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Optical Coherence Tomography Imaging of the Inner Ear: A Feasibility Study With Implications for Cochlear Implantation

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Group 2

Constructing a Model of the Cochlea from OCT Images

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Project Statement

Cochlear implants are electrode arrays that, when inserted into the cochlea of a patient suffering hearing loss, can mimic the function of the cochlea by emitting electrical signals to the brain via auditory nerve fibers. These electrical signals are created from an external microphone and speech processor and can allow the patient to understand speech sounds picked up by the microphone. The current standard practice for the insertion of such an implant into a patient starts with a mastoidectomy followed by a cochleostomy to machine the area around the cochlea and drill a hole into the temporal bone to access the cochlea, respectively. Once access to the cochlea is available, the surgeon manually inserts the implant into the cochlea using forceps. This project aims to use a robot-assisted approach to cochlear implant insertion, enacting virtual fixtures that constrain the motion of the implant within the cochlea. The virtual fixtures are based on models of the cochlea obtained from OCT imaging.

Paper Selection

The paper chosen for this seminar presentation is “Optical Coherence Tomography Imaging of the Inner Ear: A Feasability Study With Implications for Cochlear Implantation” published in *Annals of Otology, Rhinology & Laryngology* in 2008. This paper proves the efficacy of using OCT imaging to visualize inner ear structures of mice and human temporal bones, which is vital to the project. The first step towards constraining the motion of the robot within the cochlea is obtaining a reliable model. This paper both helps us ensure that models we create from OCT scans will be accurate enough to use and give us an idea of the bounds of the error present in these scans. This information is vital to applying the method to human subjects.

Problem Summary

The practice of manual cochlear implant insertion suffers from a variety of problems. During the procedure the surgeon has no visual feedback, due to the small size of the window into the cochlea and the cochlea itself. If the insertion is heading off-track, there is no real way for the surgeon to see it happening. Although surgeons are trained to have precise hand movements, the scale of the precision needed inside the cochlea is beyond anything human hands can achieve. Imprecise movements have the possibility of damaging the implant or cochlea. There are also hand tremors present that would pose a danger to the patient, due to the small scale of forces needed to cause serious damage within the cochlea.

Key Results

Using OCT imaging, high-detail scans of temporal bone were obtained. This establishes the accuracy of OCT imaging, which in turn proves that the robot-assisted insertion technique solves the main problems of the current standard practice. The creation of a model of the cochlea from OCT images can allow the surgeon to see the patient-specific shape and size of the cochlea, and the relative position of the robot can also be related to the model using the registration of the image space and robot space. The robot itself solves the problems of imprecise movements and hand tremors, as the robot is designed to be moved with sub-millimeter precision and cancels out hand tremors. The robot has been proved accurate, so the OCT being proven accurate in addition proves the feasibility of the project as a whole.

Theory

OCT imaging is based on the interferometry principle, which states that beams of light that are split, travel along different paths and then recombine have a phase difference which can be analyzed to determine the difference in distance travelled by each beam. In this case (see Figure 1) it means that our OCT system uses the phase difference of the two beams to determine the difference between the distance to the reference mirror and the distance to the temporal bone sample. If scanned along the surface of the temporal bone, a wave can be obtained that characterizes the distance from the mirror to the bone at several points. Given enough OCT scans, a model can be made from fitting a line to the calculated surface of the temporal bone. This could then be used inside of the cochlea to find a model of the cochlea.

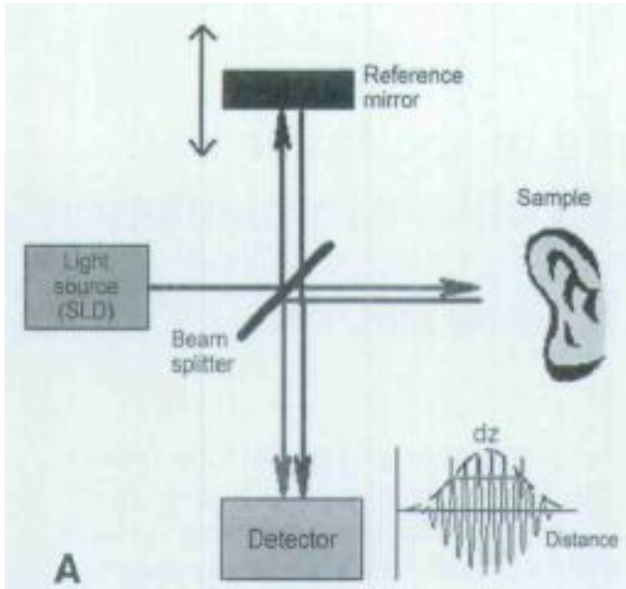

Figure 1

Courtesy Lin et al

Experiment

In order to determine that the OCT system proposed above worked properly in imaging the cochlear interior, a rotating OCT probe was developed (see Figure 2). Once inserted into the cochlea of the mice, the probe is rotated and scans are taken at various positions of the motor. The signals obtained are stable enough to use real-time image averaging to improve the signal-to-noise ratio. These scans are then fitted evenly along a polar graph to visualize the cochlear contour seen by the probe. These “b-scans” are imaged at 3.1 Hz, and obtain a resolution of about 1-2 micrometers (see Figure 3).

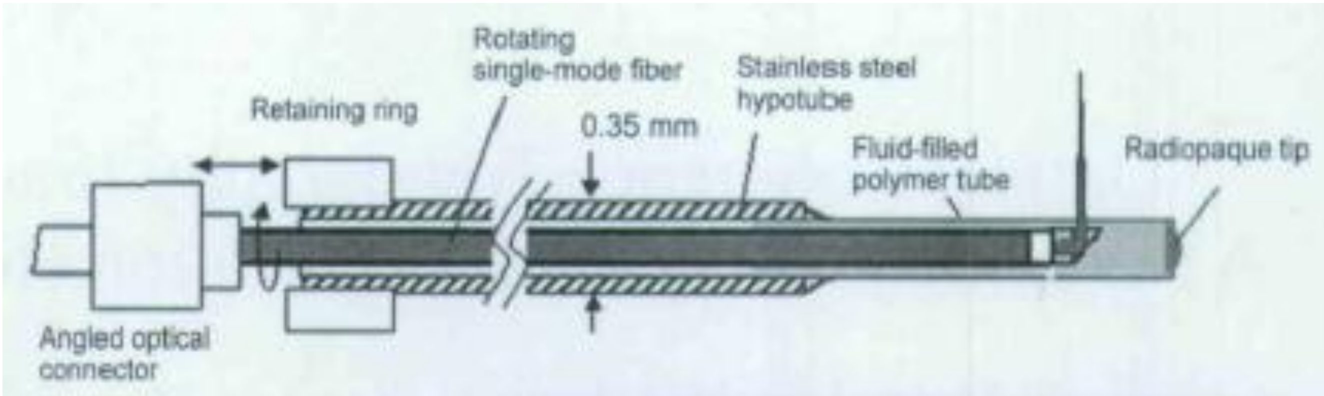

Figure 2

Courtesy Lin et al

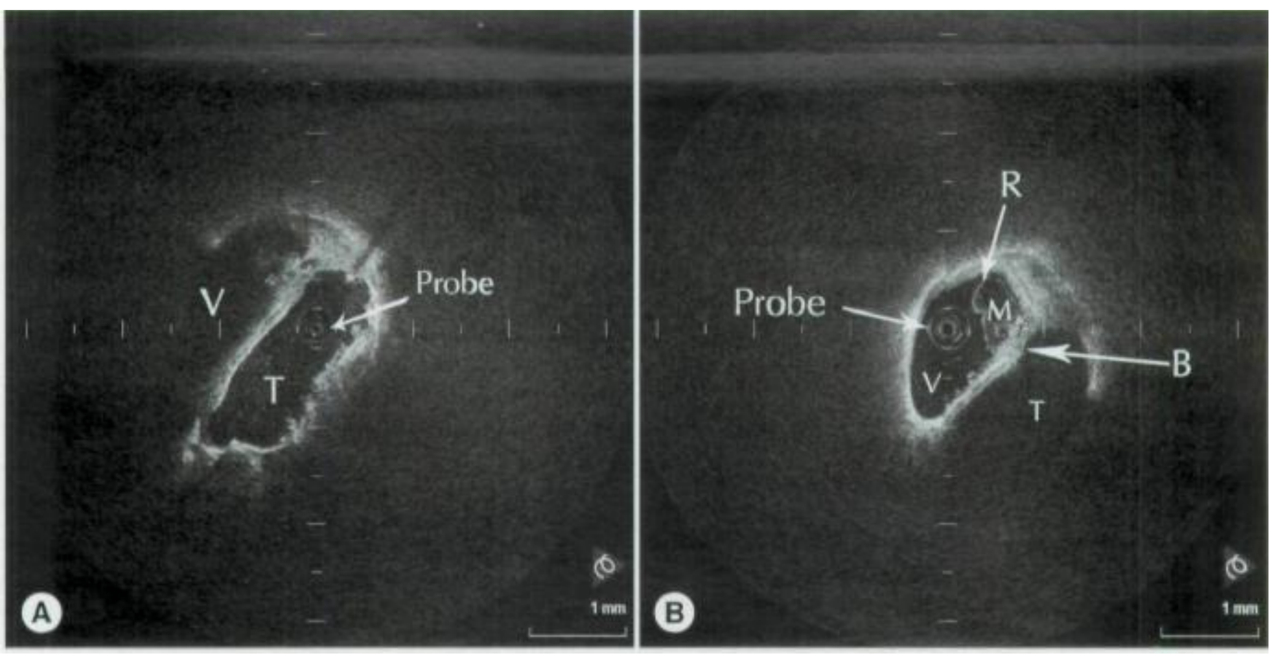

Figure 3

Courtesy Lin et al

Assessment

This paper is important because it proves the efficacy of OCT imaging within the cochlea, which is a vital component of the “Constructing a Model of the Cochlea from OCT Images” project. It uses a side-viewing probe to produce a b-scan, which is similar to the model-obtaining method used in the project. This paper doesn’t take it that one step further and attempt to obtain a contour from the data, it simply sets out to see if it is possible to obtain this data in the first place. So, it allows us to have a good starting point on imaging for our project instead of needing to test several model-obtaining techniques and seeing which ones work well.

Future work includes applying OCT imaging of the temporal bone to intratympanic injections. Information vital to this process can be obtained from the model and b-scans of the cochlea, including “round window plugs” or “false membranes” which the surgeon needs to take into account during the procedure. Endolymphatic hydrops may also be imaged using this process through the myringotomy or a tmpanometeal flap. Another possible application is a guide for intrascalar injections, which could also benefit from additional information obtained from OCT imaging. There are various possible future applications of OCT imaging, especially in the inner ear as proven here. It has incredibly high accuracy, as well as the ability to scan in confined spaces. The combination of OCT and robot control has the potential to improve upon the visualization and precision of medical procedures, as this paper helps to prove.