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High Accuracy Surface Matching and Navigation on the Lateral Skull Base

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Introduction

In the context of image guided surgery, registration describes the process of calculating the transformation between the position of the patient in the OR and pre-operative imaging data. This process can be completed in a variety of different way, but the current gold standard method is through the use of bone anchored fiducial screws. This allows the achievement of high accuracy, but introduces additional invasiveness and workflow difficulties. For image guidance in the context interventions which require high levels of accuracy, such as on the lateral skull base, there is currently little alternative to the use of fiducials. The aim of this project is to investigate alternative, non-invasive, methods for the completion of the registration process; presented herein is work towards a clinically relevant and usable method for registration based on surface matching using a tracked pointer, which has been subsequently integrated into a tablet based navigation system for surgery on the lateral skull base. The developed registration workflow was tested on a total of 6 human temporal bone specimens. The experimental protocol was divided into pre-, intra- , and post-operative stages, as described below.

Materials and Methods

Pre-Operative Planning and Surface Extraction

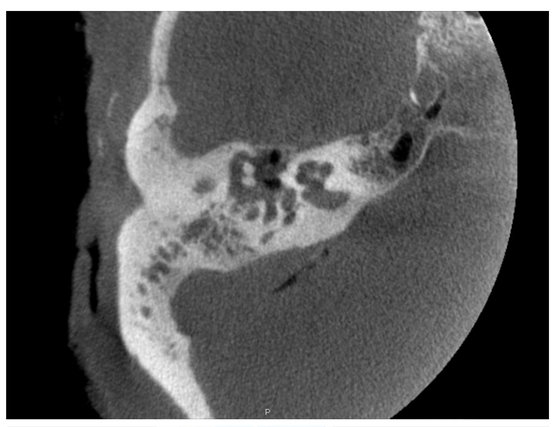
- Insertion of fiducials for use as ground truth
- Pre-operative CT imaging
- Completion of surgical plan utilizing OtoPlan planning software
- Extraction of the mastoid utilizing marching cubes
- Extraction of the bone surface from generated mastoid model
- Addition of tool tip radius along surface normals
- Export of data to OtoNav server

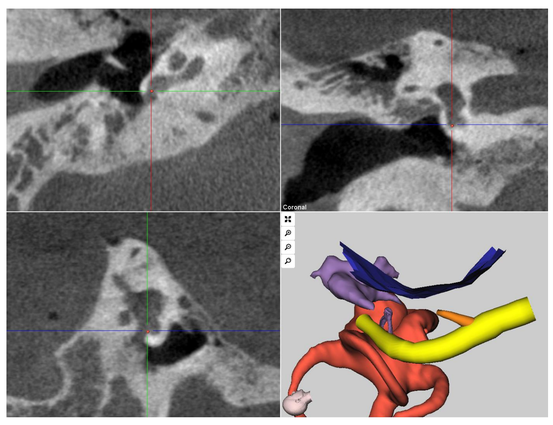
Intra-Operative Registration and Navigation

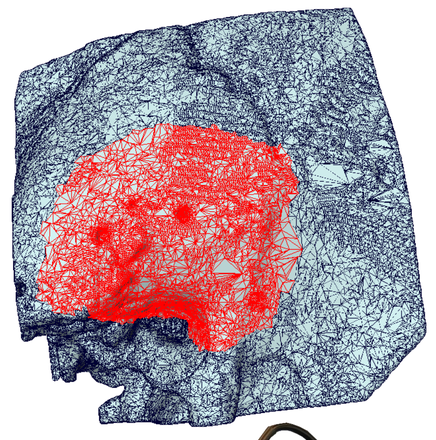
- Selection of patient and import of plan
- Verification of tool calibration
- Selection & digitization of initialization points
- Digitization of bone surface with tracked pointer
- Digitization of reference screws for post operative analysis
- Process repeated 5 times per sample

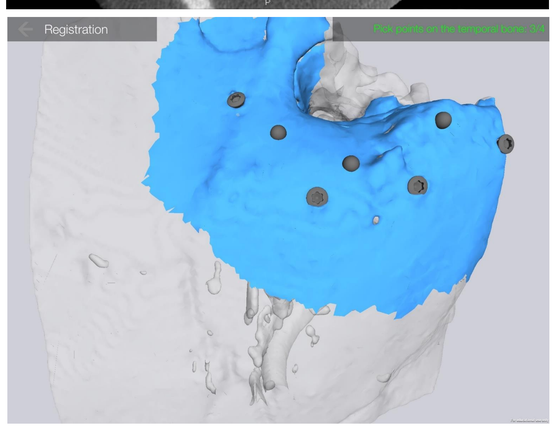
Post-Operative Analysis

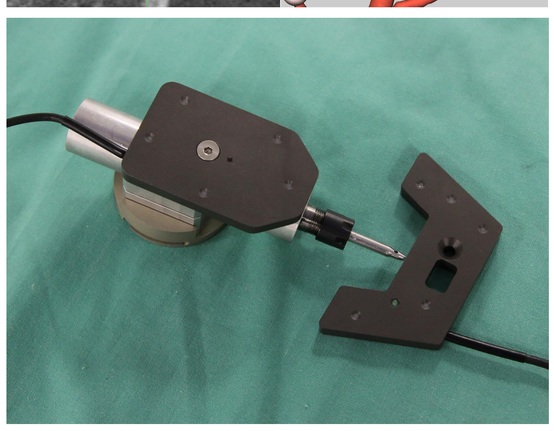
- Import of digitized positions
- Calculation of ground truth registration from fiducial locations
- Initialization of matching algorithm
- Matching of surface point clouds
- Calculation of errors at entrance and target positions

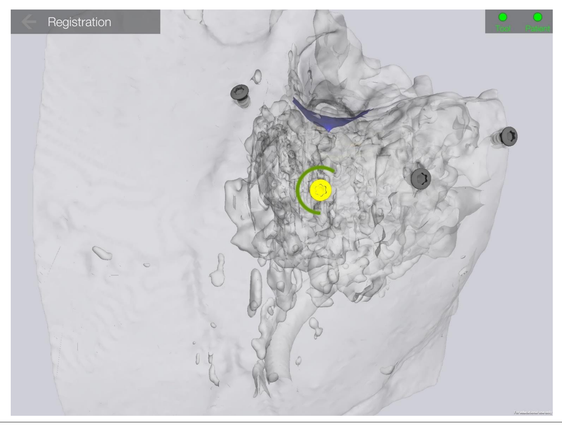


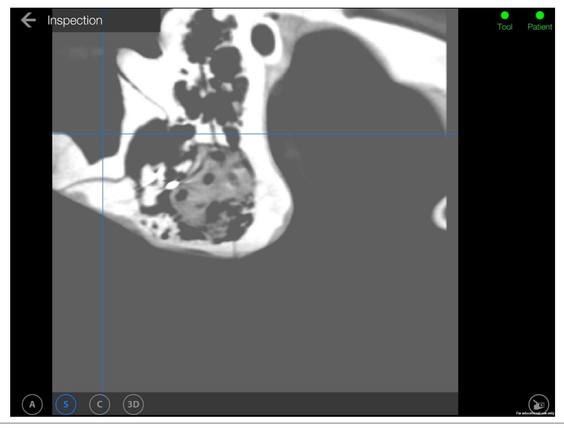








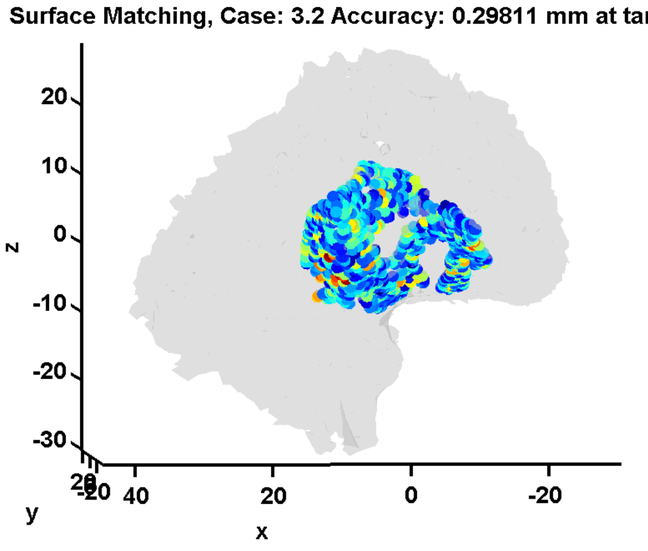




The testing workflow consists of screw insertion and pre-operative imaging, planning, surface extraction, selection of initialization points, verification of tool calibration, digitization of initialization points and mastoid surface and finally the calculation of the ground truth registration. The implemented system can be used to navigate within the mastoid with high accuracy.

Results

- Registration successfully completed for all cases
- Error at surface vs ground truth fiducial registration:
  - 0.2±0.09 mm
- Error at target on round window of cochlea vs fiducial based registration:
  - 0.27±0.09 mm
- Time:
  - Less than 5 minutes in all cases
- No significant dependence on initial matching accuracy
- Workflow robust to user errors e.g. momentarily removal of the probe from the bone surface



Sample ID	Accuracy at Surface (mm)	Accuracy at Round Window (mm)	FRE (mm)	Initial Matching Error (mm)
TB6	0.16±0.12	0.28±0.11	0.05±0.03	1.4±0.14
FR4	0.19±0.06	0.21±0.03	0.05±0.02	1.6±0.41
JH_L	0.21±0.07	0.35±0.04	0.03±0.01	2.6±0.29
JH_R	0.18±0.04	0.34±0.03	0.04±0.01	2.1±0.46
Reserve	0.12±0.02	0.17±0.03	0.04±0.01	1.9±0.31
TR5	0.34±0.07	0.23±0.08	0.03±0.01	0.99±0.80
Total	**0.2±0.09**	**0.27±0.09**	**0.04±0.02**	**1.8±0.53**

Discussion

Evaluation of the non-invasive registration workflow revealed mean errors of 0.2±0.09 mm on the surface and 0.27±0.09 mm at a target position on the round window of the cochlea, respectively. The complete calibration process took less than 5 minutes in all cases. These results represent a significant improvement over the existing state of the art for surface registration; typical values for surface registration in the region of the head vary from approximately 1 – 3 mm. The major disadvantage of this technique is the additional effort required to expose the surface of the bone for digitization, however this process is part of clinical routine during many interventions on the lateral skull base. Digitization of the bone surface was limited where possible to regions which are normally open during the current clinical routine, thereby minimizing interruptions to the existing clinical workflow. Improvement of the matching algorithm, as well as continued validation of the workflow with a variety of users is ongoing.