Navigation-Guided Transmodiolar Approach for Auditory Nerve Implantation in Human

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INTRODUCTION
Intraneuronal stimulation Versus Intrascalar stimulation
First attempts of auditory stimulation in patients with profound sensorineural hearing loss were focused on implanting electrodes directly into the auditory nerve.

In pioneering experiments by Simmons et al., bundles of 4 or 6 wires were implanted into the auditory nerves of human volunteers through a transcochlear approach [Simmons et al., 1965, 1979; Simmons, 1966]. However, the intraneuronal stimulation was abandoned in favor of more promising results from intrascalar electrodes.

Intraneuronal Stimulation and the Ossified Cochlea

In spite of having many techniques proposed to overcome this outstanding challenge.

- The total drill-out technique [Gantz et al., 1988],
- The intact canal wall drill-out procedure [Balkany et al., 1997],
- The short inferior tunnel insertion [Cohen and Waltzman, 1993],
- The double-electrode array [Lenarz et al., 2001].

All these techniques poor functional results partly because of the poor contact between the electrodes and the nerve endings [Assenova et al., 2007].

Intraneuronal stimulation can offer a theoretical solution for this challenge.
• Ordinary CI have a relatively high electrical consumption and low energy autonomy. This is explained by the distance separating ST electrodes from the auditory nerve fibers [Micco and Richter, 2006].

• In contrast, the stimulation thresholds for intraneural electrodes are approximately 50-fold less than ST stimulation Reduction in power consumption in practical clinical devices with the possibility of having a totally implantable device. [Middlebrooks and Snyder, 2007, 2008, 2010].
Limitations of Ordinary Cochlear Implants

• Modern cochlear implants commonly provide adequate auditory information for verbal communication although hearing in noise remains relatively poor even when using bilateral CI [Carlson et al., 2012].

• Many of these limitations can be attributed to:

  1- The remote location of stimulating electrodes relative to excitable cochlear neural elements. So passage of current is subjected to
     - Shunting by the surrounding volume of electrically conductive perilymph.
     - Attenuation by the semiporous bone of the osseous spiral lamina.

     Impair low threshold activation of frequency-specific neural elements.

  2- Most cochlear implants are inserted at the cochlear base and reach no further than the middle turn of the cochlea impairs frequency-specific stimulation of the cochlear apex that is responsible for low-frequency hearing. [Middlebrooks and Snyder, 2007].

Recently, Intraneural stimulation was reissued again as a mode of auditory prosthesis with an increasingly strong level of evidence that it would have a superior performance compared the ordinary CI.

1. What is the ideal surgical approach for intraneuronal stimulation? Is it feasible & reproducible?

2. Is it a safe procedure? Anatomical & Histological studies.

3. What is the expected audiological outcomes? Electrophysiological studies in animals.
Anatomical studies

• The cochlea has a unique pattern of vascular supply with no blood vessels in the central part of the modiolus no risk of vascular injury during the implantation [Badi et al., 2003; Assenova et al., 2007].

Histological studies

• Post-mortem histological examination showed little or no local tissue reaction to the long term stimulation of the modiolar segment of the auditory nerve, whether in human (after 5 years of the implantation) [Simmons et al., 1986] or in animals [Simmons et al., 1979].
Physiologic principles for Intraneuronal Stimulation

• **Intraneuronal Stimulation** provides an intimate contact between the electrodes and the auditory nerve fibers → **direct** path of the current to **restricted** populations of nerve fibers → low-threshold, frequency specific activation of the tonotopic axis of the auditory pathway including specific stimulation of low-frequency fibers that are not directly accessible by ST electrodes.

[Middlebrooks and Snyder, 2007, 2008].
The ideal surgical approach for intraneuronal stimulation

• **The transcochlear approach** through **the basal cochlear turn** by Simmons [Simmons, 1966, 1983; Simmons *et al.*, 1979] and Badi *et al.* [Badi *et al.*, 2002] destroys cochlear structures & high incidence of CSF leakage [Miller and Hillman, 2006].


• **The posterior fossa approach** to **the intracranial part** of the auditory nerve craniotomy related risks, also the tonotopic organization within the intracranial portion of the nerve might be more variable than in the modiolar trunk [Middlebrooks and Snyder, 2008].

• **The infra labyrinthine approach** to **the intracranial part** of the auditory nerve; implantation is more difficult and traumatic because the auditory nerve is free to move in this segment. Also, the access may be blocked by a high jugular bulb [Middlebrooks and Snyder, 2008].
Aim of the work
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To progress toward a minimally invasive transmodiolar cochlear implantation by evaluating the surgical feasibility of transmodiolar implantation in human using neuronavigation system.
METHODS AND MATERIALS
The study was conducted in two parts:

1- Surgical feasibility study.

2- Radio anatomical study for assessment of the most relevant anatomical parameters for the approach.
1- Surgical feasibility study

1. Specimens and Preoperative Imaging

• The study was performed on 6 adult human temporal bones.
• Preimplant High-resolution CT scan was performed in all specimens.

2. Computer-assisted approach to modiolus

• DICOM data were uploaded on a neuronavigation system (Digipointe®r, Collin Ltd., Bagneux, France). The target entry point and the modiolar length were identified on the images.
• Canal-wall-down mastoidectomy was performed.
• The modiolus was accessed through an apical cochleostomy using a piezo-electric drill (Piezosurgery®, Mectron Ltd., Carasco, Italy) with an angled insert to perform the apical cochleostomy.
• The drill trajectory was adjusted in real-time by the surgeon according to the insert position and the modiolar axis displayed on the neuronavigation screen.
• Stainless steel wire (diameter: 0.6 mm) was implanted into the modiolus and secured with bone cement.
Neuronavigation System Screen
**Experimental setting.** The temporal bone with 4 titanium screws on the mastoid was maintained firmly in a vise (The receptor of the navigation system was screwed to the squama. The emitter was attached to the piezoelectric drill to track the drill tip during the approach).
1- Surgical feasibility study

3- Assessment of the Approach

Post procedure **Cone beam CT-scan** (New Tom 5G ®, New Tom, Verona, Italy) was performed for the assessment of:

- The intracochlear wire placement.
- The precision of the entry point (Target registration error was assessed on 3 planes (X: axial; Y: coronal; Z: sagittal).
2- Radio Anatomical Study

- 122 High-resolution temporal bone CT-scans were obtained from 70 patients (39 adults and 31 children) with intact external auditory canal, middle ear and cochlea.
- The scans were analyzed for the most relevant anatomical parameters to this approach.
- The length of the modiolus with and without the overlying bone was evaluated on an oblique axial view passing through the modiolus and the lateral semicircular canal plane.
- Angles below 90° would necessitate a backward and difficult drilling and those above 90° a more inward and easier drilling.
- Anatomical parameters were compared between the specimens (n=6), the adult (n=69), and the pediatric (n=53) populations. Values were expressed as mean ± SEM. Comparisons were tested by one-way ANOVA followed by Tukey’s multiple comparison test.
Anatomical measurements; on oblique axial view passing through the modiolar and the lateral semicircular (LSCC) planes (left temporal bone)
Anatomical measurements on oblique axial views. On an oblique axial view of a left temporal bone passing through the modiolar and the lateral semicircular (LSCC) planes (Left)
1- **Surgical feasibility Study**;

The Transmodiolar approach was feasible in all temporal bones. However, the angle of the insert didn’t allow an optimal trajectory in all cases. The entry point was slightly deviated backward from the modiolar axis in two temporal bones.

- The array was completely implanted down to the inner end of the modiolus in temporal bones II, III, IV and VI with an average intracochlear length of $3.6 \pm 1.11$ mm.
- The mean vector distance of the target accuracy at the entry point ($\sqrt{X^2+Y^2+Z^2}$) was $0.065 \pm 0.0583$ mm.
- This estimation was close to the intrinsic system accuracy ($0.11$ mm).
Comparison of neuronavigation images (upper) and postoperative cone beam CT scan (lower) in specimen III in axial (left), coronal (middle) and sagittal planes (Right). The crosshair shows the position of the instrument tip. The axis of the virtual instrument corresponds to the axis of the distal segment of the instrument.
RESULTS

2- Radio anatomical study:

There was a significant difference between both age groups:

• The distance between the cochleostomy and the carotid artery. longer in adults and in the specimens than in children (3, 4.3 ± 1.35 mm, n=69 versus 3.8 ± 1.33 mm, n=53 respectively, p=0.07, one-way ANOVA).

• The distance between the cochleostomy and posterior limit of the TMJ capsule. longer in adults in comparison to children (distance 7.8 ± 0.2 mm, n=69 versus 5.9 ± 0.14, n=53 respectively, One-way ANOVA followed by Tukey’s post-test, p < 0.0001).

• In contrast, there was no difference between both age groups regarding
• The modiolar length. (Mean ± SD, 4.14±0.34 in adults - 4.22 ± 0.27 in pediatrics)
• The distance from the cochleostomy to the anterior wall of the ET or to the stapedial head.
Modiolus (ab)  Modiolus+ bone (ac)  Distance to CA (cf)  Distance to ET (cd)  Distance to TMJ (ce)

Adult (n=69)  Children (n=53)  Specimen (n=6)

Modiolus-ET angle (α)
CONCLUSIONS AND RECOMMENDATIONS
The present study suggests that:

“Navigator-guided transmodiolar approach for cochlear implantation in human is feasible under laboratory conditions. Inter-individual variability in temporal bone anatomy suggests that neuronavigation is essential for a reproducible procedure”.
THANK YOU...

وَقُلۡ رَبِّ زِدْنِی عِلْماً