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СОДЕРЖАНИЕ

CONTENT

THE VESTIBULAR IMPLANT: ELECTRICAL IMPEDANCES OF THE INNER EAR

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Keywords: *vestibular implant, sensory substitution, electrical impedance, electrical current propagation.*

Relevance

The peripheral vestibular system ("the balance organs") is located in the temporal bone. They each consist of six semicircular canals acting as gyroscopes that detecting head rotations, and four otolith organs acting as accelerometers that detect gravity and linear head motions [1]. Information from the vestibular system is used to maintain balance, stabilize gaze during head movements, and to allow spatial orientation. Bilateral vestibular dysfunction (BVD) severely impairs patients' quality of life [2]. No medical treatment to restore lost vestibular function exists and physical therapy is only mildly effective in BVD patients [3]. One of the promising and recent solutions is an artificial balance organ: the vestibular implant (VI). The idea is to substitute the vestibular organ by a number of motion sensors together with an electrical stimulator, which delivers information directly to the vestibular afferents. The VI has 3 vestibular electrodes which are placed in the inner space of semicircular canal ampullas in the vicinity of vestibular afferents. The electrodes provide the information about the head rotations by means of biphasic electrical pulses [4]. The task of this study was to assess the electrical parameters in the inner ear space to be used in current propagation models.

Objective

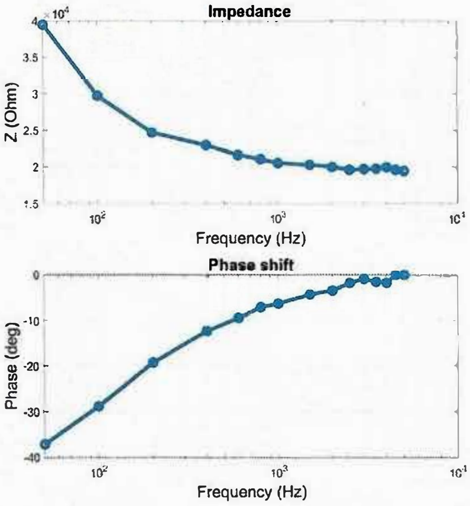
This study was aimed to investigate the electrical properties, viz. impedance, of the inner ear tissues located between three semicircular canal ampullas and vestibular nerve (Scarpa's ganglion) in human samples *in vitro*.

Material and methods

Trained surgeons (JS and LM) performed a mastoidoctomy on an isolated human head in order to reach the bony labyrinth and the vestibular nerve. Then three small fenestrations were made in the semicircular canals next to the ampullae. Four spherical electrodes made of silver with a diameter of 0.5 mm were inserted into the ampullar cavities (mimicking the position of VI electrodes) and Scarpa's ganglion. After that, each couple of electrodes was used to measure the electrical impedance and the phase shift using sinusoidal voltage signals with 0.1 V amplitude in the frequency range from 50 Hz to 5 kHz. A digital generator provided sinusoidal signals, whereas the digital oscilloscope was used to simultaneously measure the voltage V and the current I in the circuit. The impedance Z was calculated as a function of frequency according the following formula: $Z(f) = \frac{V}{I}$.

Results

The obtained volt-ampere curves (Figure) showed a non-linear behavior over the chosen range of measurement frequencies, which indicates the presence of reactive component in the impedance together with the active component related to a plateau part of the graph.



Electrical impedance (upper) and phase shift (lower) of the inner ear tissues between lateral ampulla and Scarpa's ganglion

Conclusion

Since biological tissues do not possess the inductive properties, one can assume the reactive part of the electrical impedance is caused by the capacitance. It might arise due to living cell membranes or to a double electrical layer occurring at the "electrode-electrolyte" domain, since each electrode is immersed in a liquid.

The obtained results are crucial for understanding the processes of electrical stimulation, e.g. the shape of a rectangular pulse can change drastically while passing the capacitive medium. The results will be used to develop models of electrical conductivity in the temporal bones.

Acknowledgements

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TESTING THE FEASIBILITY OF RESTORING THE HIGH-FREQUENCY DYNAMIC VISUAL ACUITY WITH A VESTIBULAR IMPLANT PROTOTYPE IN HUMANS

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Keywords: *vestibular prosthesis, vestibular implant, neural prosthesis, bilateral vestibulopathy, functional head impulse test, dynamic visual acuity.*

Relevance

During abrupt head rotations, the semicircular canals in the vestibular system detect acceleration and induce an ocular reflex that generates compensatory eye movements: the vestibulo-ocular reflex (VOR). This mechanism allows the visual environment to remain stable on the retina to preserve visual acuity in dynamic conditions (DVA). Unfortunately, the VOR is often impaired in case of bilaterally reduced (or absence of) vestibular function, a condition called "bilateral vestibulopathy". This results in loss of DVA, and, therefore, patients frequently complain of oscillopsia: the illusory movement of the visual environment.

A new test involving fast and high-frequency head movements was recently proposed to assess DVA: the functional Head Impulse Test (fHIT) (1). In this test, patients undergo abrupt head impulses to the right and left and have to identify optotype letters (Landolt C rings) that appear briefly during these impulses. The percentage of correctly identified optotypes is calculated for head impulses to each side.

At this moment, no definite therapeutic option is yet clinically available for bilateral vestibulopathy. However in the last years the feasibility of a possible treatment has been demonstrated: the vestibular implant (VI) (2). The VI attempts to restore head-motion sensitivity by capturing motion and delivering it as electrical current pulses to vestibular afferents via surgically implanted electrodes.

Objective

The goal of this case study was to investigate the feasibility of restoring the high-frequency DVA with a prototype vestibular implant, using the fHIT.

Material and methods

A 72-years old female with bilateral vestibulopathy and fitted with a modified cochlear implant incorporating three vestibular electrodes (MED-EL, Innsbruck, Austria), was available for this study. Electrical stimulation was delivered with the electrode close to the lateral ampullary nerve in the left ear. The high-frequency DVA in the horizontal plane was tested with the fHIT. After training, the patient underwent six trials of the fHIT, each with a different setting of the vestibular implant: 1) System OFF before stimulation; 2) System ON, baseline stimulation; 3) System ON, reversed stimulation; 4) System ON, positive stimulation; 5) System OFF, without delay after stimulation offset 4; 6) System OFF, 25 minutes delay after stimulation offset. The fHIT scores for right and left head impulses were compared between trials using Logistic regression.

Results

Vestibular implant stimulation improved the high-frequency DVA compared to no stimulation (see Table). This improvement was significant for "System ON, baseline stimulation" ($p = 0.02$) and "System ON, positive stimulation" ($p < 0.001$). fHIT scores changed from 19–44% (no stimulation) to maximum 75–94% (System ON, positive stimulation).

Percentage and absolute number of correctly determined Landolt C-optotypes in left- and rightward directed impulses during different test conditions. *=Significant improvement compared to condition $System_{off}$

Side Condition	Left (Implanted) % Correct answers, (absolute number)	Right % Correct answers, (absolute number)
$System_{off}$	19 (3/16)	19 (3/16)
$System_{on}^{baseline*}$	50 (8/16)	56 (9/16)
$System_{on}^{reversed}$	38 (6/16)	25 (4/16)
$System_{on}^{motion*}$	94 (15/16)	75 (12/16)
$System_{off}^{0min}$	44 (7/16)	38 (6/16)
$System_{off}^{25min}$	38 (6/16)	19 (3/16)