Surface Matching based on External and Internal Anatomy of the Temporal Bone Applicable for Lateral Skull Base Surgery

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Purpose

Surgical navigation on the lateral skull base (LSB) demands submillimetre accuracies that are unachievable with commercially available image-guidance systems. Advanced image-guidance technology however, allows for navigation with sufficient accuracy as reported in several works during the last decades. The key element to fully exploit the capability of advanced image-guidance technology is the patient-to-image registration. The routine use of navigation in LSB procedures requires sufficient navigation accuracy provided at a low effort and a wide range of application. Utilising bone anchored fiducials, registration errors of approximately 0.1 mm are achieved [1]. However, the additional required computed tomographic (CT) imaging renders the approach unsuitable for most LSB procedures. For LSB procedures requiring a retroauricular incision, surface matching (SM) based registration of the mastoid (MAS) surface was proposed [2]. The effort inherent to SM based registration is low compared to registration based on PPM of artificial fiducials. However, the range of application of the proposed method is limited. Endoscopic transcanal LSB procedures, a set of surgical approaches with increasing popularity, additionally allow for the exploitation of the bony anatomy of the external auditory canal (EAC) and the middle ear cavity (MEC) for SM.

We hypothesize that SM applied on external and internal anatomy of the temporal bone provides target registration errors (TREs) errors below 1 mm. The aim of this study was to determine associated TREs on human cadaveric specimens.

Methods

Overview

In an experiment on two human cadaveric temporal specimens we measured TREs registrations based on SM of external and internal anatomical regions of the temporal bone. PPM with fiducial screws yielded ground truth (GT) registrations.

Sample Preparation and Surgical Planning

Subsequent to performing a retroauricular incision, the two specimens were implanted with four fiducial screws and underwent computed tomography imaging (0.16 mm x 0.16 mm x 0.2 mm). Finally, each specimen was prepared with an endoscopically performed tympanomeatal flap.

The screws were automatically localized in the images using a surgical planning software [3]. The surface of the mastoid (MAS), the EAC and the MEC were manually segmented in Amira (FEI, France). Furthermore, four points on the MAS were defined (mastoid process, temporal line posterior to EAC, two in between) to provide an initial coarse alignment for the SM based registrations.

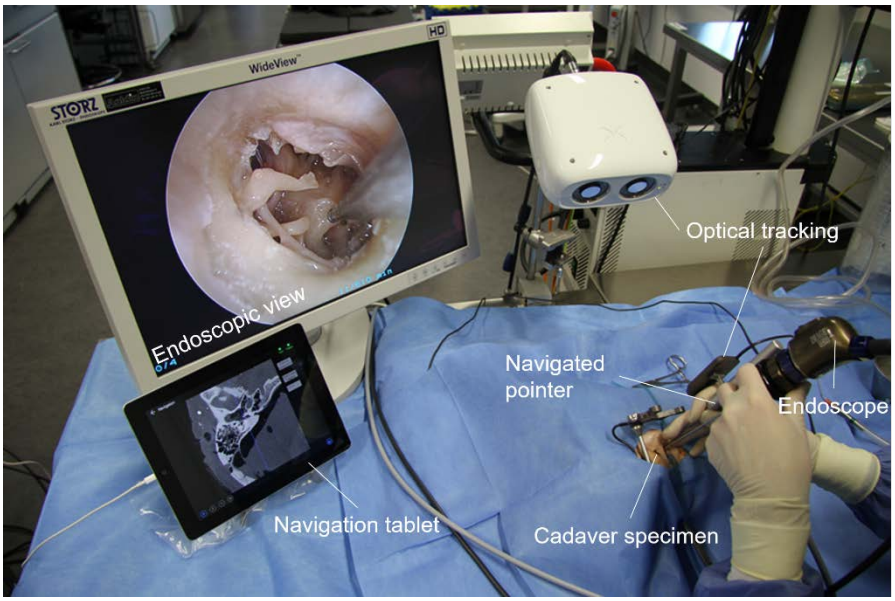
Data Collection

The planned data was loaded onto our navigation system designed for LSB surgery. The registration tool (length: 6 cm, diameter: 1 mm) was calibrated for each specimen, prior to the experiments. The

tracking camera (CamBar B1, Axios3D, Germany) was installed opposite to the surgeon. A dynamic reference base (DRB) was fixed on the specimens with a single surgical screw a few millimetres inferior the temporal line and posterior to the EAC.

For the initialisation of the SM based registrations, the four predefined anatomical landmarks on the MAS were digitized on each specimen. Subsequently, 50 points were scanned on the MAS, the EAC and the MEC successively six times by three surgeons on both specimens (Fig. 1). Surgeons were instructed to collect points with a wide spread whilst minimizing tool bending and ensuring the contact with the surface. A foot pedal was used for digitisation control.

Prior to every second attempt of surface scanning, the implanted screws were digitized for the GT registrations. Care was taken to not move the specimen locator between the surface scanning and the screw digitisation.



Registrations and Target Registration Errors

SM based registrations were calculated using an iterative closest point algorithm [4] initialised by a coarse initial registrations based on PPM [5] of mastoid surface landmarks, resulting in 36 registrations per surface. Registrations based on combinations of the surface of the MAS, the EAC or the MEC were simulated 100 times for each attempt by randomly sampling equal portions of scanned points from the involved surfaces. Consequently, the resulting combinative surface also consisted of 50 points. This yielded 3600 registrations per combinative surface.

The GT registrations were calculated using PPM [5] of the fiducial screw positions in the image and reference frame.

The TRE of each registration was calculated at 10 anatomical landmarks: round window, facial nerve at the pyramidal eminence and at the geniculate ganglion, facial recess, oval window, jugular vein, internal carotid artery, fundus and porus of internal auditory canal, petrous apex. The TREs were calculated as the distance between the landmark (selected in the image frame) transformed to the specimen's reference frame by the registration to be evaluated, and the same landmark transformed to the specimen's reference frame via the corresponding GT registration.

Results

The median TRE of the most accurate SM based registration, SM based on all three surfaces combined, was 0.37 mm with 100% of all measured TREs below 1 mm (Fig. 2). Among the SM based

registration procedures, at least 95% of all measured TREs of all procedures except SM based on the EAC were below 1 mm.

The time required for SM including the initial coarse alignment was 4.3 +/- 1.5 min.

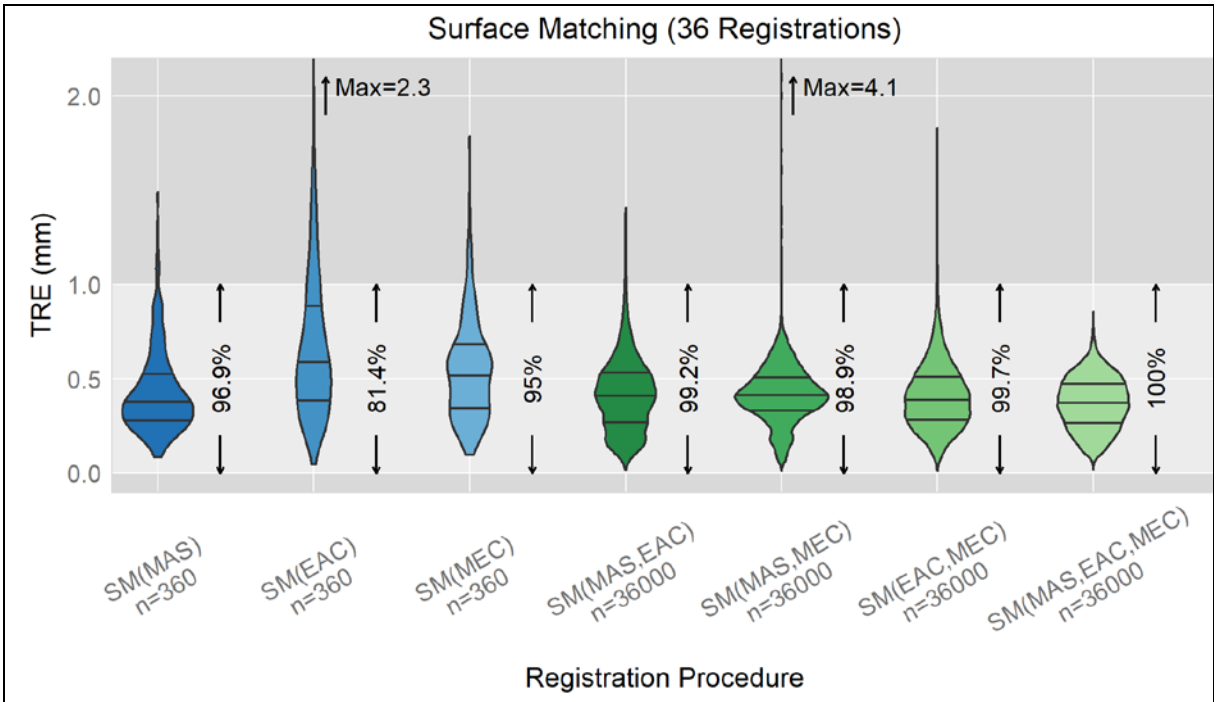


Fig. 2) TREs of measured (blue) and simulated (green) experiments. The violin-plots contain the TREs of all registrations at all 10 targets. The region of interest is highlighted (TRE < 1 mm). SM(i) refers to surface matching with surface(s) i.

Conclusion

In this work SM based registration of internal and external anatomical structures of the temporal bone was evaluated and submillimetre TREs suitable for LSB navigation were observed.

While transcanal access to internal anatomy limits the diameter hence rigidity of the employed pointer thus increasing the error of surface digitisation, proximity of the structures to target anatomy results in accuracies and precisions similar to those observed in mastoid surface registration. TREs of registrations based on the mastoid surface alone were similar to those reported in earlier work [2]. However, the addition of surface points from internal anatomy improved the registration precision. Furthermore, this study suggests that surfaces exposed in transcanal procedures (EAC, MEC) provide sufficient accuracy for navigation in the LSB extending the area of application from microscopic transmastoidal to endoscopic transcanal procedures. While landmarks on the mastoid surface were used for SM initialisation in all registrations during this study, points from internal anatomy could alternatively be used to remove the need to expose the mastoid surface in transcanal procedures.

References

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Various things

RegProc

Time

Sd

PPM4

1.503309

0.6538379

PPM8

2.425212

0.6217088

SM(MAS)

2.949002

0.6156577

SM(EAC)

5.179197

1.359092

SM(MEC)

4.902498

1.401132

the title is not written in capital letters, except abbreviations and proper nouns,

the abstract text is structured as follows:

Purpose

Methods

Results

Conclusion

Figures (1-2 max.) can be included. Multi-part figures are not allowed.

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If you include references into the appropriate field, the number of references should not exceed 5 (approx. 1 reference per 200 words). The references should be numbered with square brackets.

Reference format: [1] Lastname A, Lastname B (2017) Title. Journal 6(1):1-20

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