The drill-on time, the drill cavity volumes, and the drill speed were similar in both groups. Surgeons using EVADE approached the cochlea on average 1 mm closer, as average minimum distances were 1.1 ± 0.7 mm in the feedback group compared with 2.2 ± 1.4 mm in the control group ($P = .19$). The meatus was approached on average 0.8 mm closer in the group using EVADE (minimum distances of 0.2 ± 0.4 mm vs 1.0 ± 1.2 mm $P = .21$). The data for the carotid

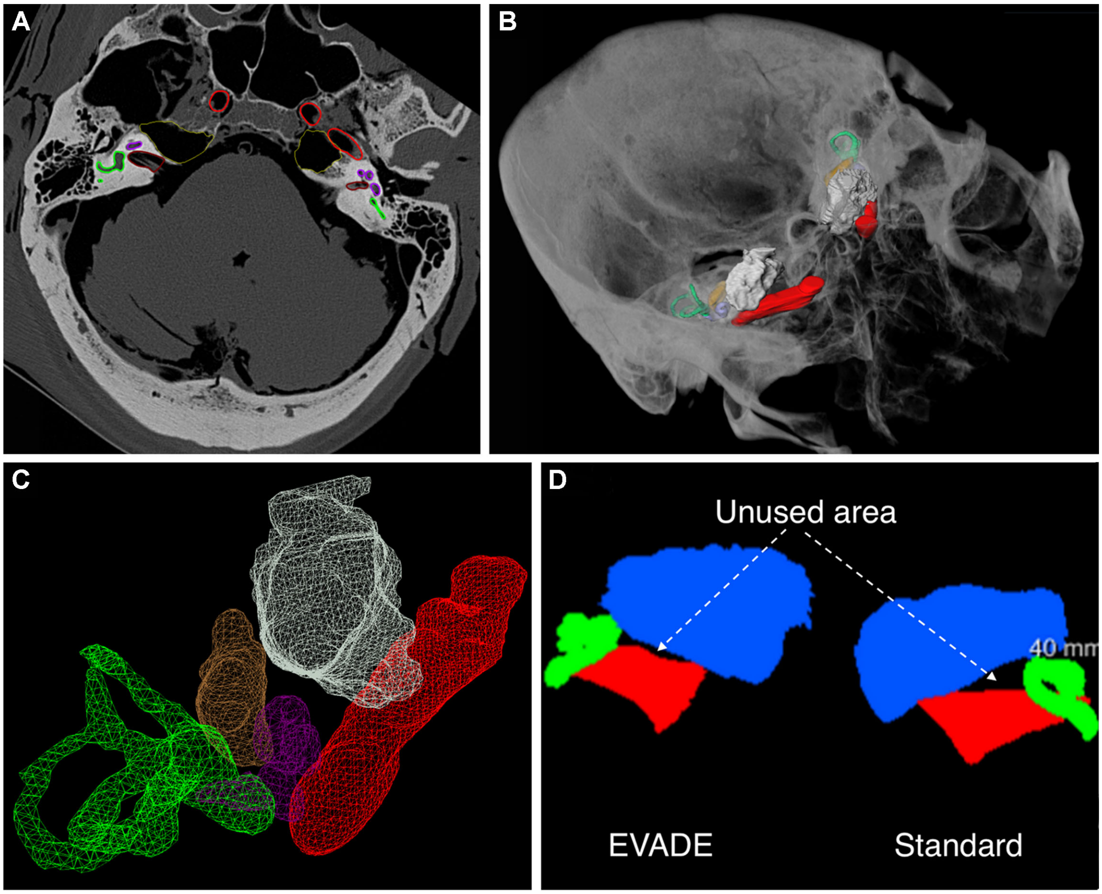


FIGURE 3. *Illustration of data analysis for the AP trial.* **A** *shows an axial image of a registered temporal bone CT-scan in which anatomical structures were outlined by manual segmentation; red = carotid artery, purple = cochlea, brown = internal acoustic meatus, and green = semicircular canals. Additionally, the 2 yellow outlines represent the left and right postoperative cavities segmented semiautomatically.* **B** *is a 3D rendering showing a translucent temporal bone in which the structures and the drill cavities (in grey) described above are shown.* **C** *shows an image zoomed in on the right side of the temporal bone to illustrate the 3D surface meshes of the drill cavity (in grey) and the anatomical structures (same color definitions as in B), which were generated to measure Euclidian distances.* **D** *shows the result of one of the maximum intensity projections along the Z-axis. The drill cavity is shown in blue, the cochlea in green, and the internal acoustic meatus in red. The 'unused area' is the designated black space between the structures.*

artery and semicircular canals were calculated but are not reported here, because they were similar between groups. The 'underused area' (see Methods: AP Trial Outcome Measure Definitions) was 0.1 ± 0.1 mm^2 in the EVADE group and 0.9 ± 1.2 mm^2 in the control group ($P = .22$). The basal turn of the cochlea was inadvertently opened by the drill on 1 occasion in the control group. The cochlea and meatus were not injured in the feedback group. See Table 1 for a group-wise comparison of outcome measures.

Surgeons rated EVADE feedback as very safe (4.6/5). They rated the usefulness of the module's visual feedback in locating anatomical structures as average (3.2/5), and the audio distance feedback as excellent (5.0/5). Surgeons rated their intraoperative anatomical orientation statistically significantly better with the feedback system as compared to standard image guidance (4.6/5 vs 3.4/5 $P = .03$). See Table 2 for detailed results of the questionnaire.

Accuracy of Virtual Drilling

Virtual drilling errors were calculated in 5 anterior petrosectomies (see Methods). The average mean error in the virtual cavities was 0.2 ± 0.1 mm. Average maximum over- and underestimation errors were 3.0 ± 0.6 and 2.2 ± 0.2 mm, respectively.

TABLE 1. Outcomes of the Standardized Questionnaires Reported Per Skull Base Surgeon

						Anatomical orientation	
Surgeon#	**Setting**	**Safety**	**Visual feedback**	**Audio feedback**	**Use clinically?**	**EVADE**	**Standard**
1	Laboratory	5	3	5	1(Yes)	5	5
2	Laboratory	5	2	5	1(Yes)	5	3
3	Laboratory	4	4	5	1(Yes)	4	3
4	Laboratory	4	3	5	1(Yes)	4	3
5	Laboratory	5	4	5	1(Yes)	5	3
6	Clinical	5	3	5	–	–	–
AVERAGE		4.7	3.2	5	5/5	4.6[a]	3.4[a]

Setting: 'Laboratory' if the surgeon performed simulated APs on a cadaver head in the laboratory, 'Clinical' if the surgeon performed AP on a patient in the operating room.
Safety: Answer to the question – How safe do you think EVADE is? (very safe: 5; not safe at all: 1).
Visual Feedback: Answer to the question – How well does EVADE's virtual drilling feedback help you to locate important anatomical structures? (a lot: 5; not at all: 1).
Audio Feedback: Answer to the question – How well does EVADE's distance control feedback help you to locate important anatomical structures? (a lot: 5; not at all: 1).
Use Clinically?: Answer to the question – Would you use EVADE to perform an AP on a clinical case? (yes: 1; no: 0).
EVADE: Answer to the question – How was your anatomical orientation during the AP performed with EVADE? (very good: 5; very bad: 1).
Standard: Answer to the question – How was your anatomical orientation during the AP performed with standard image guidance? (very good: 5; very bad: 1).
[a] Statistically significant difference between EVADE feedback and standard image guidance ($P = .03$).

TABLE 2. Outcomes of the AP Trial[a]

Outcome measure	EVADE	Standard	*P* value
Total time (hr:min)	01:17 ± 00:22	01:10 ± 00:27	.69
Petrous bone volume (cc)	5.1 ± 1.24	5.3 ± 1.6	.85
Drill time (hr:min)	00:21: ± 00:05	00:21: ± 00:04	.83
Drill speed (cc/min)	0.08 ± 0.03	0.07 ± 0.02	.58
Total cavity volume (cc)	1.51 ± 0.49	1.47 ± 0.62	.92
Underused area (mm^2)	0.1 ± 0.1	0.9 ± 1.2	.22
Cochlea			
Injured	0/5	1/5	–
Minimal distance (mm)	1.1 ± 0.7	2.2 ± 1.36	.19
Meatus			
Injured	0/5	0/5	–
Minimal distance (mm)	0.2 ± 0.4	1.0 ± 1.2	.21

[a] See the Methods section for definitions.

Clinical Feasibility

A 36-yr-old woman presented with dysarthria, an ataxic gait, and intermittent diplopia on the basis of a left-sided petroclival meningeoma. She underwent a gross total resection (Simpson grade II) via an AP. Setup of the feedback system hardware in the operating room required 23 min of additional time. Figure 2 illustrates the clinical setup. The software functioned properly during surgery; the surgeon could hear and see the audiovisual feedback given by the system. The protective perimeter was initially set to 3.0 mm and subsequently adjusted by the surgeon to 2.0 mm intraoperatively for the cochlea, internal acoustic meatus, and carotid artery structures. The surgeon reported that the provided audiovisual feedback helped to improve his surgical orientation (see Table 2). Anatomical structures receiving distance control were not injured during this case.

DISCUSSION

We evaluated the first-time use impact of an image guided feedback implementation combining distance control and virtual drilling feedback. As we hypothesized, our results demonstrate that this type of feedback improves skull base surgeons' anatomical orientation. Additionally, we are the first group to show that image guidance feedback might boost surgical performance of skull base surgeons by allowing them to 'optimize' their drill cavity. This is reflected by the fact that the cochlea and meatus were approached closer on average without being damaged, and the fact that the 'underused area' was consistently smaller in the feedback group compared with the control group. However, it is beyond this manuscript to demonstrate that these differences have clinical consequences.

Our other hypothesis was that usage of feedback reduces the risk of harming the cochlea. The cochlea was unintentionally injured on 1 occasion in the control group of this trial. This amounts to an incidence of 10%, which is a statistic that corresponds to the incidence reported in the literature.[7]

Trial surgeons evaluated audio distance control feedback as more useful than visual virtual drilling feedback. This might be explained by the fact that distance control is a form of 'proactive' feedback. Surgeons do not have to remember, or take action in order to get the information. Moreover, it allows surgeons to employ 2 senses simultaneously to acquire insight into the anatomy of the patient: hearing of specific sound signals when moving the drill, combined with visuals from the surgical field.

The cadaver setup of this research provided the advantage to minimize bias in ways that would be difficult to achieve in a clinical setting. For example, assuming left and right symmetry in the human head, bias due to anatomical variations between the control and intervention group was minimized. Moreover, memory bias in favor of EVADE was eliminated, since each trial surgeon always performed the first AP of the experiment with EVADE and afterwards with standard image guidance. In fact, our results are probably biased towards favoring the control group.

Previously, we found that the maximum 'intrinsic' target registration error of current image guidance systems is approximately 3.0 mm when using a navigated drill.[17] Note that the EVADE method was designed to neutralize these spatial errors peroperatively through distance control. Furthermore, we have demonstrated that virtual drilling during lateral temporal bone approaches had maximum errors ranging between 2.5 and 3.6 mm.[15] Therefore, the accuracy results presented here, support our hypothesis that errors do not depend on the type of approach, but rather reflect intrinsic spatial errors of the image guidance system. Note that these virtual drilling errors are unrelated to the reported AP trial results (eg, proximity of the drill cavity to the cochlea), since they were calculated with different methods (see Methods section).

Limitations

One of the limitations of this study is a small population size. A statistically appropriately powered sample size would require 146 APs, which amounts to using 73 cadaver heads (assuming group 1 incidence 10%; group 2 incidence 0%; alpha 0.05; power 0.8). Unfortunately, it was not feasible to obtain this number of cadaver heads within acceptable time frames, given the paucity of cadavers at our institutions. Therefore, we stopped data collection at the point we found trends toward effect, to prevent 'waste' of cadaver heads.

Our study has several other limitations. First, because of its cadaver and laboratory setting, it is impossible to extrapolate trial results to the clinical situation, although we do demonstrate clinical practicability of the feedback system for AP. Second, our results might be biased by the fact that all trial surgeons were right-handed. Third, it is important to emphasize that the results reported here, apply only in case of accurate delineation of anatomical structures, and meticulously performed patient-image registration with bone anchored fiducial markers on high resolution images with high geometric conformity.

CONCLUSION

In a population of experienced skull base surgeons, first-time usage of virtual drilling and drill distance control feedback, during image-guided petrous apex drilling, improves anatomical orientation in a laboratory setting. Furthermore, this study shows that during AP, errors in virtual drilling reflect the intrinsic spatial errors of an image guidance system. The presented image guidance feedback setup is clinically practicable.

Disclosures

This work was funded by a MD/PhD grant obtained by the main author (E.V.) from the government of the Netherlands, department ZonMW. A materials grant supporting this research project was obtained from Medtronic Surgical Navigation Inc, Boulder, Colorado. A personal grant supporting the main author (E.V.) was received by the Dutch 'stophersentumoren.nl' nonprofit foundation (www.stophersentumoren.nl).

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Acknowledgments

First and foremost, we express our thanks to the skull base surgeons who volunteered to participate in our research. Furthermore, we kindly acknowledge Prof. Dr Ronald Bleys from the department of anatomy for providing the cadaver heads necessary to complete this research. We also like to thank Glenn Bronkers and Saskia Redegeld for their help in setting up the experiments in our cadaver lab. Additionally, we acknowledge Rick Mansvelt Beck, André van Dieren, Sander van Thoor, Harry Teirlinck, and Claartje Beks-Ypma from the Brain Technology Institute for their technical assistance and advice.

COMMENTS

The authors have developed a system (EVADE) that might improve the ongoing advances in navigated surgery. Of particular importance in this study is the ability of the surgeon to preset certain structures or regions as "no fly" zones. The system can then alert the surgeon with an auditory warning if these regions are approximated with a surgical drill. Such a setup could lessen the need for the surgeon to stop operating in order to review a navigational screen. The surgeon can then focus on the drilling unless the alarm is heard.

My one critique of the system is that its ability to warn of nearby critical structures will be only as good as the accuracy of the navigational system. While the authors suggest a 1 mm improvement in some of the results (cadaveric specimens), I often find the suggested error in navigation at 2–3 mm. Further, the accuracy at a particular area may be worse in some regions. However, the system can be adjusted to warn at a greater distance from the structure so as to offset the navigational error.

EVADE appears to offer an additional layer of safety for drilling without being overly cumbersome or time consuming. I believe the system offers promising improvements but as with so many technical advances, the implementation will ultimately need to be coupled with surgeon experience.

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The authors present a novel concept (the EVADE image guidance software module) which uses the surgical drill adapted as a navigation tool enabling the navigation system to provide visual and audio warnings if drilling is too close to an anatomical structure such as the cochlea contoured on the preoperative image. This is a useful technique that could improve the safety of a surgical procedure in much the same way that contemporary automobiles provide warnings to a driver to enhance safety, and in a similar fashion in which electrophysiological monitoring can notify the surgeon when they are in close proximity to an important structure such as the facial nerve. The system has adjustable settings so that the surgeon may fine tune the sensitivity of the device to provide useful but not overly distracting information. The system was tested in cadaveric dissections by 5 experienced skull base surgeons who performed 2 dissections, 1 with and 1 without the EVADE system, to assess its impact upon their technique. This is a very attractive methodology, and further testing on a larger scale as it moves into surgical practice would be appropriate to ascertain the utility and safety of this methodology. Confirmation of the accuracy and reproducibility is needed before implementation and acceptance in surgical practice is achieved. The study utilized highly experienced surgeons, and it would be of similar interest to see how this methodology would impact the technique of less experienced surgeons as well.

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