Surface laser registration in ENT-surgery: accuracy in the paranasal sinuses – a cadaveric study*

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SUMMARY

Over the past decade, surgical navigation systems have found widespread use in ENT-surgery. Navigational accuracy highly depends on the registration process. The objective of this study was to assess the accuracy in the paranasal sinuses and lateral skull base after surface laser registration using the navigation system VectorVisionCompact® (BrainLab, Heimstetten, Germany). Repeated measurements were performed on two cadaver heads. Sixteen titanium screw fiducials per head were placed in facial bones, the paranasal sinuses and the lateral skull base, thereby serving as exactly identifiable measurement points. The respective influence on measurement accuracy depending on the localization and conformation of the registration area was evaluated by performing symmetrically bilateral as well as strictly unilateral registrations. The resulting overall accuracy for a symmetrically bilateral surface laser registration was 1.13 ± 0.53 mm, ranging from 0.77 (sinus frontalis) to 1.76 (petrous bone) mm, and thus proved to be clinically sufficient. Increasing distance between target point and registration area went along with a decline in accuracy. Navigational accuracy was significantly influenced by the choice of the registration area. Best accuracy was detected after symmetrically bilateral registration.

Key words: accuracy, image-guided surgery, laser registration, paranasal sinuses

INTRODUCTION

Surgery of the paranasal sinuses and the frontolateral skull base, in close proximity to vital structures such as brain, carotid artery or optic nerve, is potentially hazardous and requires the utmost precesion. Over the past decade, surgical navigation systems have found widespread use in ENT-surgery [1]. They are appreciated as useful tools for clarifying complex anatomy and assisting in the exact positioning of surgical instruments, especially if intraoperative orientation is further complicated by the loss of surgical landmarks from previous surgeries or tumor destruction [2-4]. The clinical efficiency of navigation systems is influenced by human factors, for example requirements for specific skills, as well as surgical system properties [5]. Technical reliability of image-guided surgery (IGS) highly depends on successful registration, which is the process of establishing a correlation between a preoperative image data set (e.g. CT scan) and the intraoperative anatomy. Many registration methods are based on external markers, e.g. adhesive skin markers, bone screw markers or markers fixed on a headband or a Mayfield clamp [4,6]. Contour-based registration (e.g. surface laser registration), which aligns the unique contours of the face instead of external fiducial markers, is an attractive alternative to these methods in ENT-surgery because of its considerably higher practical convenience. It eliminates the need for the time-consuming application of external markers, which have to be fixed in the identical position at the time of the CT scanning prior to registration and at the time of surgery. Navigational accuracy has been reported to be slightly lower after surface registration as compared to fixed-marker based registration protocols, though [7-9]. As the registration process of calculating a mapping relationship between the image and the surgical anatomy can never be accomplished perfectly, inaccuracy is an inherent limitation of IGS systems. Surgical navigational accuracy, also referred to as target registration error (TRE), is defined as the distance between the real position of a surgical target or instrument and its indicated position in the CT scan [10].

So far, data about the actual surgical accuracy in the paranasal sinuses are only sparse [8,11]. In an experimental study using headset-based registration, theoretical TRE values as low as 0.3-0.4 mm were reported for vaguely defined anatomic land-

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marks in sinus cavities and skull base. Clinical relevance of these data has been questioned, though, as clinically observed navigational accuracy is generally substantially higher [11]. For systems relying on laser-based registration, e.g. the VectorVision® system (BrainLab, Heimstetten, Germany), no studies determining navigational accuracy specifically in the sinuses or skull base, i.e. in the area of interest for sinus surgery, have been published. Results of previous studies using skin-affixed fiducials for accuracy measurements [7,9] cannot be easily applied to the situation in the paranasal sinuses as there is evidence that accuracy is influenced not only by the registration method but also by the position of the target point relative to the registration area [8,12].

The purpose of the present study was to assess the accuracy in the paranasal sinuses after surface laser registration using the navigation system VectorVisionCompact® (BrainLab). Objective and standardized measurement conditions should be guaranteed by the use of cadaver heads, which are superior to other experimental models such as skulls or plastic heads when doing surface scanning. Furthermore, the respective influence on measurement accuracy depending on the configuration and symmetry of the registration area was to be evaluated in this study.

MATERIALS AND METHODS

Navigation system execution

The experiments were performed on two cadaver heads (Institute of Anatomy, Munich University). Titanium screws fixed in facial bones, the paranasal sinuses and the frontobasal region served as exactly defined target fiducials. The exact landmark locations are listed in Table 1 and Table 2. Axial spiral computed tomography scans (slice thickness 1 mm) were obtained and transferred to the passive optical navigation system VectorVisionCompact® (BrainLab, Heimstetten, Germany).

Contour-based registration was performed with a handheld laser scanner device (z-touch®). No external markers are needed for this registration method. The system automatically correlates the position of the scanned area to the reference star and calculates each coordinate link with the corresponding point from the CT data set. Fixing the reference star to the skull by a bone screw ensured its constant position during the whole measuring procedure. Points for the surface laser scanning were distributed along the nasion, the forehead and the orbita rim. These parts are hairless and the skin covers the bones tightly, thus forming an individual spatial relief. Tissue shifting between CT scanning and registration is neglectable in these areas [6]. The laser reflections detected by the infrared cameras of the navigation system represent the localization data, which is transferred to the system. Having detected a sufficient number of points (approximately 100), this three-dimensional information is matched with the image data set of the tomographies.

In order to determine whether the navigational accuracy is affected by the configuration and location of the registration area relative to the surgical field, in addition to symmetrically bilateral registration, strictly unilateral registration was performed by exclusively scanning areas located on the left or the right half of the face, respectively.

Navigational accuracy was assessed as previously described [7,9,13,14]. The pointer was aimed at the clearly defined central depression of the target fiducials, which can be easily identified both in reality and on the navigation screen. In the paranasal sinuses the correct positioning was guaranteed by endoscopic control. The distance between the target point and the tip of the pointer was measured separately for the three planes (axial, coronar, sagittal) using the scale on the navigation screen. The

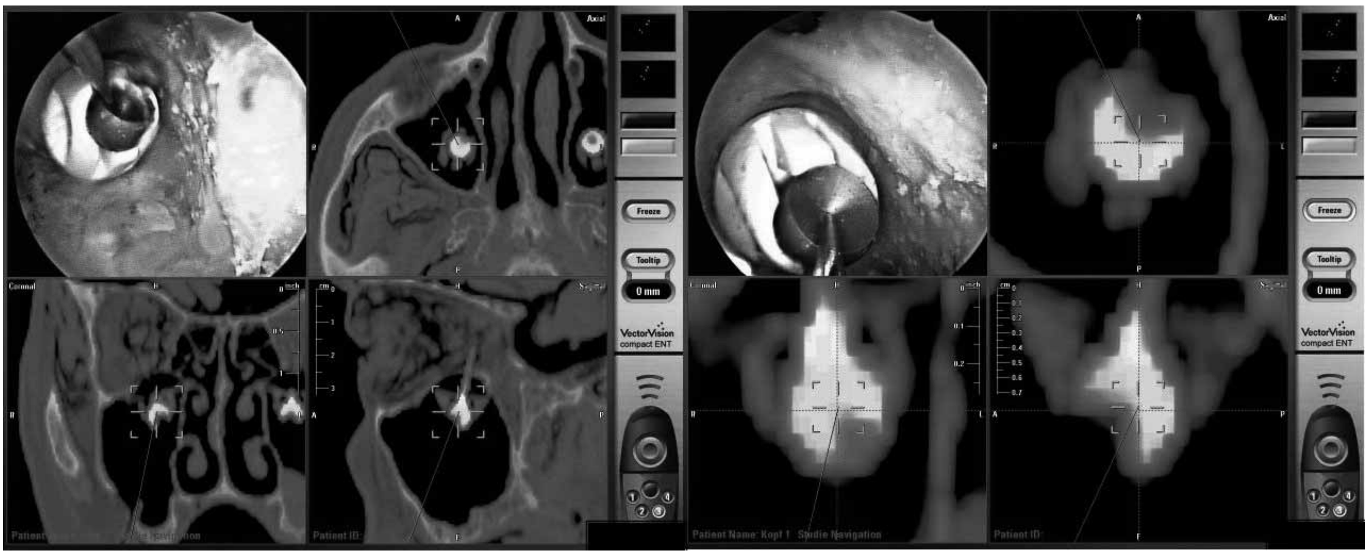

Figure 1. Screenshots during cadaver accuracy measurements (overview and zoom mode). The fiducial landmark of the left maxillary sinus is shown. The positional deviation was determined by use of the metric scale in 600% zoom mode (right).

Table 1. Each of the two cadaver heads was registrated 10 times choosing a symmetrical target area (n=20 for each landmark). Data are expressed as mean values (mm) ± standard deviation.

Position of superficial landmarks	Accuracy (SD) [mm]
frontal, left	1.01 (0.56)
frontal, right	0.89 (0.42)
temporal, left	1.12 (0.23)
temporal, right	1.06 (0.40)
preauricular, right	0.98 (0.38)
preauricular, left	1.11 (0.39)
retroauricular, left	1.74 (0.44)

Table 2. Each of the two cadaver heads was registrated 10 times choosing a symmetrical target area (n=20 for each landmark). Data are expressed as mean values (mm) ± standard deviation.

Position	Accuracy (SD) [mm]
Sinus maxillaris (left)	1.02 (0.34)
Sinus maxillaris (right)	1.02 (0.27)
Sinus frontalis (posterior left)	0.91 (0.30)
Sinus frontalis (posterior central)	0.78 (0.37)
Sinus frontalis (posterior right)	0.77 (0.30)
Sinus ethmoidalis (top)	1.27 (0.42)
Sinus sphenoidalis	1.25 (0.47)
Lateral skull base	1.40 (0.64)
Petrous bone	1.76 (0.45)

highest value from these three measurements, i.e. the maximum deviation, represents a reasonable approximation to the navigational accuracy.

Within each of the three tested conditions (unilateral left, unilateral right and symmetrically bilateral registration) 10 replicate measurements were performed for each of the two cadaver heads amounting to a total of 20 replicates per registration method for each landmark. Each replicate measurement consisted of shutting down and restarting the computer, reregistration by surface laser scanning and relocalization of the target fiducials.

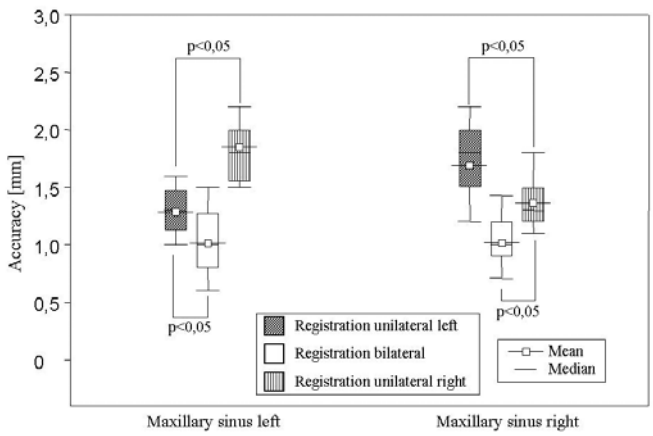

Figure 2. Accuracy at landmarks in the maxillary sinuses. Accuracy, measured in the maxillary sinuses after unilateral left, unilateral right and symmetrically bilateral registration.

Statistics

Data are expressed as mean values (mm) ± standard deviation. Differences in mean accuracy values depending on the registration area were tested for statistical significance by the Kruskal-Wallis-test.

RESULTS

The mean accuracy values for each landmark after symmetrical bilateral registration are shown in Table 1 and Table 2, resulting in an overall accuracy of 1.13 ± 0.53 mm. Single accuracy measurements ranged from 0 mm to a maximum value of 3.2 mm.

Accuracy values obtained for the superficial landmarks

Table 3. Each of the two cadaver heads was registrated choosing 10 times strictly the left and 10 times strictly the right half of the face as target area (n=20 for each landmark). Data are expressed as mean values (mm) ± standard deviation.

Position	Accuracy after unilateral registration (SD) [mm]	
	Registration left	Registration right
frontal, left	1.50 (0.40)	1.89 (0.39)
frontal, right	1.68 (0.52)	1.26 (0.48)
temporal, left	1.34 (0.31)	1.73 (0.25)
temporal, right	1.58 (0.49)	1.26 (0.58)
preauricular, right	1.61 (0.44)	1.26 (0.46)
preauricular, left	1.41 (0.44)	1.85 (0.40)
retroauricular, left	1.98 (0.44)	2.49 (0.42)
Sinus maxillaris (left)	1.29 (0.24)	1.85 (0.26)
Sinus maxillaris (right)	1.69 (0.38)	1.37 (0.26)
Sinus frontalis (posterior left)	1.17 (0.28)	1.11 (0.27)
Sinus frontalis (posterior central)	1.09 (0.37)	1.03 (0.28)
Sinus frontalis (posterior right)	1.16 (0.29)	1.10 (0.30)
Sinus ethmoidalis (top)	1.54 (0.21)	1.41 (0.34)
Sinus sphenoidalis	1.73 (0.49)	1.78 (0.46)
Lateral skull base	1.81 (0.48)	1.94 (0.56)
Petrous bone	1.90 (0.48)	2.20 (0.54)

revealed the following trend: increasing distance between target point and registration area went along with a decline in accuracy. Accordingly, accuracy was comparatively high at the frontal landmarks (1.01 ± 0.56 and 0.89 ± 0.42 mm), which are directly neighbouring on points used for registration, while the maximum deviation of 1.74 ± 0.44 mm was detected at the fiducial placed in the retroauricular area, i.e. in considerable distance to the registration area (Table 1).

This observation also applies to the accuracy determined for the fiducials inside the paranasal sinuses and the lateral skull base. Likewise, accuracy was highest next to the registration area in the frontal sinuses (0.91 ± 0.30 mm, 0.78 ± 0.37 mm and 0.77 ± 0.30 mm), while a loss of accuracy could be stated for the further distant landmarks in the sphenoid sinuses (1.25 ± 0.47 mm), the lateral skull base (1.40 ± 0.64 mm) and the petrous bone (1.76 ± 0.45 mm) (Table 2).

Measurement accuracy was significantly influenced by the choice of the registration area. Registration restricted to one half of the face resulted in higher accuracy at ipsilateral landmarks compared to contralateral ones ($p<0,05$) (Table 3). Highest accuracy values were detected after symmetrically bilateral registration. In Figure 2 accuracy values following left-sided, right-sided or bilateral registration are exemplarily shown for the landmarks located in the maxillary sinuses. Similar results were achieved for the superficial landmarks.

DISCUSSION

Confident use of image-guided surgery requires exact knowledge about the accuracy that can be expected under the chosen conditions. Accuracy may, for example, vary with respect to the navigation system, the registration protocol, or the spatial relationship between surgical and registration area. Therefore, differences in the setting must be considered when interpreting the results from the numerous studies addressing navigational accuracy. The accuracy values obtained by surface laser registration in this study are comparable to those reported by Khan et al. (1.9 mm) [13] or Schlaier et al. (1.31 mm) [9], who, however, used fixed landmarks for registration. On contrast, the deviations described here are markedly lower than those of former surface-based registration studies (2.77 mm [9]; 2.4 – 2.8 mm [7]) performed with the VectorVision® system (BrainLab, Heimstetten, Germany). The higher average accuracy of 1.13 ± 0.53 mm, ranging from 0.77 (sinus frontalis) to 1.76 (petrous bone) mm, can be explained by the optimized measuring conditions in our study: potential changes in the position of the target fiducials between CT scanning and accuracy measurement could be prevented by the use of cadaver heads, which not only provided an ideal model of in vivo skin properties for the registration process but also allowed the application of bone-anchored target fiducials. Furthermore, these specifically designed fiducials made it possible to exactly define the measurement points both in reality and on the screen, thereby warranting a highly objective measuring procedure. This way we did not have to rely on anatomic structures such as the nasion, the nose tip or the external auditory canal as previously reported [7,9,13,15]. The use of these rather vaguely defined anatomic points with a diameter of several millimetres leaves room for interpretation and increases the risk for under- or overestimating the navigational accuracy.

By placing fiducials in the paranasal sinuses and the lateral skull base, the accuracy could be assessed directly in areas of ENT-surgical procedures themselves. This is of some importance since accuracy decreases with growing distance to the scanned area as has been shown previously [6,11] and could be confirmed by our results as well. Therefore, accuracy values obtained for superficial landmarks cannot be easily transferred to intracranial regions.

So far, only few studies have investigated the surgical accuracy that can actually be achieved in the paranasal sinuses. High navigational accuracy has been suggested in an experimental study reporting very low target registration errors (TRE) between 0.3 and 0.4 mm measured for anatomic landmarks in the sinus cavities and skull base [11]. The slightly higher values noted by us might be explained by the differences in the respective registration method (headset-based vs. surface laser registration) and the choice of measurement targets (less exactly defined anatomic landmarks instead of titanium screws). More recently, Knott et al. [8] determined navigational accuracy using touch-based, contour-aligning registration. TRE was reported as 1.5 mm at screw targets at the anterior ethmoid and the sphenoid [8], which is in good agreement with our results based on surface laser registration.

The mean accuracy as determined in this study meets clinical requirements. More importantly, even the maximum deviation of 3.2 mm is still in the range of accuracy values that are generally considered sufficient for clinical purposes (1 – 3 mm [3,16]). In contrast to the optimized conditions of our study, the real conditions of surgery are likely to lead to a certain loss of accuracy. The matching precision between the CT-image data and the actual patient anatomy may be impaired by the dislocation of the headband carrying the reference star, the altered skin reflexions after disinfection, and particularly the changes of the mimic occurring between the CT imaging and the intraoperatively relaxed face [17]. Nevertheless, accuracy can be expected to be still acceptable.

While there is good evidence that the accuracy varies with the distance between surgical target and registration area [6,8,11], it has not been explored conclusively to what degree navigational accuracy is influenced by the conformation of the registration area and the distribution of the registration points. From a practical point of view, this is of some importance since it could occasionally be desirable to restrict the registration area to only part of the face, depending on the intended surgical procedure and related positioning.

Performing the measurements on cadaver heads allowed the comparison of different target areas for the laser scan with respect to their influence on measurement accuracy. As expected, registration restricted to the contralateral half of the face led to the lowest accuracy. Interestingly, even if target measure point and registration area were ipsilateral, accuracy was still significantly lower compared with the accuracy values obtained after symmetrical, bilateral scanning. Therefore care should be taken when choosing the registration area to use points for scanning that are symmetrically distributed and cover as much of the patient's face as possible. It is important to consider this when preparing the operation site, as it may be necessary for best results to do the registration before positioning, disinfection or sterile covering.

CONCLUSION

In this study, navigational accuracy was assessed directly in the paranasal sinuses and the lateral skull base. This region is of eminent importance for the ENT surgeon. The accuracy of the navigation system after surface laser registration proved acceptable. A sensible choice of the registration area and thorough symmetrically bilateral scanning are inevitable for optimal results.

DECLARATION

The authors declare that no conflicts of interest exist.

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