Results

When applying mode IN, a significantly reduced incision-to-suture time was registered within both groups. Within the group Draf IIB, it was reduced to 68.5 % (from 67.1 to 46.0 min). Resection efficiency, i.e. the ratio between the width of the frontal sinus ostium and the required total surgery time, widely differed to the benefit of group IN. Within both groups, the questionnaire revealed a high level of confidence in SMGS functionalities (100 %).

Conclusion

The results here show that it could be possible to carry out endonasal sinus drainage Type IIB and III under instrument navigation. The measuring result corresponds with result from other studies and proves once again the increasing quality and acceptance of simple navigation procedure. However, the intranasal drill is used as priority instrument and the change between the drill and navigation pointer is reduced.

Since the selected intervention does indeed involve an appropriate, yet rare indication, the number of cases that were available is small (12 procedures per group, respectively). It would be advisable to collect more observations in future examinations. Furthermore, there was an omission of sufficiently-detailed sub-categorization (e.g. in the interim times) for several parameters (e.g. resection efficiency), in order to retain both the overview of results as well as the focus on issues at hand.

Glossary

COS	Change of surgical strategy
DC	Distance control
FESS	Functional endoscopic sinus surgery
IN	Instrument navigation
ISC	Instrument situs condition
LOQ	Level of quality
ON	Operator navigation
SMGS	Surgical management and guidance system
SNZ	Schnitt-Naht-Zeit/suture-cutting-time
TT	Tool tracking
VSC	Visual surgery conditions

Pre-operative identification of force-density based pose estimation accuracy

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Keywords Cochlear implant · Tool pose estimation · Density · Robotic drilling · Drilling bone

Purpose

Force-density based pose estimation is a novel method for determining the location of a tool within the body based on only its interaction with the surrounding tissue. The proposed application of the approach is for the localization of a drill within the mastoid during the minimally invasive drilling of a trajectory from the surface of the mastoid to the inner ear; a procedure known as direct cochlear access (DCA). DCA aims to reduce the invasiveness of inner ear access for cochlear electrode insertion by removing the need for a mastoidectomy, in which a significant segment of the mastoid is milled away. Due to the vital structures within the region between the mastoid surface and the inner ear, it is necessary that the surgeon visualize and avoid these structures or that the drilled trajectory be highly accurate. Damage to the facial nerve may leave the patient without movement of the facial muscles, injury to the chorda tympani may alter the sense of taste, damage to the ossicles may eliminate residual hearing and drilling through the ear canal may lead to infection.

Force-density pose estimation works by correlating axial forces observed during the drilling process with the densities along a number of candidate trajectories within a region of interest, extracted from 3D imaging data. It may help to ensure patient safety in accuracy critical interventions such as DCA by providing an alternative method for tool localization in case of calibration, registration or absolute tracking errors. The accuracy of the method (0.29 ± 0.17 mm) has been proven to be highly robust to changes in drill methodology and tooling; however, due to the nature of the approach it was hypothesized that the effectiveness of the pose estimation algorithm would be highly dependent on the anatomy of the patient within the region of interest.

This abstract presents initial work on the identification of a method for pre-operatively determining the likely accuracy of the pose estimation algorithm based on the variation in the density throughout a pre-defined region of interest.

Methods

A total of 27 data sets were utilized; force data was obtained while drilling trajectories within the mastoid of 7 cranial cadaver specimens. A variety of drilling parameters were used, presenting differences in the feed rate and the tool geometry of the drill bit.

"Pre-operative" analysis of the variability was completed by measuring the mean absolute error (MAE) between the density along the planned trajectory and the surrounding candidate trajectories. The variability within the complete search space was then taken to be the mean of these differences, such that a search space containing a large number of trajectories similar to the planned trajectory provided a lower variability score than one in which many trajectories were different to the reference.

These variability values were then compared to the final accuracy of the pose estimation for all cases. Final estimation accuracy was determined by calculating the distance between the estimated drill position and the actual drill position, determined through segmentation of post-operative imaging.

Results

A method for pre-operatively determining the variability of the bone density within the defined search space was successfully identified and implemented in MatLab and a custom Otologic planning software (OtoPlan). Examples of search spaces with the highest and lowest variability are shown in Fig. 1 (left: search space with high variability. right: search space with low variability). The planned trajectory is in the center of the search space. The facial nerve (FN) is shown in yellow.

Pose estimation accuracy versus pre-operative variability is shown in Fig. 2.

Conclusion

This work has presented a method for pre-operatively estimating the effectiveness of a tool localization algorithm based on the interaction between a drilling tool and the surrounding tissue. Through analysis of the variation in density within a region of interest it appears that it may be possible to pre-operatively predict the effectiveness of the

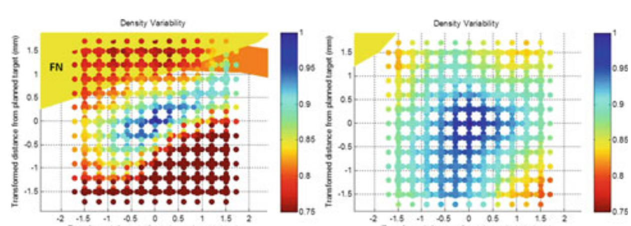

Fig. 1 Examples of search spaces with the *highest* and *lowest* variability

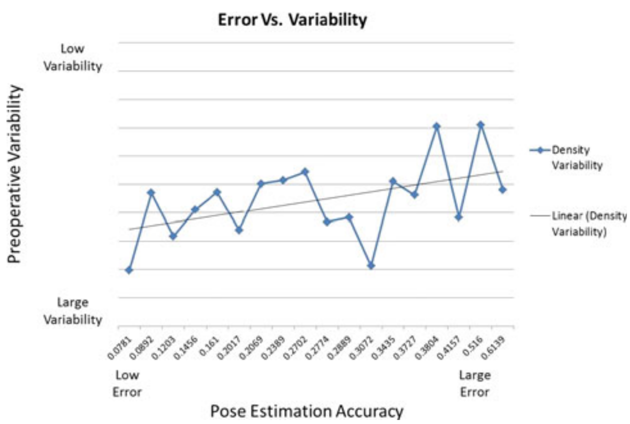

Fig. 2 Pose estimation accuracy versus pre-operative variability

pose estimation algorithm. There exists a correlation between the overall accuracy of the estimation algorithm and the pre-operatively defined "risk" value.

Note however that further investigation into the exact method of pre-operative analysis is required. While a relationship between search space variability and estimation accuracy does exist, it appears to be quite weak.

As currently implemented, the pre-operative analysis does not take into account additional errors which may be introduced by the drilling process itself. Imperfections in the force data, such as those caused by the use of multiple drill bits per drilled hole (for example for centering or the drilling of a pilot hole, allowing the use of stiffer drill bits) or pecking (in which the drilling process is completed in steps, thereby reducing thermal effects) are likely to have some significant effect on the overall estimation accuracy in addition to variations in patient anatomy.

Providing a pre-operative measure of the likely accuracy of the algorithm potentially gives the surgeon greater confidence in the effectiveness of the algorithm, thereby allowing improved decision making and confidence in the effectiveness of the overall robotic system, as well as improved patient safety.

Surgical planning tool for robotically assisted cochlear implantation

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Keywords Surgical planning · Image guided robotic surgery · Cochlear implantation · Segmentation

Purpose

The implantation procedure of cochlear implants, used to treat profound to severe hearing loss, requires access to the middle ear by drilling in the lateral skull base. The most invasive component of the procedure is the mastoidectomy during which, a large cavity is milled out of the mastoid in order to locate and preserve risk structures such as nerves. Because the size of the mastoidectomy (Ø30–40 mm) is much larger than is physically required to insert the electrode (<Ø1 mm), several surgical strategies have been proposed to reduce invasiveness. The direct cochlear access (DCA) is such a procedure wherein a small diameter tunnel (Ø1.5 mm) is drilled from the origin on the outer surface of the mastoid, avoiding sensitive anatomy, and terminates in the middle ear cavity in the region of the round window. It has been shown that a safe and accurate DCA can only be performed using an image guided stereotactic system, which relies on the quality of a surgical plan and the accuracy at which it can be registered to the physical patient intraoperatively. As a result, a preoperative planning system which allows for the segmentation of critical structures of the ear is needed to safely and effectively plan DCA procedures.

For the facilitation of DCA, a surgical planning tool which enables the surgeon to interactively: (a) define landmarks for patient-to-image registration, (b) identify the necessary anatomical structures and (c) define a safe DCA trajectory using patient image data [typically computed tomography (CT) or cone beam CT (CBCT)] is required. To our knowledge, no end-to-end solution fitting this description is available. To this end, we have developed a dedicated end-to-end software tool for the planning of DCA procedures.

Methods

Although the proposed planning software could be used with any surgical navigation system, it has been optimized for use with a five degree of freedom serial kinematic surgical robot system which was developed as a dedicated solution for cochlear implantation using the DCA approach wherein the robot drills a preoperatively planned DCA trajectory through the mastoid to the middle ear. From a preoperative CBCT data set, a plan is performed in three primary steps: the detection of fiducial marker positions for patient-to-image registration; the segmentation of relevant anatomical structures and the definition of a trajectory.

To enable the drilling of a DCA tunnel with accuracy >0.5 mm, a substantially higher target registration error is required. In order to achieve sufficiently high accuracy (approximately 5 times greater than the current gold standard) an automatic algorithm that removes user variability was required. An initial coarse localisation of each fiducial screw is manually defined with a user-supplied single selection. Thereafter, the exact registration position of the fiducial is determined automatically by matching a solid model of the fiducial with its imprint in the image.

The definition of a DCA trajectory initially requires 3D segmented models of the relevant anatomical structures of the ear including: the mastoid for definition of the trajectory entry position; the basal turn of the cochlea and the round window as a target for the drilled trajectory; and the auditory ear canal wall, the facial nerve, the chorda tympani and the ossicles as anatomy to preserve during the drilling process. Structures are segmented semiautomatically using combinations of interactive drawing, thresholding and region growing.

A smooth insertion of a cochlear electrode into the cochlea depends to a large extent on how well the insertion axis aligns with the basal turn of the cochlea. To facilitate the planning of an ideal insertion angle, a cylinder, representing the insertion trajectory is displayed relative to the basal turn of the cochlea. In addition, the angle between the currently selected trajectory and the ideal trajectory (axis fitted to the basal turn) is provided. Using these parameters, the trajectory is defined with a user selected point on the mastoid surface such that the trajectory avoids the previously modelled structures (refer to Fig. 1 left). Distances from the tunnel surface, as defined by the drill diameter, to each structure are calculated and visually presented to the user (refer to Fig. 1 right) along with predicted target registration error associated with the defined trajectory and fiducial configuration.

Verification of the planning tool was performed by performing the entire DCA procedure in a clinic-like environment. In short, the entire DCA workflow was performed on three cadaver specimens. Beginning with fiducial placement, and CBCT imaging, a surgical plan was created using the proposed software and exported to the robot system. Each specimen was registered to the image-based plan using the implanted screws, and the robot subsequently drilled the planned