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„Instrument Flight" to the Inner Ear

A team of surgeons and engineers of Inselspital, Bern University Hospital, and the ARTORG Center for Biomedical Engineering Research, University of Bern, have developed a high-precision surgical robot for cochlear implantation. On 15 March they report on their first successful Robotic Cochlear Implantation (RCI) in *Science Robotics*.

To embed an electronic cochlear implant device into the ear of a deaf patient, the surgeon has to create a precise access from behind the ear, through the skull bone all the way into the inner ear. The implant electrode that bridges the damaged part of the inner ear to allow the patient to hear again is then carefully inserted into the cochlea through the access in the bone. Currently this procedure is carried out manually and the ear, nose and throat surgeon directly views the access into the cochlea through the opening in the skull bone.

The aim of the Bernese research project was to investigate robotic cochlear implantation technology that could lead to a novel implantation procedure with improved hearing outcomes for CI patients. The researchers found that the use of surgical planning software and a robotic drill process could allow access to the cochlea through a tunnel of approximately 2.5 mm in diameter in a straight line from behind the ear. However, the size and scale of such a robotic procedure mean that the robot carries out the drilling procedure without the need for direct, manual operation by the surgeon. The challenge for RCI was to design and develop a failsafe safety system that could track and control the robotic drilling activity beyond the capabilities of the human surgeon, meaning without direct visual control. In the same way that avionics allow a pilot to fly a plane by instrument solely based on read-outs from the cockpit, the surgical robot developed by the researchers for RCI has the capabilities to perform surgery that a surgeon cannot carry out manually without a robot.

The critical developments that have led to the breakthrough first procedure on a patient are the reliable, computer-controlled safety mechanisms applied to the actions of the robot when drilling the tunnel into the side of the patient's head. The minimally-invasive keyhole tunnel runs at a safe distance between the facial nerve and the chorda tympani nerve into the cochlea so that the electrode wire of the implant can be inserted through this opening into the cochlea at the preplanned angle.

Safe navigation and drilling inside the human ear that avoids damage to these nerves and the microscopic structures of the inner ear is accomplished through a combination of three interlocking safety components that act as the eyes, ears and touch of the surgeon. Outlining the safety elements, Prof Weber of the ARTORG Center for Biomedical Engineering Research, University of Bern, explains: "The robot relies on a number of sensors which are a high-accuracy, optical tracking system,

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a sensor for resistance that can “feel” the texture of the bone while drilling, and a radar-like nerve stimulation probe that sends small electric pulses into the bone from which the robot can compute whether or not it is on the preplanned track”. All of this instrument information tells the surgeon, where the robot is at any given moment and controls safe drilling.

“This first Robotic Cochlea Implantation is the result of a decade of multidisciplinary research by a team of biomedical engineers, neuroradiologists, neurologists, audiologists, allied health professionals and surgeons,” says Prof Marco Caversaccio of the Department of ORL, Head and Neck Surgery, Inselspital, Bern. The technology underwent rigorous technical and laboratory testing stages to ensure patient safety that would allow the translation of such complex technology from the lab into the operation room.
“Our results encourage us that we have addressed many of the challenges of using a robot for cochlear implantation surgery,” Caversaccio adds. Follow-on developments including drug delivery to the inner ear are being planned. These translational biomedical engineering projects will involve support through the Swiss Insitute for Translational and Entrepreneurial Medicine – sitem-insel AG http://www.sitem-insel.ch.

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Legend
Fig 1: RCI Trajectory for entry into the cochlea at the preplanned angle. Yellow: Facial Nerve, Orange: Chorda Tympani, Light Blue: Cochlea, Dark Blue: Posterior Wall of the External Auditory Canal, Purple: Ossicles, Green: Planned Trajectory, Grey: Robot Drill Bit.

Fig 2: Robot aligned with entry trajectory on phantom head.

Fig 3: RCI drill trajectory across the mastoid bone.

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