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Automated measurement of skull thickness in surgical planning for implantation of bone anchored hearing aids

Purpose:
Multiple surgical procedures at the lateral and frontal skull base require the insertion of skull anchored implants such as bone anchored hearing aids (BAHA), epitheses or osteosynthesis material or even bone-coupled reference arrays for intraoperative navigation. These procedures imply the risk of penetration of the skull with consecutive meningitis or intracerebral abscesses. In principle, navigation technology provides the possibility to define regions of safety preoperatively and to relocate them intraoperatively in order to increase therapy safety. To the authors' knowledge current navigation systems known do not provide software features which match to this clinical question.

Method:
We implemented a self-edited planning environment based on the software platform LabVIEW®, National Instruments, Munich, Germany). According to the input of the surgeon (length of implant + a safety margin of 2 mm, desired perspective) the skull surface can be mapped and segmented into safe and risky regions within a few steps. In this preliminary approach a simple threshold-based algorithm has been applied. The accuracy of the automatic algorithm has been evaluated by three independent investigators by measuring the skull thickness manually at 50 different locations within the multi slice CT (MSCT) dataset.

Results:
The algorithm still has problems to deal with anatomical situations such as emissary veins, distinct spongiosa of the bone and artefacts as head holding elements which should be extracted from the imaging dataset before segmenting the skin and bone overview of the skull. Manual skull thickness measurements by the investigators A, B and C revealed significant differences (automatic vs. manual skull thickness measurement) of 0.3 ± 0.42, 0.8 ± 0.74 and 0.5 ± 0.55 mm. The most evident differences occurred in direction of the z-axis due to the non-isotropic voxel size.

Conclusion:
First clinical results of investigations indicate that it makes sense to apply intraoperative navigation technology on the implantation of bone anchored implants. The use of custom-made software could reduce preoperative efforts and provide intuitive visualization. The skull thickness measurements by the three investigators diverge significantly which is probably due to the subjective decision which grey value of a voxel represents bony tissue and which not (investigators were free to adjust the windowing as they supposed to achieve optimum results). Hence, future investigations will compare the algorithm's accuracy with *in situ* measurements of temporal bone specimens. The threshold-based algorithm has to be optimized in order to deal with regions of extensive cancellous bone (risk of misinterpretion as intracranial space or emissary). Furthermore it is intended to re-transfer the preoperative planning into the navigation system so as to guide the surgeon to the preoperatively defined optimum site of implantation.

Keywords:
bone anchored hearing aids, surgical planning, automatic image analysis