Insertion of electrode array using percutaneous cochlear implantation technique: a cadaveric study

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Abstract

Cochlear implantation is a surgical procedure for treating patients with hearing loss in which an electrode array is inserted into the cochlea. The traditional surgical approach requires drilling away a large portion of the bone behind the ear to provide anatomical reference and access to the cochlea. A minimally-invasive technique, called percutaneous cochlear implantation (PCI), has been proposed that involves drilling a linear path from the lateral skull to the cochlea avoiding vital structures and inserting the implant using that drilled path. The steps required to achieve PCI safely include: placing three bone-implanted markers surrounding the ear, obtaining a CT scan, planning a surgical path to the cochlea avoiding vital anatomy, designing and constructing a microstereotactic frame that mounts on the markers and constrains the drill to the planned path, affixing the frame on the markers, using it to drill to the cochlea, and inserting the electrode through the drilled path. We present in this paper a cadaveric study demonstrating the PCI technique on three temporal bone cadaveric specimens for inserting electrode array into the cochlea. A custom microtable, which is a type of microstereotactic frame that can be constructed in less than five minutes, was fabricated for each specimen and used to reach the cochlea. The insertion was successfully performed on all three specimens. Post-insertion CT scans confirm the correct placement of the electrodes inside the cochlea without any damage to the facial nerve.

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1. Purpose

Cochlear implantation is a surgical treatment for patients with sensorineural hearing loss. An electrode array is inserted into the cochlea to stimulate the auditory nerve and is coupled to an internal receiver, which forwards signals to the electrode array. The current surgical technique for cochlear implantation includes mastoidectomy and posterior tympanotomy, which requires a wide surgical exposure to clearly identify anatomic landmarks for avoiding injury to critical structures such as the facial nerve, which when damaged causes paralysis of the ipsilateral side of the face. Average time for this traditional approach is 171 minutes [1]. To reduce the invasiveness, a minimally-invasive surgical technique called percutaneous cochlear implantation (PCI) has been developed. PCI involves drilling to the cochlea via a linear path from the skull avoiding damage to the surrounding vital anatomy. Customized microstereotactic frames are used to provide guidance and constrain a surgical drill along the planned path. This technique has the potential to reduce the average surgical time to about 60 minutes. In this paper, we report the cadaveric study that demonstrates the insertion of electrode array into the cochlea using the PCI technique.
2. Methods

PCI via customized microstereotactic frames involves the following steps.

1. Fiducial marker implantation: Three fiducial markers are bone-implanted surrounding the ear.

2. CT acquisition: A CT scan is acquired. We use an xCAT ENT mobile CT scanner (Xoran Technologies, Ann Arbor, MI) with a voxel size of 0.3 mm in all directions.

3. Automatic path planning: The structures of the ear, namely the cochlea, the facial nerve, the chorda tympani, the external auditory canal, the labyrinth, and the ossicles, are automatically segmented in the CT image [2, 3], and a safe drill trajectory is determined that will aim at the cochlea avoiding the critical structures [4]. The fiducial markers are also localized in the CT image.

4. Design and fabrication of surgical guide: A microstereotactic frame, called a Microtable, is then designed automatically such that it will mount, as shown in Figure 1, on the fiducial markers and constrain the drill to the planned drill path. The Microtable consists of a small tabletop with three legs for mounting the tabletop on the markers with lengths adjusted to produce the desired orientation. The tabletop has three holes though which the three legs are attached and a target hole to guide tools along the desired trajectory. The tabletop is fabricated using a standard computer-numeric-control (CNC) milling machine in less than 5 minutes [5].

5. Drilling to the cochlea: The Microtable with a custom drill press attached is mounted on the fiducial markers and used to drill to the cochlea [6].

6. Insertion of electrode: After drilling, the drill press is removed and a manual insertion tool [7] is used to insert the electrode into the cochlea. Figure 1 shows the assembly during insertion into a temporal bone specimen, and the insertion tool with the cochlear implant electrode array loaded is shown attached to the Microtable. Via the control knob, the electrode array is pushed through the drilled hole (performed in the previous step) and into the cochlea using the advance off stylet (AOS) technique.

Figure 1. Percutaneous cochlear implantation. Microtable is shown attached to the fiducial markers on the temporal bone cadaveric specimen. The insertion tool is attached to the Microtable and guides the electrode array into the cochlea through the drilled path.
3. Results

PCI was performed on three cadaveric temporal bone specimens. All the steps described in the Methods section were performed on each cadaveric specimen. Custom Microtables were made for each specimen to enable drilling to the cochlea and insertion of electrode array into the cochlea. Drilling was performed using a 6 mm twist drill bit from the lateral skull toward the target until the drill was 20 mm from the target and then using a 1.9 mm twist drill bit for the remaining 20 mm to the target. A CT scan was acquired after drilling to make sure the desired trajectory was achieved. In all the specimens, the drill reached the cochlea without damaging the facial nerve. Figure 2 provides a screenshot of a post-drill CT scan showing the drilled path to the cochlea and the planned path (red dashed line). Insertion was then performed using the Microtable and manual insertion tool (Figure 1). A third CT scan was acquired after insertion of the electrode to analyze the quality of the insertion. In all the specimens, the insertion was satisfactory with the electrode array inside the cochlea as desired. Figure 3 is a screenshot of a post-insertion CT scan showing that the electrode array is inside the cochlea.

4. New or breakthrough work to be presented

The traditional surgical technique for cochlear implantation is widely invasive and takes an average of 171 minutes [1]. The PCI technique described is a minimally-invasive technique which can potentially be performed in 60 minutes. The cadaver study reported is the first one demonstrating the insertion of electrode array into the cochlea using this approach. With the availability of an intraoperative CT scanner, all the steps involved in PCI can be implemented completely in the operating room.
5. Conclusions

We have demonstrated on cadaveric specimens the PCI procedure to perform cochlear implantation. Customized Microtables, which are microstereotactic frames that can be manufactured in less than five minutes, were used to guide the drill and insertion tool along the desired path. Drilling and electrode array insertion into the cochlea was successfully performed without any damage to the facial nerve. The results provide encouragement to extend this technique to clinical implementation.

6. Previous submissions: The PCI technique has been described earlier, but the cadaveric study for inserting electrode array using the manual insertion tool has not been presented before.

References