A NEW METHOD TO DETERMINE THE OPTIMAL ORIENTATION OF SLIM MODIOLAR COCHLEAR IMPLANT ELECTRODE ARRAY INSERTION

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Background and purpose – Our goal was to determine the optimal orientation of insertion of the Slim Modiolar electrode and develop an easy-to-use method to aid implantation surgery. In some instances, the electrode arrays cannot be inserted in their full length. This can lead to buckling, interscalar dislocation or tip fold-over. In our opinion, one of the possible reasons of tip fold-over is unfavourable orientation of the electrode array. Our goal was to determine the optimal orientation of the Slim Modiolar electrode array relative to clear surgical landmarks and present our method in one specified case.
Methods – For the measurement, we used the preoperative CT scan of one of our cochlear implant patients. These images were processed by an open source and free image visualization software: 3D Slicer. In the first step we marked the tip of the incus short process and then created the cochlear view. On this view we drew two straight lines: the first line represented the insertion guide of the cochlear implant and the second line was the orientation marker (winglet). We determined the angle enclosed by winglet and the line between the tip of the incus short process and the cross-section of previously created two lines. For the calculation we used a self-made python code.
Results – The result of our algorithm for the angle was 46.6055°. To validate this result, we segmented, from the CT scan, the auditory ossicles and the membranaceous labyrinth. From this segmentation we generated a 3D reconstruction. On the 3D view, we can see the position of

ÚJ MÓDSZER A VÉKONY PERIMODIOLÁRIS COCHLEARIS IMPLANTÁTUMELEKTRÓDA IDEÁLIS BEVEZETÉSI IRÁNYÁNAK MEGHATÁROZÁSÁRA
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Háttér és cél – Célunk az volt, hogy meghatározzuk a vékony perimodioláris elektróda bevezetésének optimális irányát a műtéti orientációt segítő anatómiai struktúrákhoz képest, és könnyen használható módszert dolgozzunk ki az implantátum műtétjének segítésére. Bizonyos esetekben az elektródasor a cochleán belül visszafordul. Véleményünk szerint ennek a problémának az egyik lehetséges oka az elektródasor kedvezőtlen bevezetési iránya. Módszerünket egy kiválasztott speciális eseten mutatjuk be.
Módszerek – A méréshez az egyik cochlearis implantátummal ellátott betegünk preoperatív CT-felvételét használtuk. A felvételt egy nyílt forráskódú és ingyenesen használható képmegjelenítő szoftverrel, a 3D Slicerrel dolgoztuk fel. A mérési módszer kezdeti lépése az üllő rövid nyúlványa csúcsának a kijelölése. Ezután létre kell hozni a cochlearis nézetet, és ezen a nézeten két egyenes vonalat berajzolni: az első vonal az elektródasor vezetőjét, a második vonal az orientációs jelzőt jelenti. A meghatározni kívánt szög az orientációs jelző és az üllő rövid nyúlványát a korábban felvitt egyenesek metszéspontjával összekötő egyenes által bezárt szög. A számításhoz egy saját python kódot használtunk.
Eredmények – Az algoritmusunk eredménye 46,605° volt. Ennek validálásához a hallócsontokat és a hártyás labirintust kiszegmentáltuk a CT-felvételből, majd ebből készítettünk egy 3D-s modellt, amelyben láthatjuk az előző vonalak helyzetét az anatómiai struktúrákhoz képest. Ezután elforgattuk a 3D-s modellt a vonalakkal

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the previous lines relative to the anatomical structures. After this we rotated the 3D model together with the lines so that the insertion guide forms a dot. In this view, the angle was measured with ImageJ and the result was 46.599°.
Conclusion – We found that our method is easy, fast, and time-efficient. The surgery can be planned individually for each patient, based on their routine preoperative CT scan of the temporal bone, and the implantation procedure can be made safer. In the future we plan to use this method for all cochlear implantation surgeries, where the Slim Modiolar electrode is used.

Keywords: *cochlear implantation, surgery planning, image processing, tip-fold over, Slim Modiolar*

együtt, hogy az elektródasor vezetője pontként ábrázolódjon. A szöget ImageJ-jel megmérve az eredmény 46,599° lett.
Következtetés – Megállapítottuk, hogy módszerünk egyszerű, gyors és időhatékony. A műtétet minden beteg számára egyedileg lehet megtervezni a műtét előtt készített CT-felvétel alapján, és segítségével biztonságosabbá tehető a vékony perimodioláris elektróda implantációja. A jövőben tervezzük, hogy minden vékony perimodioláris elektródával folytatott műtét előtt elvégezzük a méréseket, ezáltal növelve az implantáció sikerességét.

Kulcsszavak: *cochlearis implantáció, műtéti tervezés, képfeldolgozás, tip-fold over, Slim Modiolar*

Cochlear implantation is an effective hearing rehabilitation technique for patients with severe-to-profound sensorineural hearing loss[1]. The spiral ganglion cells are directly stimulated by electrical signals that are transmitted via an electrode array that is surgically inserted into the cochlea. This can lead to buckling, interscalar dislocation or tip-fold over[2–5]. Another possible hazard is short circuiting and implant loss.

The highest proportion of the cochlear implants (CI) that were implanted at the Department of Otorhinolaryngology, Head and Neck Surgery, University of Szeged were Cochlear™ Nucleus® CI532 and CI632 since 2015. Both devices are mounted with one of the thinnest perimodiolar electrode arrays (Slim Modiolar)[6]. Periomodiolar means that the electrode array is pre-curved and this property predisposes its close-to-modiolus or modiolus hugging position. The reason our team has preferred this specific electrode array is: its potential to be superior to the thicker Contour Advance and straight electrode with regards to proximity to the modiolus; lower energy consumption for stimulation and less trauma to the cochlea[7–10]. On the other hand, although easy after proper training, the insertion procedure can be challenging[11]. An adverse event, tip fold-over of the Slim Modiolar electrode, has been reported with higher incidence than with other electrodes.

In our opinion, one of the possible reasons of tip fold-over is unfavourable orientation of the electrode array. Thus, proper orientation of the electrode during insertion can be considered a possible method of prevention of tip fold-over. Our goal was to determine the optimal orientation of the Slim Modiolar array relative to clear surgical landmarks and present our method in one selected case.

Methods

For the measurement, we used the preoperative CT scan (slice thickness 0.6 mm, no gap, bone kernel) of one of our cochlear implant patients. Selection criteria were good quality high-resolution CT scan of the temporal bones, without a reported anatomical malformation and uncomplicated cochlear implantation with a perimodiolar (Cochlear™ Slim Modiolar) electrode array. The good quality of the CT scan and the normal anatomy of the selected 70-year-old male subject was confirmed by a radiologist who obtained subspecialisation in head and neck imaging. These images were processed by an open source and free image visualization software: 3D Slicer (version: 4.10.1, operating system Win10)[12–14], that is available on all platforms (Win, Mac, Linux). This software is able to read many image file formats, including DICOM. After having imported the DICOM files, we converted the image series into single ".nrrd" files, the proprietary file format of 3D Slicer. By doing this conversion process, 3D Slicer anonymizes the images, after which the images do not contain any personal information on the patient.

In our case study we present our semi-automatic algorithm to perform the measurements related to visible surgical landmarks.

In the first step, the user created the cochlear view (Plane A)[15]. The basal turn of the cochlea is best seen in one special plane, i.e. the cochlear view. This plane can be easily created by rotating the coronal plane. The plane of the cochlear view is practically the plane of the proper electrode insertion.

Subsequently, the user created two straight lines: the first line represented the insertion guide of the

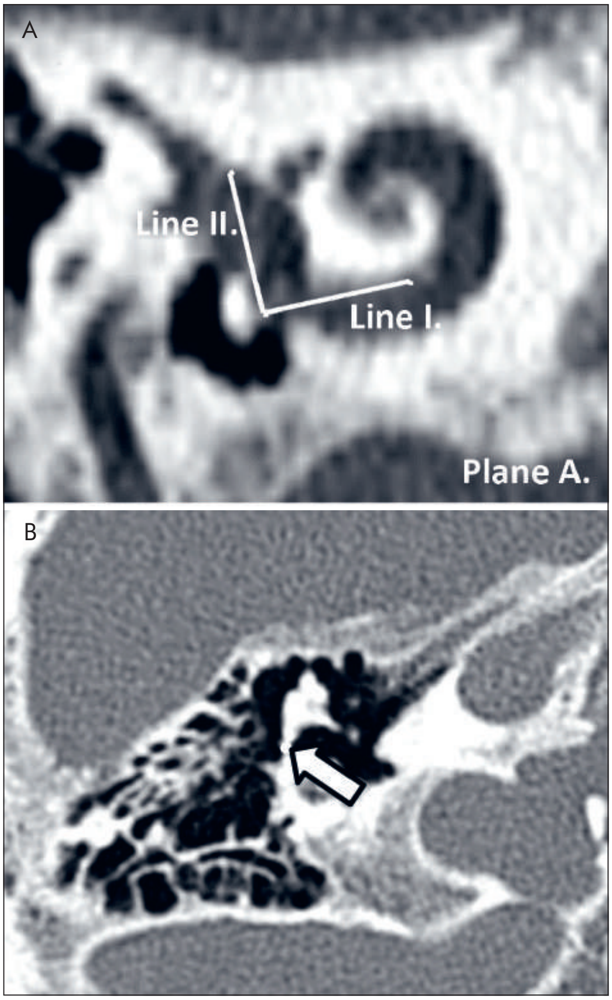

Figure 1. A. *The cochlear view of the right cochlea (Plane A), and the lines defined as Line I. (insertion guide) and Line II. (orientation marker, called winglet),* **B.** *the tip of the incus short process on the axial plane in the right temporal bone (arrow)*

cochlear implant (Line I.) and the second line the orientation marker (winglet, Line II.) shown in **Figure 1.A**. These two lines are perpendicular to each other and intersect at the round window. Finally, the user marked the tip of the short process of the incus **(Figure 1.B)**. The incus short process was depicted on the CT scan and was connected with the cross-section of the winglet and the insertion guide. This is the line to which we compare the position of the winglet.

The above mentioned three parameters are sufficient to calculate the optimal angle of the orientation marker. We determined the angle enclosed by Line II. and the line between the tip of the incus short process and the cross-section of Line I. and Line II. This third (virtual) line is coded as Line III. Although the surgeon is able to visualize the depth (3D view) with the surgical microscope, estimation of angles and planning the surgery is easier and more accurate in one plane (2D view). For this reason, we projected Line I. and Line II. onto one common plane (Plane B). This plane is perpendicular to the Plane A Line I., and parallel with Line II. **(Figure 2)**.

Plane B will be outside the real surgical view. Nevertheless, we do not need to move the Plane B (projection plane) into the view of the surgery, because the projection does not change the measured angle. For this mathematic problem, we wrote an algorithm in python (Python 3), to quantify the angle enclosed between these lines in degrees.

Results

The good quality of the CT scan of the right temporal bone was confirmed by a trained head and neck radiologist. The radiologist also confirmed that the temporal bone was free of anatomical malformation, which was consistent with the official radiologist's report. Each step by the user (determination of the landmarks, lines and planes) was approved by the radiologist. The postoperative radiography showed unremarkable position of the electrode inside the cochlea **(Figure 3.A)**. On **Figure 3.B** is shown a microscopic view with the landmarks (incus short process, round window) and the electrode array with the insertion sheath. The result of our algorithm for the angle between the projected lines (incus–round window and insertion direction) was 46.605 degrees. To validate this result, with 3D Slicer we segmented the auditory ossicles and the

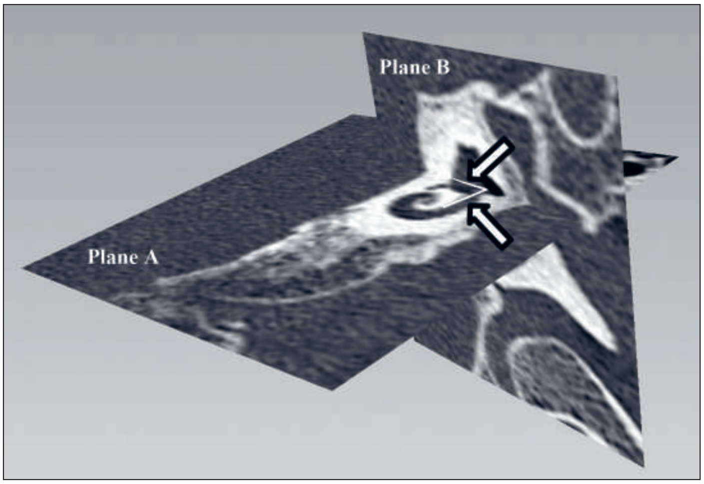

Figure 2. *Plane A: the cochlear view of the right cochlea with the drawn lines (Line I. and Line II.) as shown by arrows, Plane B: the projection plane that contains the line of the orientation marker (Line II.). The user projected the reference line onto Plane B*

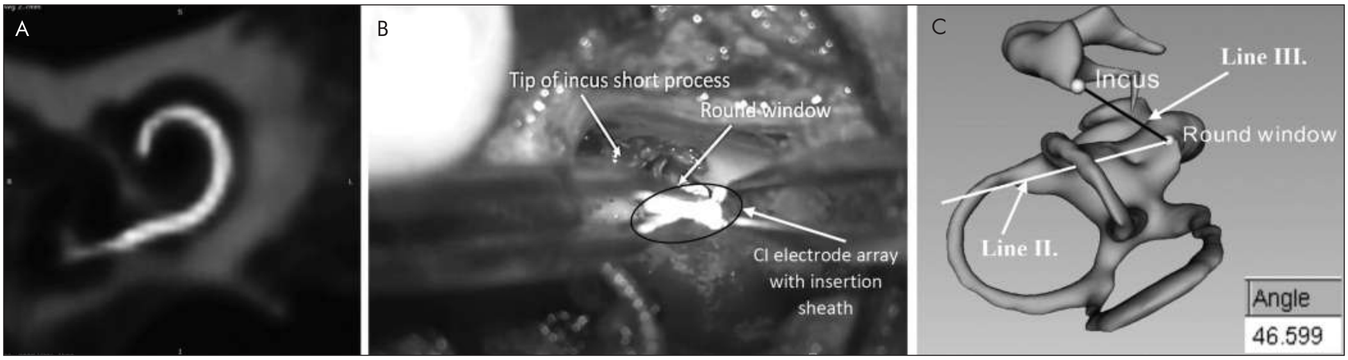

Figure 3. A. *Postoperative 3D volume tomography of the inserted electrode, reconstruction in the cochlear view.* **B.** *The microscopic view through the posterior tympanotomy to the landmarks (incus short process, round window) and orientation of the electrode array with the insertion sheath.* **C.** *3D model of the auditory ossicles (i.e. incus, malleus and anterior crus of stapes) and the membranaceous labyrinth. Black line: reference line (Line III.), white line: orientation marker (Line II.), the angle (measured with ImageJ) was approx. 47 degrees*

membranaceous labyrinth (on CT the liquid and air are hypodense). From this segmentation, we generated a 3D reconstruction. On the 3D view we can see the position of the lines, as shown previously on **Figure 1.A** and **Figure 2** (Line I., Line II.) relative to the anatomical structures **(Figure 1.B)**. Afterwards, we rotated the 3D model together with the lines (Line I., Line II. and Line III.) so that the insertion guide (Line I.) forms a dot as shown in **Figure 3.C**. In this view the angle was measured with ImageJ and the result was 46.599°.

Discussion

Our goal was to determine the optimal orientation of insertion of the Slim Modiolar electrode and develop an easy-to-use method to aid implant planning and surgery. Reference structures that can be clearly visualized during surgery and clearly noticed on the CT image, are essential. The short process of the incus and the round window were chosen as clear anatomical landmarks, due to their nature of visibility during routine cochlear implant surgery via posterior tympanotomy. The surgeon is able to detect these landmarks and relate the position of the electrode array to them. With this measurement tool we aimed to effectively prevent electrode tip fold-over[2, 4, 5], a relatively common adverse event from Slim Modiolar electrode. We assume that a possible reason of tip fold-over is unfavourable orientation of electrode during insertion. Other reasons include the various anatomical structure of cochlea, for example: size, orientation, length, and malformations[16], so it is necessary to individually plan the surgery beforehand.

In this paper we presented a new method to determine the optimal insertion angle of the Slim Modiolar cochlear implant electrode. We found that our method is easy, fast, and time-efficient. The surgery can be planned individually for each patient based on their routine preoperative CT scan of the temporal bone and the implantation procedure can be made more safe. In the future, we plan to use this method for all cochlear implantation surgeries, where the Slim Modiolar electrode was used.

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