Surgical Planning Tool for Bonebridge Implantation Using Topographic Bone Thickness Maps

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Purpose

The Bonebridge™ (BB, MED-EL Corporation, Innsbruck, Austria) is a bone conduction hearing implant employed for patients with conductive and mixed hearing loss, as well as single-sided deafness. The large size of its implantable transducer (height 8.7 mm and diameter 15.8 mm) in comparison to the limited size of the implantation site (the temporal bone) introduces the risk of interference with critical anatomical structures such as the sigmoid sinus or the middle fossa dura. Currently, to plan a position and orientation for the implant, surgeons inspect 2D image slices from computed tomography (CT) data sets. Due to the complex variation in bone thickness and the limited area in which the device can be implanted, establishing an optimal or safe implant location can be a challenging task for the surgeon. Several methods and software tools have previously been developed to assist surgeons in planning the position of the BB [1-4]. In previous work [2-3], a topographic bone thickness map (TBTM) was developed and tested for the planning of BB implantation procedures. Despite promising efficacy results, the approach was rendered clinically inapplicable due to the time required to perform a plan (30 to 70 minutes) and the technical skills required to create the plan.

Automated segmentation of the temporal bone is challenging as it is highly interspersed with air cells. In [1], a statistical shape model was used to enable a fast and automatic bone segmentation, however, the model excludes malformed anatomy, which limits its clinical applicability. Others proposed methods using thresholding followed by manual correction to generate the temporal bone surfaces [2-4]. Herein, a planning software tool for BB implantations enabling clinical users to conduct a TBTM plan in less than 15 minutes on both typical and malformed anatomy is presented.

Methods

The proposed planning software tool for BB was developed using the C++ programming language and is structurally based on a previously developed planning software for cochlear implantation procedures [5]. From a preoperative CT data set, a plan is performed in four primary steps: 3D reconstruction of the bone, TBTM generation and display, implant positioning and patient transfer.

To achieve faster reconstruction of the bone, a volume of interest bounded anteriorly by the external auditory canal, caudally by the mastoid tip, cranially by the skull base, and posteriorly by the sigmoid sinus (or beyond in retrosigmoid applications), is firstly adjusted by the user. Subsequent image processing is performed in the defined volume. In order to facilitate the consecutive segmentation of the bone using thresholding, air cells are removed using a hole filling image filter which uses morphological reconstruction to remove local minima not connected to the boundary of the image. Thresholding is then applied using a manually set threshold prior to island removal and 3D reconstruction using the marching cubes algorithm.

Preceding TBTM generation, the generated model of the bone is divided into inner and outer surfaces semi-automatically. The user defines a cutting trajectory by picking three landmarks: on

the temporal line behind the mastoid tip, on the mastoid tip and on the temporal line in front of the mastoid tip. The shortest geodesic path is computed between the three landmarks and defines the cutting path to separate the two surfaces. The distances between the inner and outer surfaces are computed using the closest vertices of both meshes and are colour encoded and mapped to a TBTM [2].

The position of the Bonebridge transducer is automatically defined as the centre of a region on the bone surface with maximum average depth and minimal average curvature (see Figure 1). If no minimum thickness is found, an implant position is proposed at the centre of mass of the outer surface. Subsequently, the surgeon can fine-tune the pose of the transducer manually by dragging it within the 3D scene.
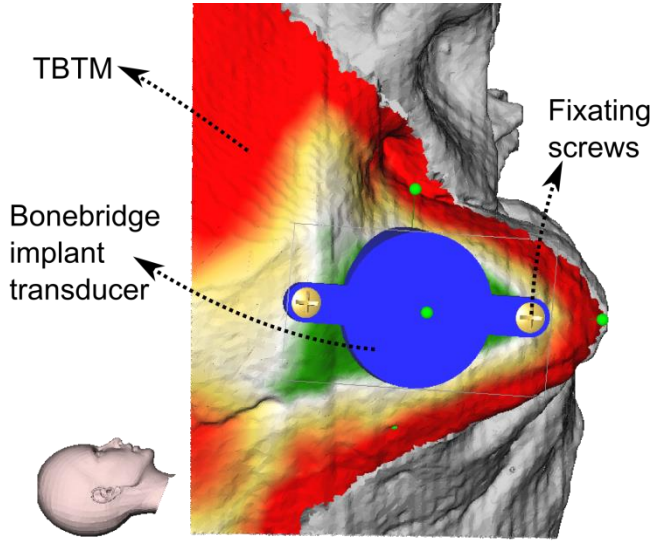

Figure 1. TBTM and proposed implant pose using the proposed planning software.

Results

The accuracy of the TBTM generation in the proposed planning software was evaluated on a 3D phantom model of a stepwise wedge (40 mm × 20 mm). To assess the accuracy independent of imaging errors, image data was simulated by exporting a CAD model of the phantom in DICOM format. Additionally, the accuracy of the thickness calculation was evaluated using CBCT images of the rapid prototyped physical phantom (Planmeca 3D, Planmeca, Finland) (V = 96 kVp, I=12mA, 0.15 mm isometric resolution). A thickness calculation accuracy of 0.09 ± 0.06 mm was obtained independent of imaging errors (N=32) and 0.48 ± 0.26 0.48 mm inclusive of imaging error (N= 32).

The feasibility of the approach was validated in the planning of implant positions for five patients from the Inselspital, Bern. The average time of planning was less than 10 minutes. Surgeon reported that the plan was particularly useful in more challenging cases (e.g. retro-sigmoidal implantation required) (see Figure 2).
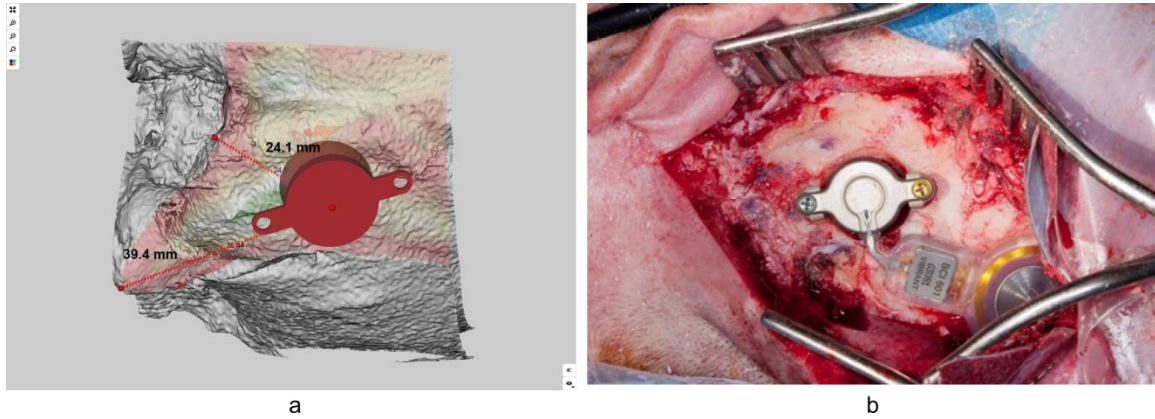
Figure 2. A clinical case of retrosigmoid BB implant insertion: (a) proposed implant pose with distances to two anatomical landmarks – the mastoid tip and the posterior wall of the ear canal; (b) implanted BB transducer.

Conclusion

Within this work a semi-automatic system for planning a bone conduction hearing implant pose was presented. It provides a fast and semi-automatic segmentation of the temporal bone, using morphological operations to fill in the air cells inside the bone. An optimal implant pose is proposed, which is the centre of the region on the bone with maximal average thickness, minimal average curvature, and size as that of the Bonebridge implant transducer. Intuitive manipulation options for manual fine-tuning of the implant position are presented to the user. Finally, a tool for measuring the distance between anatomical landmarks is provided in order to facilitate the transfer of the plan to the operating room.