

## Literature Review

### ROBOTIC BONE DRILLING ASSESSMENT

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April 16, 2017

#### Selected papers:

- 1) Strauss, Gero, Kirill Koulechov, Mathias Hofer, Elmar Dittrich, Ronny Grunert, Hendrick Moeckel, Eva Muller, Werner Korb, Christos Trantakis, Thomas Schulz, Juergen Meixensberger, Andreas Dietz, and Tim Lueth. "The Navigation-Controlled Drill in Temporal Bone Surgery: A Feasibility Study." *The Laryngoscope* 117.3 (2007): 434-41.
- 2) Grunert, R., G. Strauss, H. Moeckel, M. Hofer, A. Poessneck, U. Fickweiler, M. Thalheim, R. Schmiedel, P. Jannin, T. Schulz, J. Oeken, A. Dietz, and W. Korb. "ElePhant - An anatomical Electronic Phantom as simulation-system for otologic surgery." *2006 International Conference of the IEEE Engineering in Medicine and Biology Society* (2006)
- 3) Hofer, Mathias, Elmar Dittrich, Christian Baumberger, Mario Strauß, Andreas Dietz, Tim Lüth, and Gero Strauß. "The influence of various registration procedures upon surgical accuracy during navigated controlled petrous bone surgery." *Otolaryngology - Head and Neck Surgery* 143.2 (2010): 258-62.

#### Introduction

A mastoidectomy is a type of surgery that involves the removal of a portion of the mastoid bone. Bone drilling in a mastoidectomy procedure requires a high degree of precision and accuracy as to avoid damages of critical structures near the drilling site. The Galen System was developed at Johns Hopkins to address the issue of tight spaces near sensitive anatomy in minimally invasive Head and Neck surgeries. To evaluate the effectiveness of this system in assisting the bone drilling process, we plan to design and conduct surgical studies comparing the use of the system to free hand use of the drill. Our project will involve designing studies, designing and fabricating phantoms, and analyzing data collected from conducted experiments. Towards this end, we have selected the above literature to provide us with guidance on how to design the study and the phantom such that a mock mastoidectomy procedure is well simulated, and what parameters to use to evaluate the performance of the procedure.

The three papers listed above are published by the same research group. The group had developed a Navigation-Controlled drill for use in temporal bone surgeries, and then worked on designing and conducting experiments to evaluate the performance of their drill. Use of the Navigation-Controlled (NC) drill requires a surgeon to determine the workspace in CT record preoperatively. The surgeon then holds the drill and operates regularly until the drill switches off automatically once borders of the predefined workspace are reached.

The first paper chosen documents the first feasibility study of the NC drill. The design of the phantom used in this study is described in further details in the second paper. The third paper then documents a separate study on comparing various methods to register the NC drill, and involves the use of a different phantom.

## Paper 1: The Navigation-Controlled Drill in Temporal Bone Surgery: A Feasibility Study

### Phantom Design and Fabrication

Please refer to the critical review of the second paper for details on the phantom used in this study.

### Experiment Design

The workspace was first defined manually in CT data. Ten trial surgeons were then asked to perform the mock mastoidectomy on the phantoms. Five of these surgeons were inexperienced in otologic surgery and performed the mock mastoidectomy with the NC drill. The other five surgeons who were experienced in otologic surgery performed the mock mastoidectomy both with and without the NC drill. When the Navigation Control function was turned off, surgeons still had access to navigation information via a screen but would have to rely on their own judgement as when to stop drilling. The three experimental groups are summarized in the following table.

Group	Number	Mode
Surgeons inexperienced in otologic surgery	5	With Navigated Control
Surgeons experienced in otologic surgery	5	Without Navigated Control (could view navigation information)
		With Navigated Control

Something else to note is that the inexperienced group was requested to continue drilling in all directions until the drill switched off automatically, while the experienced group using the NC drill did not receive such instructions and could decide when to stop the procedure based on their own judgement. As a result, I don't think the experiment results between the two groups are directly comparable. In my opinion, the inexperienced group was formed to test the feasibility of the NC drill (e.g. in the worst case scenario, even if the surgeon is not familiar with the anatomy, will the drill ensure the safety of the procedure?). And the experienced group was recruited to evaluate how the NC drill compares to a regular drill.

### Evaluation Criteria

The parameters used to evaluate the performance of the mock mastoidectomy are summarized in the following table.

Evaluation Criteria	Procedure for Measurement
Time	Record time
Deviation from planned volume	3D reconstruction of resulting phantom using CT data, compare with pre-determined workspace
Number of injuries to high-risk structures	Record counts
Extent of injury to facial nerve	Light intensity of fiber-optic detector
Minimal distance to high-risk structures	Evaluation of CT images

I believe a modification can be made to the 'deviation from planned volume' criterion, because even if two drilled cavities have the same volume, the shapes of the cavities could be drastically different. Here are two criteria that I think are more informative of the precision of the procedure: 1) Percentage of pre-determined workspace that was successfully removed 2) Volume of excess drilling (drilling beyond pre-determined workspace).

## Results

The article provides measurements of all the evaluation criteria listed above for each experiment group. A summary of the results is provided in the table below. These results may serve as a guideline to how one can expect devices designed to assist mastoidectomy procedures to perform relative to conventional surgical tools.

Group	Time	Speed of resection	Deviation to planned volume	Number of injuries
Experienced w/o NC	715s	9.62 mm <sup>3</sup> /s	-39.9%	1 facial nerve injury
Experienced + NC	817s	10.08 mm <sup>3</sup> /s	-34%	0

## Summary and review

The evaluation criteria used in the study was comprehensive and many quantitative measurements were made possible by their use of the Electronic Phantom (extent of facial nerve injury) and CT scans (comparison to planned volume, minimal distance to high-risk structures).

## **Paper 2: ElePhant - An anatomical Electronic Phantom as simulation-system for otologic surgery**

The Electronic Phantom was designed and developed with the goal of making available an anatomically correct simulation system that could be used to evaluate different computer assisted surgery systems and to train physicians for otologic surgery.

### General Anatomical Structure

- CT of human skull acquired with CT Siemens Somatom Volume Zoom
- Segmentation of anatomical structures using Mimics 9.0
- 3D printed with 3D printer Z<sup>TM</sup>510: building material based on plaster infiltrated with polyurethane and acetone to simulate human bone properties
- Phantom consists of two modules, module 1 fits inside module 2 via a pin-hole-connection
  - Module 1: petrous bone including mastoid and high-risk structures (needs to be replaced for each experiment)
  - Module 2: rest of the skull (reusable)

### High-risk Structures

- High-risk structures represented by electrically conductible materials: sigmoid sinus, horizontal semicircular canal
  - Originally printed as hollow channels, then filled with an alloy (lead, bismuth, tin)
  - Tip of structures connected with analogue output (0.5V) and input channel of data acquisition card PCI 6621 (DAQ-card)
  - Milling cutter connected with ground of DAQ-card
  - If high-risk structure is damaged, current through structure will not flow to its input channel but over the milling cutter to the ground
- High-risk structures represented by fiber optics: facial nerve

- LED provides light through fiber optic and a photodiode at the other end detects the light intensity
- Photodiode is connected with an input channel of the DAQ-card
- If facial nerve is damaged, the light intensity detected will be reduced
- Possible to determine percentage of damage in cross-sectional area of the fiber optic based on illuminance level
- During the simulation procedure, number of contacts between the milling cutter and the high-risk structures is recorded. In addition, there is the option of turning on the feedback feature, which sends a graphical and acoustic signal when the contact occurs.

### Evaluation of Phantom

Seven surgeons performed mock mastoidectomies using the ElePhant and then filled out a questionnaire based on their evaluation of the phantom. The surgeons were pleased with the anatomical correctness and the electronic system response of the phantom. However, they believed that the milling properties still required improvement because unbound plaster powder that accumulated inside the phantom cavities during the procedure could not be removed.

### Summary and review

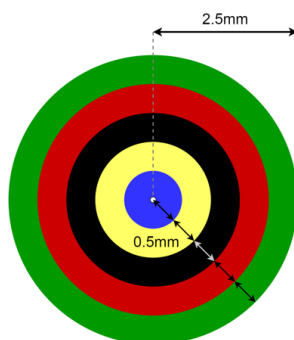
The paper provides in-depth details on the design of the phantom, which is helpful to have when one wants to develop a phantom for similar usage.

## **Paper 3: The influence of various registration procedures upon surgical accuracy during navigated controlled petrous bone surgery**

### Phantom Design and Fabrication

This study uses a phantom that is different from the one described above. It constitutes a simpler representation of the petrous bone.

- Petrous bone model based on patient CT data
  - 3D printed with Spectrum Z510
- Color-coding of facial nerve (diagram shown below)
  - Each color ring is 0.5 mm wide
  - The blue and yellow color layers lay within the facial nerve
  - The black, red and green color layers lay outside the facial nerve



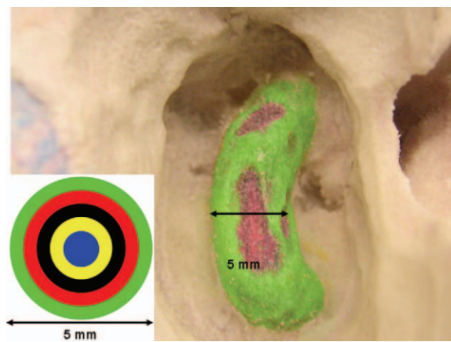
### Experiment Design

The study aims to compare the performance of two registration methods: dental splint registration and fiducial registration. Besides from the registration method, other experimental settings were kept

consistent between the two study groups. The workspace was determined preoperatively such that it came in direct contact with the border of the facial nerve (transition from the black color layer to the yellow). Ten medical students without surgical experience were recruited to conduct the mock mastoidectomy procedures. Each test subject drilled one model from each of the two groups using the NC drill. Test subjects were told to drill out the cavity until the drill came to a stop at all resection edges. Test subjects were not informed of the location and significance of the facial nerve nor of the color-coding significance.

### Evaluation Criteria

Evaluation of the resulting phantoms was conducted by five jurors. The jurors would examine the phantoms under a microscope, and determine the drill's closest proximity to the facial nerve based on the color-coding of the facial nerve. For example, if a juror were to examine the model shown below, he might decide that the drill approached the red layer, which translates to a distance of 0.5 mm to 1 mm away from the facial nerve. This decision was then recorded in a table similar to the one shown below.



Outside facial nerve				Within facial nerve	
>1.5 mm	Green 1.5 to 1 mm	Red 1 to 0.5 mm	Black 0.5 to 0 mm	Yellow 0 to -0.5 mm	Blue -0.5 to -1.5 mm

### Summary and review

The idea of color coding the facial nerve is very interesting, and provides an easy way of obtaining quantitative measurements just through simple visualization. However, printing such a phantom will require a more advanced 3D printer with a fuller spectrum of colors while the 3D printers on campus allow only for a maximum of two distinct colors.

### **Conclusion**

The papers discussed above provide many interesting ideas regarding designs of the phantom and evaluation methods of the simulated mastoidectomy procedure. Due to the time scope of our project and the resources available to us, we will need to come up with a simpler phantom design, but we should keep in mind the need to represent the high-risk structures in the phantom. The evaluation criteria mentioned in these articles, including time to finish procedure, deviation from planned workspace, number of injuries to the facial nerve, and minimal distance to the facial nerve, are in line with the criteria we came up with before reading the articles. We were particularly interested in learning how we could measure deviation from planned workspace and minimal distance to the facial nerve, and while these articles do provide solutions, we will need to take into consideration the resources available to us and decide on whether we need to come up with alternative methods to evaluate these two parameters.