

## **Evaluation of Registration strategies for the application of the fiagon navigation system at the lateral skull base**

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### **Abstract**

#### **Background:**

The aim of this study was to evaluate a new navigation system (fiagon GmbH) on the lateral skull base, since prior clinical practice has been limited to the paranasal sinuses.

#### **Material and Methods:**

We performed repeated measurements and registrations on titanium screws, which were attached to specific anatomical locations on five temporal bone specimens. The focus of the investigation is to determine the Target Registration Error and in step 2 a comparison of different registration methods (titanium screws vs. surface), where the influence of surgery retractors was also observed.

#### **Results:**

Design and operation of the navigation system proved effective and easy to use on the lateral skull base. Handling proved to be uninhibited in the surgical area without consideration of line-of-sight. For a registration strategy with 3 onesided attached Fiducials the Target Registration Error is 0.8 mm on the surface of the mastoid and in the mastoid cavity regarding the titanium screws. Measurements of the titanium screws at the inner ear canal showed a mean deviation of 1.6 mm.

The smallest Target Registration Error in the comparison of different improved registration methods was found for registration on titanium screws attached on both sides of the head (Mean: 0.6 mm), followed by surface registration at the face including laterobasis (Mean: 0.9 mm) followed by registration in the mastoid cavity only (Mean: 1.0 mm) .

#### **Conclusion:**

The measured values correspond to our clinical expectations and can be used if the Target Registration Error is known and respected.

An intra-operative imaging may allow the application of titanium screws for navigation (gold standard) within the same general anesthesia during surgery or it may provide the collection of already manipulated tissue surfaces for registration. In this case respective possibilities would be provided to increase precision.

## Introduction

Clinical use of navigation systems in head-neck surgery is common in paranasal sinus surgery and on the lateral skull basis. The navigation system establishes a connection between preoperatively produced image data and the intraoperative situs and it enables the surgeon constant evaluation regarding instruments and the patient's anatomy during surgery. The clinical benefit of a navigation system depends decisively on the qualitative and quantitative properties. For a surgeon, qualitative properties constitute usability for a particular intervention, operating comfort, especially regarding importing data and registration procedure, the latency (-liberty) of the display or the sensation of how the navigation system lies inside the hand and how well it may be guided.

Quantitative properties are the Fiducial Registration Error (FRE) and Target Registration Error (TRE), as well as the navigation errors Fiducial Localization Error (FLE) and Target Localization Error (TLE)), the work volume and the purchasing and consumer mean price. The aim of this study is the evaluation of a new navigation system based on the electromagnetic principle. The focus of the investigation was to determine the Target Registration Error regarding the lateral skull base and the comparison of different registration methods (titanium screws vs. surface), as well as the influence of ferromagnetic instruments.

Electromagnetic navigation does not require visual contact between the tracked instrument and the sensor system.

Detection of the position and orientation of the surgical instruments occurs relative to the patient due to detection of the magnetic field via sensor coil. The operating mode of an electromagnetic navigation system is described in [1].

## Material and method

The navigation system (fiagon) essentially consists of a hard ware module (fig. 1), an application software, a magnetic field generator (fig. 2) and application specific sensors (fig. 3), such as a head localiser and a flexible pointer, which has sensor coils applied at the top. For registration transformation is calculated on the basis of point pairs (anatomic or artificial field markers within the model and situs) as well as a subsequent Iterative Closest Point algorithm based on further surface points.

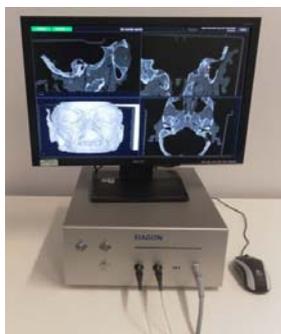


Fig. 1: Hardware module



Fig. 2: Navigation head with magnetic field generator



Fig. 3: Application specific sensors

Measurements were carried out with the navigation system on five temporal bone specimens to determine the target point deviation factor. The selected target structures were marked with four titanium screws per temporal bone specimen respectively. Three more titanium screws were attached to the mastoid for registration. Four of the five temporal bone specimen were mastoidectomied, all specimens were liberated to a great extent of the soft tissue cover.

During preparation of the experiment a computer tomography was carried out on all temporal bone specimen with a slice thickness of 1 mm. The navigation data set was imported through the system and the titanium screws, which serve for registration or evaluation were marked manually in the image data (fig. 4).



Fig. 4: Determination of registration and evaluation points in the image data coordinate system

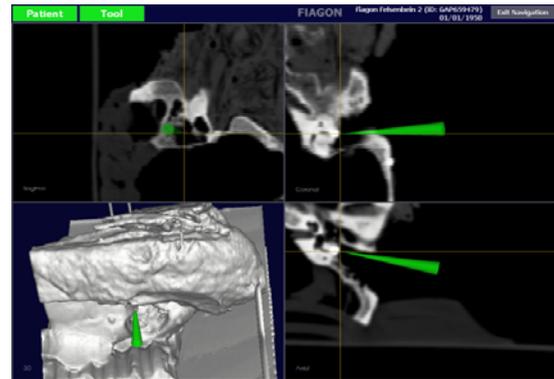


Fig. 5: Experimental measurement of position errors with attached patient localiser and according visualisation on screen

Hereby the image data coordinate system is determined and these positions are saved as a reference. After registration on three titanium screws ten repeated measurements were carried out on the titanium screws, which were to serve for evaluation (fig. 5). The measured data was recorded for every titanium screw position and Target Registration Error as well as the standard deviation were calculated.

In a second test set-up a comparison was carried out between the registration on titanium screws and the registration on the basis of the surface. To increase information six titanium screws (fig. 6) were attached to the head frontally, occipitally, and in the region of the zygoma on both sides, and a new temporal bone specimen CT was carried out with 1 mm slice thickness. The registration process was repeated five times per side and the Target Registration error was determined again for the titanium screws in respect to the mastoid surface, the mastoid cavity and the inner ear canal. The surface registration was first registered from temporal to occipital, and subsequently in the drilled mastoid cavity. These two registrations were contrasted with the registration on titanium screws. These methods were chosen due to possible pre- or intraoperative situations. Furthermore the influence of ferromagnetic instruments was observed (fig. 7).



Fig. 6: Titanium screw: frontal, zygoma, occipital



Fig. 7: Influence of surgery retractors

## Results

Design and use of the navigation system proved effective and easy to use on the lateral skull base. The registration process could be carried out swiftly by sampling three or six given titanium screws. Guiding the flexpointer in one's own hand evoked a familiar feeling since the form is very similar to the usual aspirator used in head-neck surgery.

While verifying registration no process was rejected by us or the system due to high inaccuracy. We were able to observe free handling in the surgical area without consideration of line-of-sight, as is sometimes the case with optical navigation (line-of-sight problem). The still present possible perturbation due to metallic instruments and tables can be further improved. The metallic retractors necessary during surgery on the lateral skull basis partly interfered with the electromagnetic field. On the plane of the retractor itself, i.e. on the mastoid surface, no application of the system was possible. In the mastoid cavity and the inner ear canal measurements could be carried out. Regarding the onesided fiducial registration, deviations between measured and calculated position are summarized in table 1. Overall the error on the mastoid and in the area of the drilled mastoid cavity (e.g. the lateral arch) constitutes a mean of 0.8 mm. Measurements of the titanium screw at the inner ear canal showed a mean deviation of 1.6 mm. The titanium screw at the inner ear canal was not sampled at the anatomic specimens through the operated situs but by turning the specimen from the intracerebral direction.

Table. 1: Deviations of measured and calculated position

Landmarks	Mastoid surface and mastoid cavity	Inner ear
Mean (TRE) ± Standard deviation	0.8 mm ± 0.4	1.6 mm ± 0.5
measurements n	140	50

Evaluation of different registration methods presented improved results. The least Target Registration Error occurred with registration of six titanium screws, followed by surface registration at the face including laterobasis followed by registration in the mastoid cavity only (table 2).

Table 2: Comparison of different registration methods

	Registration methods		
	Six titanium screws	Surface temporal occipital	Surface mastoid cavity
<b>TRE total (MEAN± STD)</b>	<b>0.6 ± 0.3</b>	<b>0.9 ± 0.4</b>	<b>1 ± 0.4</b>
TRE mastoid surface (MEAN ± STD)	0.65 ± 0.30	0.95 ± 0.40 <u>Retractor: not possible</u>	0.7 ± 0.25
TRE mastoid cavity (MEAN ± STD)	0.50 ± 0.25	0.90 ± 0.45 <u>Retractor: 1,2± 0.6</u>	1.0 ± 0.30
TRE Inner ear (MEAN ± STD)	0.65 ± 0.30	0.95 ± 0.40 <u>Retractor: 0.9± 0.4</u>	1.3 ± 0.40

Registration of six titanium screws that were attached circularly at the head and registration of the surface from temporal to occipital showed no increase of the Target Registration Error from the mastoid surface to the inner ear canal. In contrast, registration in the drilled mastoid cavity only showed an increase of the Target Registration Error. The measured values correspond to our clinical expectations and can be used if the Target Registration Error is known and respected.

## Discussion

A Target Registration Error of 0.8 mm approximately corresponds to the values that were measured for the paranasal sinuses [2]. Here only surface registration on the face was used. In comparison, our Target Registration Errors with a CT slice thickness of 1.00 mm with onesided registration on Fiducials on the mastoid surface and in the mastoid cavity proved similar, regarding the inner ear canal (1.6 mm) it was slightly higher. The slice thickness always presents a limiting factor since accuracy of the position presentation can only lie maximum within the range of the slice thickness. Hereby a slight slice thickness can lead to improved results, whereby the slice thickness can constitute up to 0.5 mm. The expected accuracy will lie within the range of slice thickness +20%. An acrylic glas (PMMA) phantom with Fiducials was examined to find out whether a different TRE exists when using a multislice CT (MSCT) or an experimental flat panel VCT [7]. Average TREs were calculated and the results were compared to the t-test. The average TRE with MSCT (0.82 mm [standard deviation 0.35 mm]) was significantly higher than with application of the fpVCT (0.46 mm [standard deviation 0.22 mm]) ( $p < 0.01$ ). Results are further influenced by accuracy when sampling the Fiducials intraoperative, which lies at approximately 0.2 mm. The accuracy of the marker of the Fiducials in the image data record is difficult to quantify. Theoretically here, too, accuracy can be expected to lie above slice thickness.

However, the executor may add the missing information knowledge-based and greatly improve the result. Example: The slot of a screw is not visible in the data record. Due to the knowledge that it is located in the middle of the screw (by extension of the thread) a marker can be placed here.

Estimation: 0.5 mm. Kral et al. [6] examined the learning curve with registration of navigated interventions at the skull basis. Four doctors in training without experience with navigation lead a point-to-point registration consecutively on five anatomic specimens. The target value presented the application accuracy after every registration (TRE).

An inverse progression of the learning curve appeared of: 3.3 mm (TRE- value of the first registration) to 1.6 mm (TRE- value of the fifth registration). This shows another important influencing factor, which must be considered regarding the use of navigation systems and the evaluation of TRE-values.

Berry et al. [3] examined the effect of distribution of patient markers (Fiducials) on the Target Registration Error using the Stryker-Leibinger navigation system (Freiburg, Germany) on a plastic model. They found, as our measurement of the inner ear canal shows, too, that the Target Registration Error increases the more the target point lies outside the registration zone. Schipper et al. [4] also showed similar results with a navigated cochlear implant on the temporal bone specimen. An increase of the Target Registration Error was presented, also when referencing titanium screws with an increase of surgery duration and depth of invasion of the bone along the surgery corridor. At first a Target Registration Error of 1.2 mm occurred, which increased to 1.6 mm with the insertion of the CI electrode. Due to the missing information regarding a registration process at the cranial bone before drilling, a limitation of the reliable navigation on the lateral skull basis appeared. Of course the question of how to avoid errors regarding patient registration and image data referencing arises repeatedly [5]. The titanium screws used on the temporal bone specimen, which had been brought in before the performed CT imaging (gold standard), are still rather unsuitable for clinical application if it needs to be two-stage preoperatively. However, good detectability regarding the CT and the patient and the independence of surface changes due to tumor, swelling or repositioning proves advantageous during surgery.

In the operating room surface registration or registration regarding anatomical field markers have been established routinely [5]. But since direct comparison of different registration methods achieved the best results with registration on titanium screws, an intraoperative imagery could allow an application of Fiducials during operation within the same anesthesia, or it may provide collection of already manipulated tissue surface. In this case respective possibilities would be provided to increase precision.

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