

Clinical Application of a New Dental Reference System for Computer Assisted Surgery at the Lateral Skull Base

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Abstract: *Objective:* The safest method for a reliable registration on the lateral skull base is the placement of fiducial markers into the patient's bone by screws. An alternative method is the use of a resin splint that is fixated to the maxillary dentition, which carries the fiducial markers. Then the invasive fixation using bone screws becomes unnecessary. The aim of this study was to evaluate the accuracy of a new dental reference array (DRA).

Methods: The DRA was initially tested in laboratory settings and was then applied to ten patients with surgery on the lateral skull base. An individual formed maxillary dental splint was created out of polymethylmethacrylate. The Vector Vision compact® (BrainLAB, Germany) navigation system measured the deviation on several target markers at the lateral skull base in one phantom trial, one cadaver skull and ten patients.

Results: The DRA was perfectly adjusted to the phantom. The average deviation was only 0.5mm. The average deviation on four different target markers in the cadaver trial was 0.6 mm. In five patients the accuracy was acceptable (<1.2mm). But in the other five cases the deviation was more than 10mm due to different problems which were analysed carefully.

Discussion: The DRA could resolve the problem of invasive marker fixation with little additional effort and cost. However, the successful use depends on the individually formed dental splint, which has to be perfectly adjusted to the maxilla, because the additional weight of the extraoral part acts as a lever and may dislocate. It is essential that the splint does not cant; the reference extension must not graze the skin of the patient; during surgery no coverage should pull on the DRA, otherwise the repositioning is not accurate. When avoiding all this, the accuracy of the dental reference array is sufficient for image-guided surgery of the lateral skull base.

Keywords: Dental, reference, cas, lateral skull base, registration, auricle, ear, navigation, splint, maxilla.

INTRODUCTION

Image-guided surgery using frameless stereotaxy is based on high resolution volume data of the patient. Surgery of the lateral skull base is predominantly computed tomography (CT) image data. A necessary prerequisite for safe navigation is the accurate registration of the patient's preoperative image data to the intraoperative reality.

For paranasal surgery a surface matching by laser or pointer proved suitable in the last decade [1, 2]. However, on the lateral skull base, the hairy skin surface, lack of bony anatomical landmarks and the soft auricle, leads the skin surface matching method to unacceptable deviations [3]. In this region fiducial marker registration provides a better level of accuracy, although fiducial marker registration based on anatomic landmarks is not accurate [4].

Markers must be attached to the patient's body before image data acquisition. In registration, the image data is matched to the patient intraoperatively by locating the fiducial markers on the patient's body. The safest method for a reliable registration is the placement of fiducial markers into the patient's bone by screws, as this prevents dislocation, which can occur in soft tissue mounted fiducials [5]. The use of titanium screws drilled into the skull is a common method [6].

An alternative method to fiducial marker placement in head surgery is the use of a resin splint that can be fixed to the maxillary dentition, and which carries the fiducial markers (Fig. 1). Intraoperatively, it is used to attach the reference frame for the navigation system. As a result, invasive fixation using bone screws becomes unnecessary. The concept has proven its accuracy for intraoral interventions, such as the navigated placement of dental implants [7, 8].

The aim of this study was to evaluate the accuracy of our modified dental reference array (DRA) on the lateral skull base.

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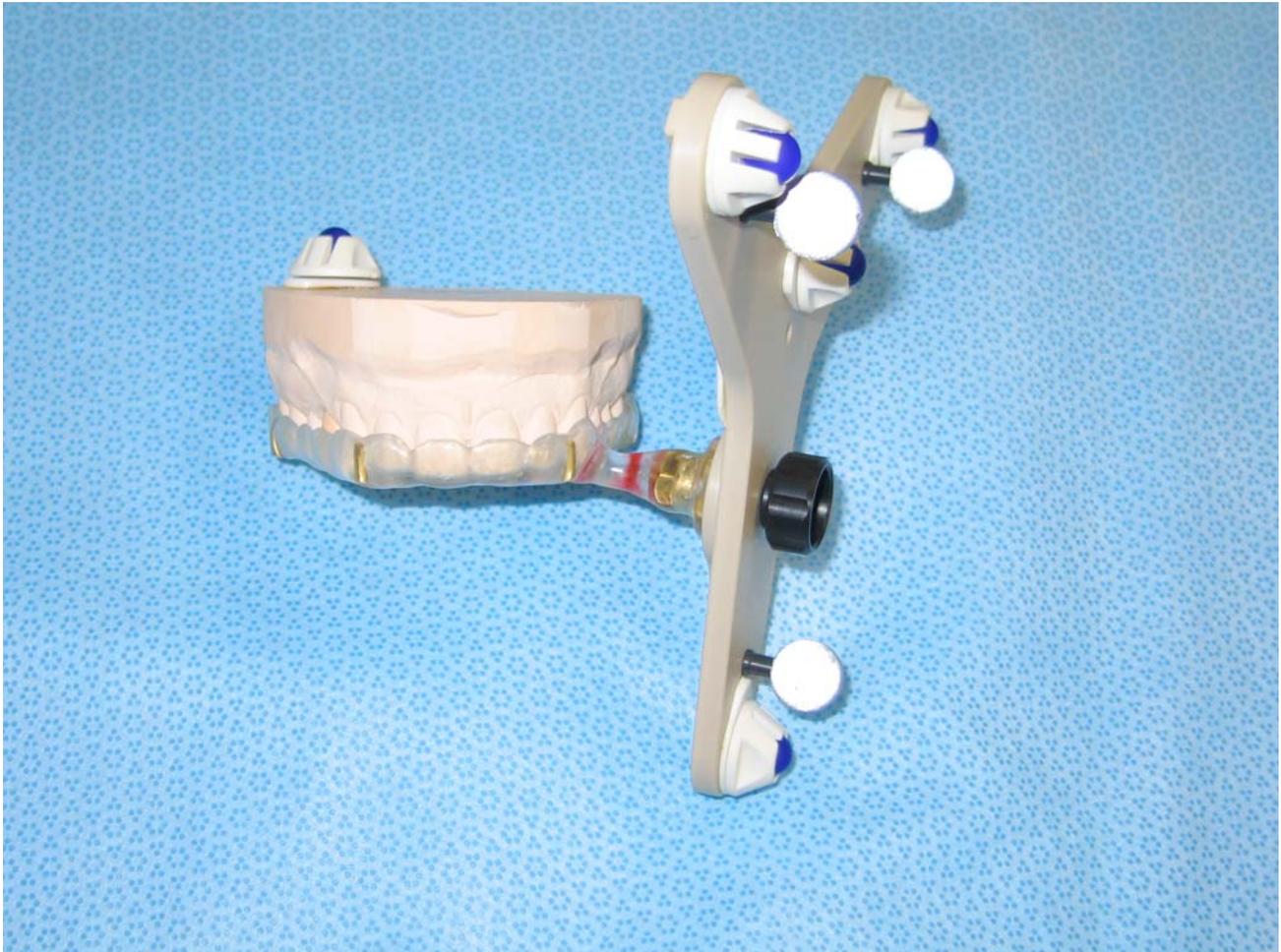


Fig. (1). Dental reference array with the fiducial markers and the passive reflection balls for the navigation system. An additional fiducial served as target marker on the maxilla of the phantom.

MATERIAL AND METHODS

For this study the Vector Vision compact® (BrainLAB, Germany) navigation system was used with the ENT 7.8 software update. The DRA was initially used in cadaver- and phantom-based targeting trials. Due to the encouraging laboratory results it was then applied to ten patients.

After taking impressions of both jaws and a registration of the maximal intercuspitation, an individual formed maxillary dental splint was created out of Polymethylmethacrylate (PMMA, Ortocryl®, Dentaurem J. P. Winkelstroeter KG, Germany) in the Department of Prosthodontics, LMU, Munich. A three-dimensional reference body with six fiducial markers and three passive reflecting balls was made out of polyethylene allowing an undisturbed CT-Scan (Fig. 1).

After the registration of the six fiducial markers, the plastic reference body was changed to a sterile aluminium reference star leaving only the three passive reflecting balls for the navigation system. During the phantom and cadaver-based trials the reference array was fixated on a PMMA pedicle of the left side, i.e. left mouth ankle. In the clinical application the reference body was fixated on the side of the operated ear. It is crucial that the DRA is fixated rigid to the maxilla. Therefore the used cadaver and all tested patients had to have stable teeth.

The preoperative imaging was performed on a spiral CT-Scan (Somatom Sensation 64, Siemens, Germany) in 1mm axial reconstruction. Accuracy was then measured as deviation from the real pointer position in situ to the indicated pointer position of the navigation system. The deviation was measured in all three levels, i.e. coronar, sagittal, axial, and the worst value was taken. For achieving valid and exact results corresponding target points had to be defined in the following:

- In the phantom an additional fiducial marker was fixated on the maxilla (Fig. 2).
- In the cadaver skull four titanium screws were fixated in different places in the lateral skull base (Fig. 3).
- The patients' clear anatomical landmarks like the tragus, the centre of the ear drum, the ossicle (stapes or umbo) and the promontorium were targeted (Fig. 4).
- In the PMMA splint of the phantom and cadaver several tiny titanium pins of a defined length were embedded (Fig. 5). These pins were additional target markers for the confirmation of a valid registration, although they were not placed in the region of interest (the lateral skull base). The phantom and the cadaver were registered ten times by the navigation system.

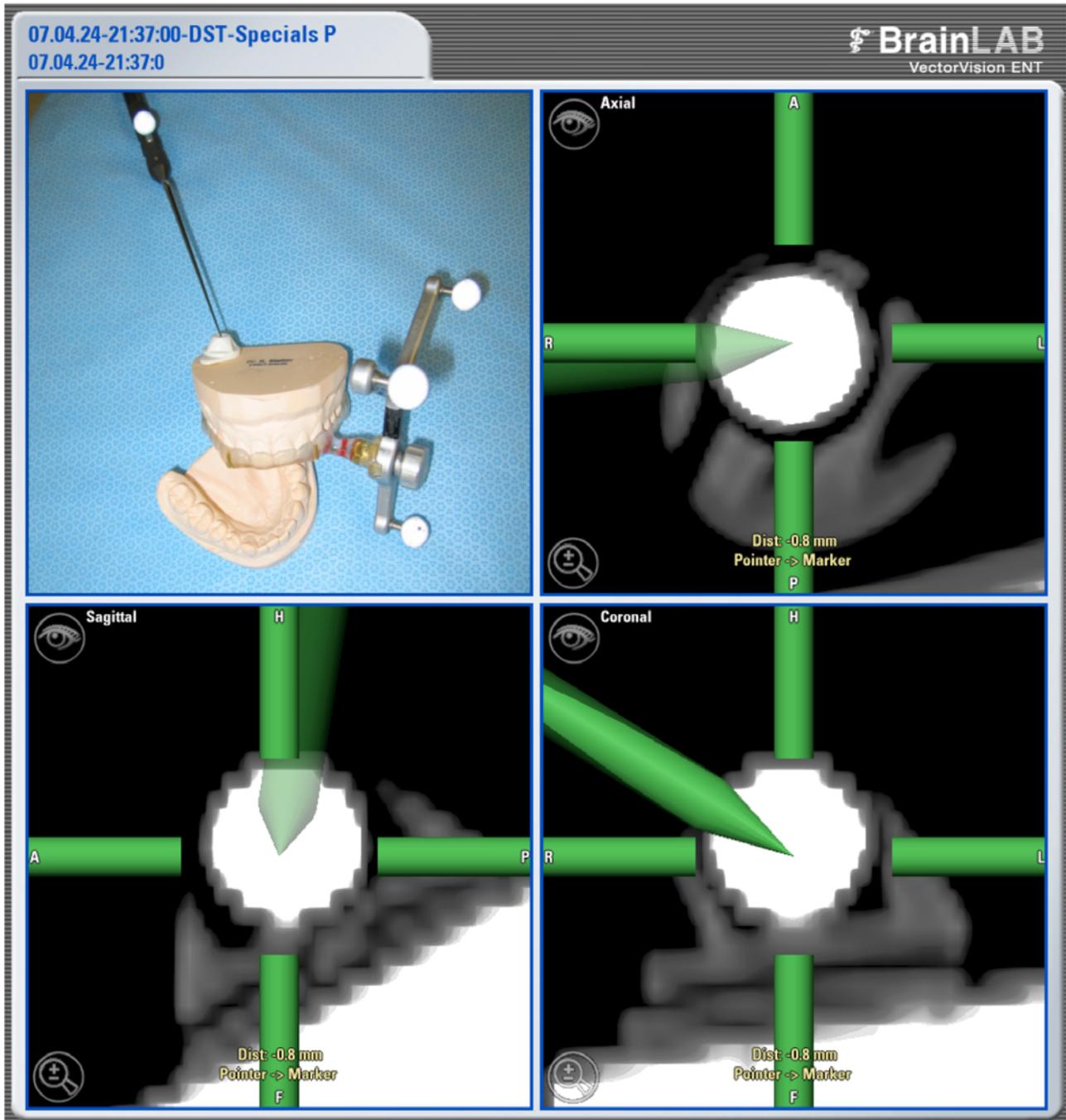


Fig. (2). Screenshot of the phantom trial. The target marker is touched with the pointer; the tip deviation is 0.8mm in all dimensions.

After each registration the navigation system was rebooted, the DRA was replaced on the maxilla and deviation of all target markers was measured again.

After approval from the local ethic committee, ten patients with indications for surgery and CT-Scans of the ear were selected for the clinical application of the DRA. In all patients surgery could be performed without navigation and the patients were informed that the method has not been established yet. The indications for surgery and the diseases respectively are listed in Table 1.

RESULTS

The DRA could be perfectly adjusted to the phantom. The average deviation in ten measurements was only 0.5 mm (standard deviation 0.2 mm) with no outlier. The titanium pins in the dental splint had the same accuracy.

Adjusting the DRA to the cadaver was more complicated because the cadaver skull had only eight teeth (Fig. 5). However, the average deviation of all four screws after ten measurements was 0.6 mm (standard deviation 0.24 mm). The deviation worsened after implanting the DRA for the seventh

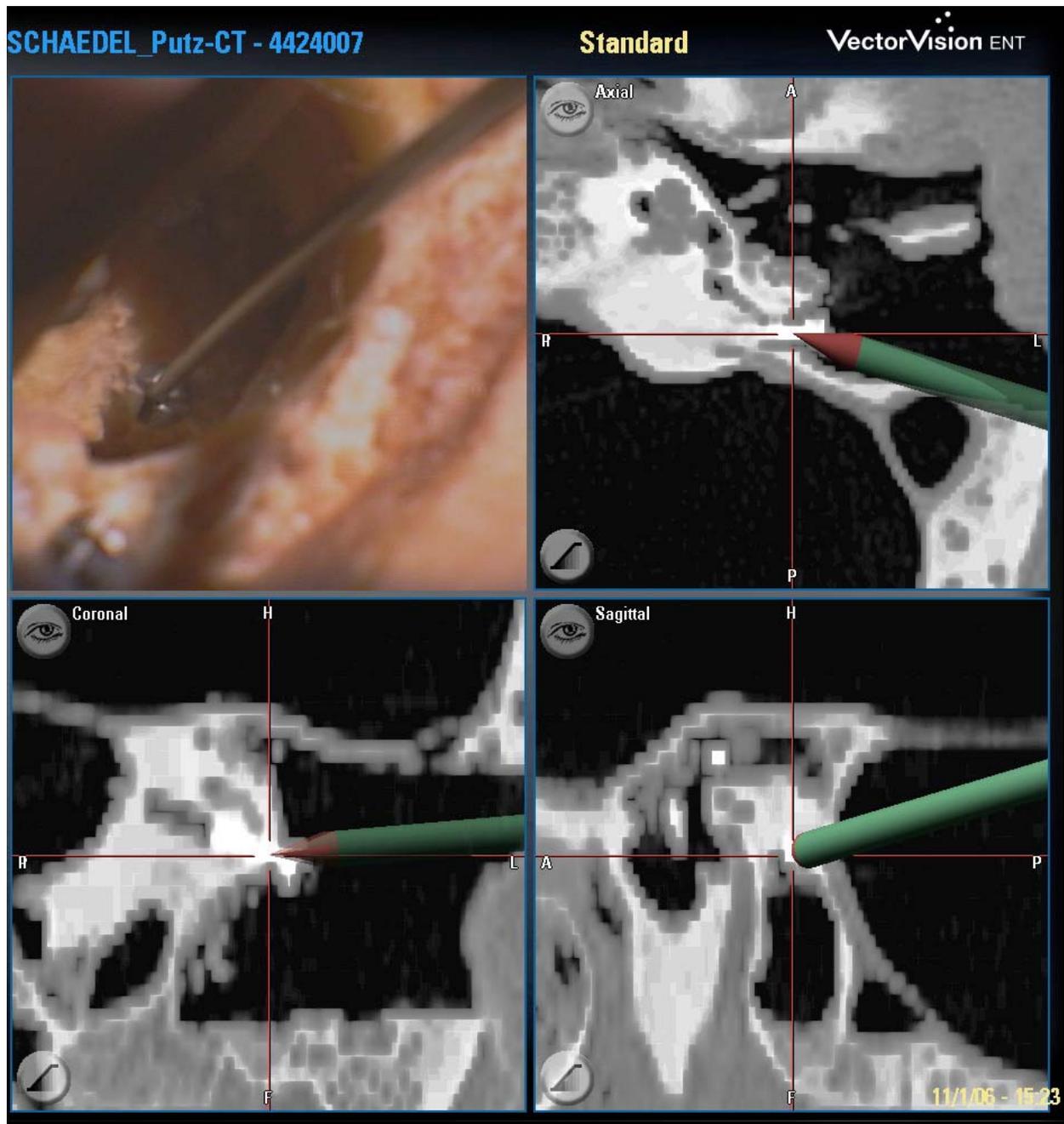


Fig. (3). Screenshot in zoom mode (600%) of cadaver measurement. The titanium screw in the mastoidal bone (target marker) is touched with the pointer. The red tip of the pointer indicates 1mm. The tip deviation is less than 1mm on all sides.

time on the remaining eight teeth. There was no significant difference between the particular screws (Table 2).

The measured accuracy in the ten patients was wide spread. Exact values in Millimetres were difficult to object intraoperatively due to the absence of definite target markers. The measured anatomical landmarks, such as the promontorium, the ear drum, the tragus or the outer auditory canal, are not precise enough for statistically expressive results. The method of measurement of clinical accuracy can never be as exact as in laboratory settings. Table 1 shows the results of accuracy during surgery. For exact operations in this area the deviation must be less than 1mm. In five patients (50%) the accuracy was acceptable. But in the other five cases the

deviation was more than 10mm or could not be objected. Several problems could be identified in the group of high deviation:

- The straight pointer was too long for the space between the microscope and the patient's ear. Therefore, the following patients were navigated with curved needles or short suction tubes (Fig. 6).
- The polyethylene reference body was wedged on the dental splint in the CT-Scan, so the same position of the reference body during the operation could not be restored, which led to an unacceptable high deviation.

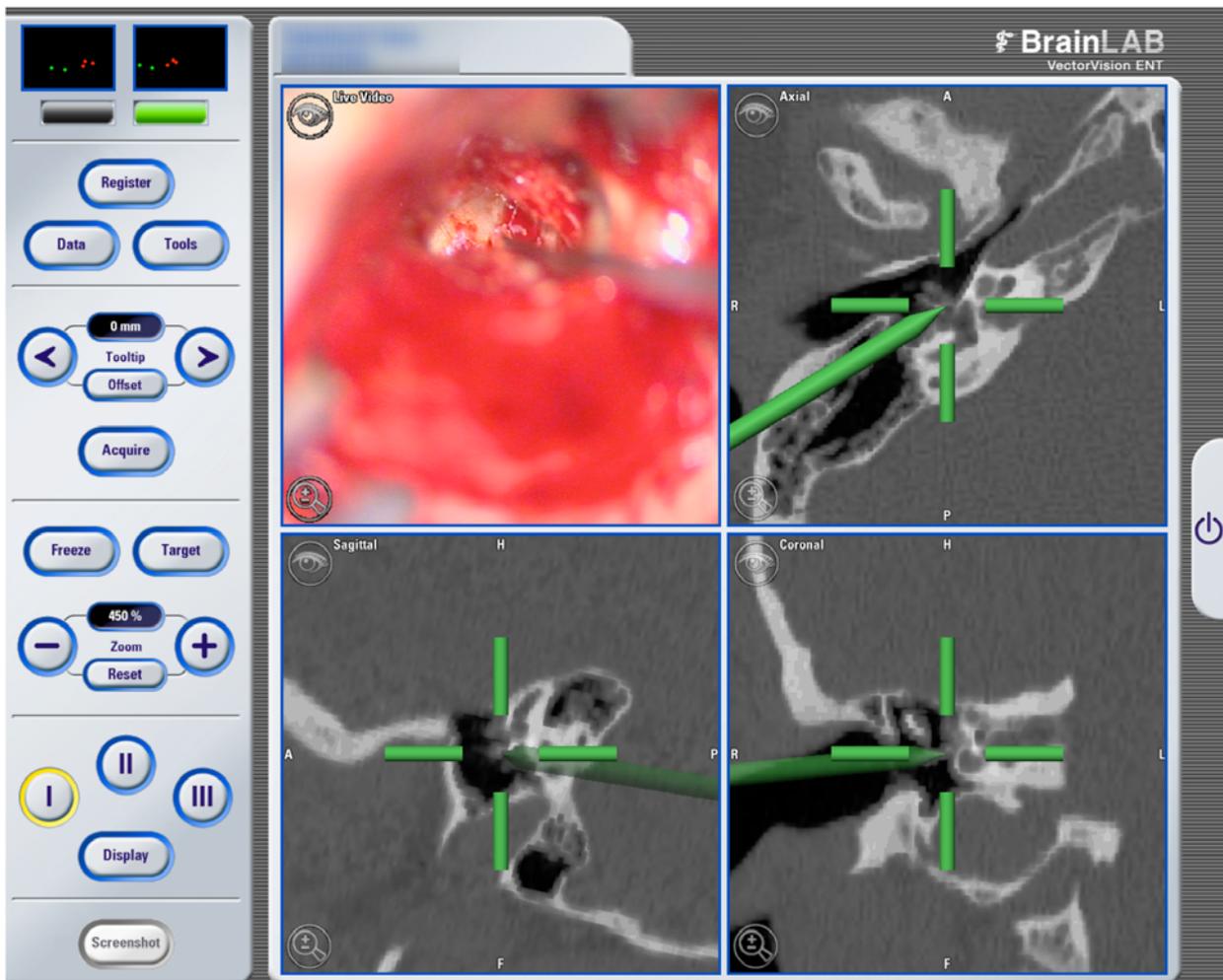


Fig. (4). Intraoperative screenshot of a revision stapedectomy. The curved needle is gently placed on the stapes head (target marker). The tip of the needle was registered by the navigation system before; it shows no relevant deviation.

- The sterile covers of the patient's face pulled on the pedicle of the DRA; this changed the initial position of the reference star.
- The reference array touched the patient's cheek during the CT-Scan. Intraoperatively the patient's skin is covered with sterile sheets; this lifted the position of the reference array.
- The dental splint was too loose due to multiple insertions over ten month in revision surgery of a cholesteatoma.

DISCUSSION

The gold standard registration method in image-guided surgery of the lateral skull base is fiducial marker registration [9]. It is the most accurate method, but depends on the absence of changes in fiducial marker positions between preoperative imaging and intraoperative registration. Therefore this registration is normally based on invasively fixed fiducial markers (e.g., bone screws). Furthermore, for intraoperative navigation, a dynamic reference frame has to be attached rigidly to the patient's head, enabling the navigation system to track changes in the position of the head. Here, as well, the safest method is the invasive attachment using bone screws or Mayfield's clamp.

As a less invasive alternative, image-guided surgery based on the registration of fiducial markers mounted on an intraoral template is already used for intraoral interventions. Unfortunately, the intraoral fiducial marker registration does not provide acceptable results for operations of the lateral skull base, because the registered region (intraoral) is too far away from the surgical region (ear) and accuracy depends heavily on the distance of the target marker from the registration site [6]. Therefore the fiducial markers have to be closer to the region of interest. Hence, various systems based on a maxillary template have been proposed.

Howard *et al.* created in 1995 an extraoral, bilateral extension with bearings for fiducial markers with acceptable results of repositioning accuracy [7]. A problem with this concept is the large bilateral extension which makes it impossible to lay the patient's head on one side for surgery.

The system developed by Fenlon *et al.* is conceived as a locking splint that has to be assembled from multiple, individually fabricated parts for the CT Scan and different parts for the intraoperative use [10]. Although the idea of this system relates to that of the DRA, the extraoral reference frame is bigger, bilateral and the distance of the intraoperative reference unit to the ear is wider.

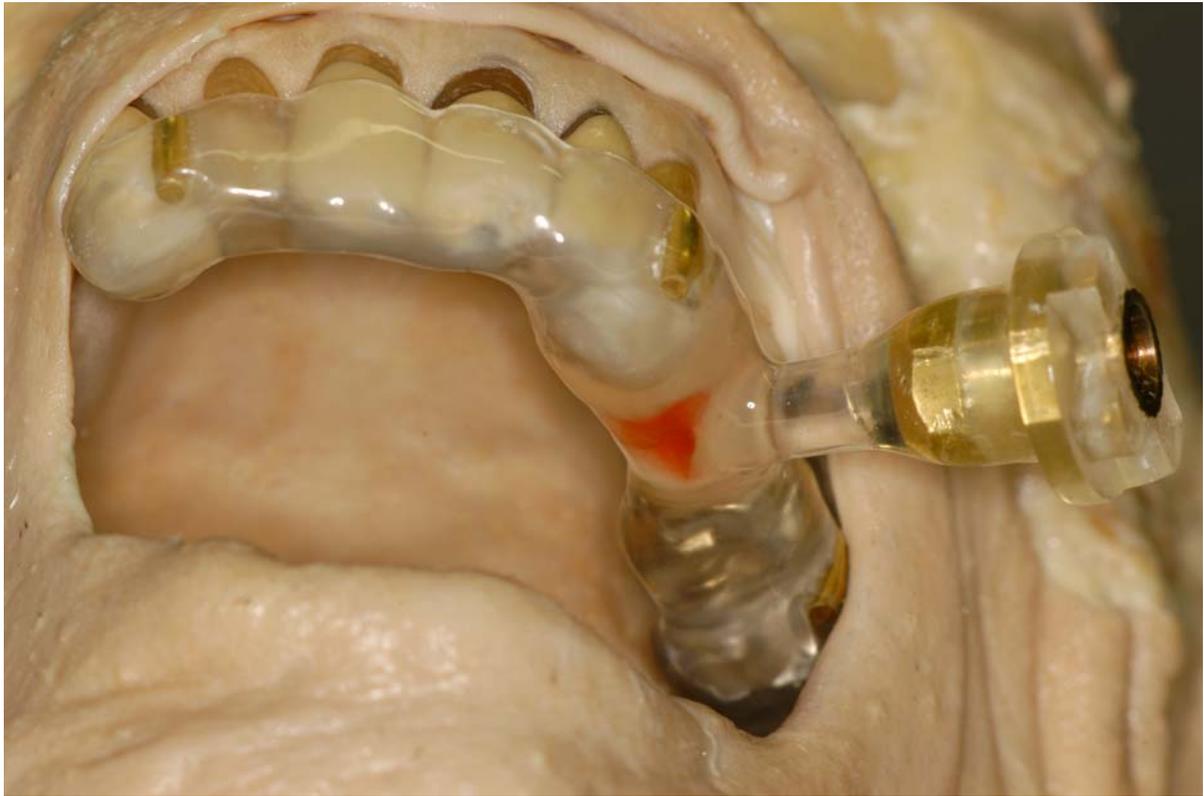


Fig. (5). DRA in the cadaver skull with only eight teeth. The remaining teeth had to be stuck. As additional target markers three titanium pins are embedded in the dental splint.

The VBH-System (named after Vogele, Bale and Hohner) uses an extraoral registration frame connected to the mouthpiece which can be removed after registration. The system needs no extraoral support but instead a vacuum pump is used to ensure that the template adheres to the maxilla [11]. However, this system does not work with every navigation system because the registration requires particular software. Other systems were provided with additional supports for the nasion or the external auditory canal [12]. The extraoral support relying on soft tissues reduces the possibility of re-attachment. This is a known issue for nonrigid fixation of registration devices like headbands or headsets [13].

Another concept is markerless registration based on laser surface scanning. Intraoperatively, the patient's auricle is scanned using a laser surface scanner and is matched to the skin surface extracted from CT image data [3]. Simple laser based registration systems could not reach the accuracy of fiducial marker registration [14]. However, with a special laser scanner systems and more surface points recorded, Marmulla *et al.* achieved an acceptable registration accuracy [3]. An additional benefit of this solution is that, in cases where diagnostic CT imaging is already performed, there is no need for additional imaging with mounted fiducial markers. However, this new system is not commercially available,

Table 1. Indications for Surgery, Clinical Accuracy and Causes for Massive Deviations

Pat.ID	Age	Disease	Date Surg.	Clinical Accuracy	Cause of Deviation
OS	59y	Otitis media chronica	04.05.2007	not applicable	Pointer too long for microscope focus
PJ1	56y	Cholesteatoma	10.05.2007	20-30mm	DRA was wedged during CT Scan
EA1	41y	Recurrent cholesteatoma	12.06.2007	10mm on promontorium	Sterile covers pulled on DRA
JS	31y	Displaced stapes prosthesis	18.02.2008	1mm on stapes head	
OS2	60y	Recurrent otitis media chronica	28.02.2008	1mm on hammer head	
PJ2	56y	Cholesteatoma 2nd look	17.03.2008	1mm on promontorium	
HJW	42y	Cholesteatoma	02.04.2008	30-40mm	Reference array touched the skin
EA2	42y	Cholesteatoma 2nd look	09.04.2008	> 15mm	Dental splint was too loose
SR	21y	Secretory otitis media chronica	14.04.2008	1mm on tragus and ear drum	
RFP	39y	Cholesteatoma	23.04.2008	1mm on auditory canal (bone)	



Fig. (6). Intraoperative Setting: Navigation with a fine curved needle. The straight pointer is too long for the space between the microscope and surgical field.

requires additional hardware and software and would not integrate easily into present navigation systems.

Table 2. Deviation of navigated positions of target markers (Titanium Screws) in the cadaver skull. Screw 1 and 2 are placed in the mastoidal cells, Screw 3 is in the outer ear channel and screw 4 is in the Promontorium. All values are in Millimetres

Registration	Screw 1	Screw 2	Screw 3	Screw 4
1	0.6	0.7	0.5	0.6
2	0.5	0.5	0.7	0.6
3	0.6	0.8	0.6	0.5
4	0.4	0.8	0.5	0.1
5	0.3	0.7	0.4	0.3
6	0.7	0.5	0.8	0.8
7	0.4	0.4	0.5	0.2
8	0.8	0.5	0.7	0.8
9	1	0.9	0.8	0.8
10	1.1	1	1.1	0.9
Average	0.64	0.73	0.63	0.51
Standartdev.	0.26	0.16	0.22	0.28

All screws average: 0.63mm.
All screws standard deviation: 0.24mm.

The concept presented in this study resolves the problem of invasive marker fixation with an individually formed dental splint. It works with any navigation system without additional hardware (except the CT-compatible reference array) or particular registration software. The registration site is very close to the surgical field. However, the successful use depends upon several key features:

- The individually formed dental splint has to be perfectly adjusted to the maxilla, because the additional weight of the extraoral part acts as a lever and may dislocate.
- The patient must be able to reposition the dental splint (the patient should exercise this several times with the help of the dentist). The occlusion is a probable indicator for the patient, whether the splint is located correctly or not. It is essential that the splint does not cant, for as it would then be adjusted to the maxilla but not in the correct position.
- The reference extension must not graze the skin of the patient.
- During the CT-Scan the polyethylene reference array may not touch the CT-Scanner and during surgery no coverage should pull on the DRA, otherwise the repositioning is not accurate.
- When using the microscope: Calibrated smaller and shorter instruments are needed for navigation because the standard pointer may be too long and thick.

Another problem could be the extraoral scaffold, which might represent an impediment for the surgeon. In this case it is useful to implement another reference array in the skull for registration. The fiducials of the DRA would only be used for the initial marker registration. Intraoperatively the navigation system uses the passive marker reflectors of the skull reference array.

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