# Target error evaluation of a minimal invasive cochlear implant strategy using a patient specific miniature stereotactical frame

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***Abstract:***

*Minimally invasive cochlear implant surgeries require a very high accuracy of at least 0.5 mm when drilling a canal through the most critical spot, the facial recess [1]. Important anatomical structures in the vicinity of the minimal invasive access path, including the facial nerve and the chorda tympani must be preserved.*
*We conducted a quantitative verification study on five temporal bone specimens using the patient specific miniature stereotactical frame called „Microtable“. The Microtable is developed at Vanderbilt University (Nashville, TN) and evaluated in a multi center study together with the Medical School Hannover (MHH). After classical mastoidectomy and opening of the facial recess we measured the target error at the facial recess in an extra „post-OP“ CBCT (Cone Beam Computed Tomography) scan with a sham drill bit inserted.*

*Keywords: minimally-invasive, computer-aided, cochlea, CI, microtable, facial recess*

## 1 Problem

How to quantify the target error at the location of the facial recess? From endoscopic images alone, an assessment of the exact erro difficult to obtain (see Figure 1). Mechanically measuring the clearance between the (sham) drill bit and the bone canal of the facial ne or the chorda tympani can only provide a rough estimate and is usually the basis to decide whether a (linear) drill path is satisfying or r

## 2 Material and Methods

The Microtable [2] is a system composed of custom hardware (Figure 1, left two images) and planning software developed at Vanderbilt University Medical Center and investigated in a multi center study together with the Hannover Medical School. For the first time, a custom made mobile milling machine is set up and tested to produce the individual Microtables for this study. Basically, the Microtable is a miniature stereotactic frame, screwed rigidly onto the temporal bone and it is fabricated to guide a drill on a specified linear trajectory. The clinical setting would be as in Figure 1 in the left image, except that the Microtable would be screwed onto the head of the patient and instead of the sham drill bit there would be a linear drill guide [2].

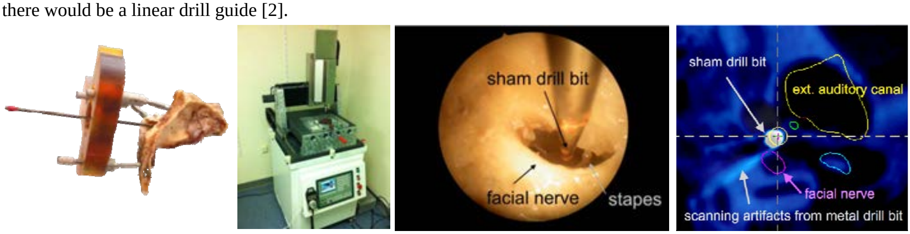


**Figure 1:** ***Left***: Microtable with sham drill bit (testing stick) inserted and mounted on a temporal bone specimen as it was CBCT scanned a second time to evaluate the target error at the facial recess. ***Middle-left:*** Custom made, mobile milling machine. ***Middle-right***: Visual inspection (endoscope) of the testing stick at the facial nerve. ***Right***: CBCT scan orthogonal to the axis of the sham drill bit and rotated such that it is roughly comparable to the middle endoscopic image (of the very same temporal bone). Even if the facial nerve is indeed preserved, it is obvious that there is a deviation between the planned drill path (circle outline) and the actual one, represented by the sham drill bit. (Note: Blue tint is only to register the two scans.)

First, a patient specific trajectory is planned based on the segmented anatomical structures and the position of the spherical markers on top of the bone anchors (screws). Second, the holes are milled (on a 4-DOF CNC milling machine) at the needed locations and to a depth that defines the orientation of the platform as previously planned. Third, the ”legs“ of the table are inserted, fixed, and the table is mounted onto the spherical anchors [3].
In this verification study, we produced individual Microtables for five human temporal bone specimens, performed classical mastoidectomy, opened the facial recess (was done by an experienced ENT surgeon), and measured the target error between the planned and the actual trajectory at the facial recess. To quantify the accuracy, we registered the CBCT scan from the planning phase with a second CBCT ”post-op“ scan and measured the distance between a sham drill bit seen in the CBCT image and the planned drilling (Figure 2, right). This study captures the accumulated errors: (1.) The detection of the positions of the spherical markers, (2.) the firmness of the bone anchors, (3.) the screw connections from bone anchor to spherical marker, (4.) the accuracy of gripper attachment to the spheres, (5.) the clearance of the driller (or sham drill bit), and (6.) the tightening of the legs onto the platform.

## 3 Results

Endoscopic view (Figure 1, middle-right) confirmed that the sham drill bit successfully reached a clinically adequate target location and critical anatomical structures remained undamaged for all five evaluated temporal bone specimens.

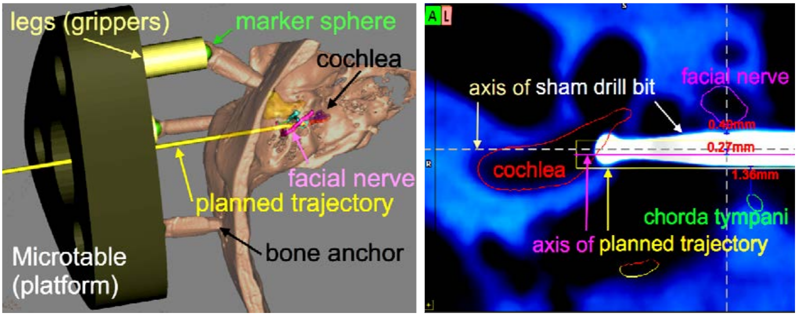


**Figure 2:** ***Left***: 3D model of a scanned temporal bone specimen and attached Microtable in the planning software. The spherical markers were already attached to the bone before scanning. Critical anatomical structures are semi-automatically segmented (not scope of this study) and displayed. The orientation and position of the platform is defined by the depths of the holes in the platform and the legs. The planning software outputs the G-CODE commands for the milling machine to fabricate the individual Microtable. ***Right***: Measurement of target error (at the facial recess) and distances to the nerve structures (exemplary). The rectangular outline is the planned drilling trajectory and the actual sham drill bit is seen in the CBCT “post-op” scan (bright structure). The dashed horizontal line is the visually estimated center of the sham drill bit, from which we measured the distance to the planned center which is 0.27 mm for this sample. (Note: Blue tint is only to register the two scans.)

In the registered CBCT scans (Figure 2, right), the mean distance between planned and actual trajectory at the facial recess was 0.46 mm ± 0.18 mm (SD). Registration and resolution of the CBCT scans yields an estimated measurement precision of 0.1 to 0.2 mm. The individual results are listed in Table 1.
For the specimen named TB03b, we identified the source of the unsatisfying large deviation of 0.75 mm to be a result of a worn-out milling head which has been used to create at least four other Microtables before TB03b. One consequence of the abrasion of the milling head is that the insertion of the grippers (the legs) into the Microtable platform requires large forces. With the new milling head we then produced M57, M58 and M59 where the insertion of the grippers was unproblematic.

| # | *Specimen name* | *Target error at facial recess in mm* |
|---|---|---|
| 1 | TB02 | 0.40 mm |
| 2 | TB03b | 0.75 mm |
| 3 | M57 | 0.43 mm |
| 4 | M58 | 0.50 mm |
| 5 | M59 | 0.21 mm |
| | ***mean*** | **0.46 mm** |
| | ***SD*** | **0.18 mm** |

**Table 1:** The target error at the facial recess (which is the maximal distance of the planned drilling path to the actual drilling path)

## 4 Discussion

The Microtable has already proven its accuracy earlier in controlled lab environments. It is one of the most promising approaches to enable minimal invasive access to the cochlea in the future. Therefore, the main goal of this study was *not* to push the theoretical possible accuracy further but instead to quantify and assess the precision under realistic conditions *at our lab* – which is not the lab the Microtable has been developed at. Clearly, we have to improve on the overall accuracy and identify at which point of the mechanical chain (see section 2 „Material and Methods“) the largest error was introduced and how the construction process can perhaps be optimized.

## 4 Conclusion

While we can report to have reached the necessary accuracy (=0.5 mm) for 80 percent of our specimens, we clearly have to improve and investigate what has been the main cause of the larger deviations from the planned trajectory. Additionally to the worn out end-mill for TB03b, we found that the sham drill bit had a small clearance, which could amount for 0.2 to 0.3 mm error alone. We hope to decrease this clearance by a proper drill guide. Another 0.1 mm error may stem from the registration of the two CBCT scans that we used to measure the error.
The in vitro study done by the skilled team at Nashville (TN) [2] with another type of milling machine reports a target error of 0.31 ± 0.10 mm.

## 5 Acknowledgements

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## 6 References

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