Analysis of changes in auditory nerve signals following simulated tinnitus for the verification of cochlear model

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Abstract – **For an interpretation of the tinnitus phenomenon, reticular lamina which transmits energy in a cochlear was assumed as a mass and the components for the stiffness and control were added to the model even though it is perceived just as a thin layer. Then, animal experiment with guinea pigs was devised to evaluate the effect of tinnitus on the auditory nerves. Salicylate was introduced to the animal based on the Jastreboff's tinnitus model for the simulation of tinnitus conditions. It was found that the induction of salicylate caused the variations on the neural responses even without sound stimulation. Also, under the stimulation of sound with different frequencies, power contents varied in chronological order after the injection of salicylate. Parameters for the cochlear model could be extracted based on the results of this study. Moreover, protocols and the effect for the tinnitus treatment using electrical stimulation could be established.**

Keywords – tinnitus, cochlear model, sound stimulus, nerve signal, salicylate

I. INTRODUCTION

Tinnitus is the condition that one feels the sound without external source even in the completely silent soundproof chamber [1]. Ninety-five percent of persons say they have experienced tinnitus of under 20dB, which is not termed as tinnitus clinically. Usually, tinnitus is accompanied with almost every ear disease. Tinnitus itself is not disease, but in chronic and subjective tinnitus, it happens suddenly without special causes. Almost 20% of tinnitus patients complaint that they are inconvenient even in everyday life and it would be direct cause of a depression [2].

Sound in the duct of cochlear is changed to electrical energy and transmitted to the brain via auditory neurons. If any part of the sound path were impaired, tinnitus would possibly happen. Etiology of tinnitus has not yet been confirmed and there have been no satisfactory treatment methods. Therefore, it is very difficult to provide effective treatment methods for the suppression of tinnitus. These are because of the lack of quantified understanding on the mechanism of sound transmission up to the auditory cortex. That is, to provide the effective methods for tinnitus treatment, theoretical understanding for the tinnitus should be established.

For an analysis of sound transmission and those characteristics regarding various pathological disorders in the auditory system, living constitutions should be understood by the simulation of model [3-6]. This study is composed of two main areas, electrical model of cochlear and analysis of changes in nerve signals under simulated tinnitus conditions. Auditory nerve signals to the different frequencies of sound stimulation are obtained following tinnitus induction using salicylate. Results from this study could provide the basis for the verification of the cochlear model. Moreover, conditions for the treatment of tinnitus, electrical stimulation, could be provided.

Report Documentation Page

Report Date	Report Type	Dates Covered (from... to)
25 Oct 2001	N/A	-

Title and Subtitle Analysis of Changes in Auditory Nerve Signals Following Simulated Tinnitus for the Verification of Cochlear Model	**Contract Number**
	Grant Number
	Program Element Number
Author(s)	**Project Number**
	Task Number
	Work Unit Number
Performing Organization Name(s) and Address(es) Division of Electronics and Information Engineering Chonbuk National Univ Korea	**Performing Organization Report Number**
Sponsoring/Monitoring Agency Name(s) and Address(es) US Army Research, Development & Standardization Group (UK) PSC 802 Box 15 FPO AE 09499-1500	**Sponsor/Monitor's Acronym(s)**
	Sponsor/Monitor's Report Number(s)

Distribution/Availability Statement
Approved for public release, distribution unlimited

Supplementary Notes
Papers from 23rd Annual International Conference of the IEEE Engineering in Medicine and Biology Society, Oct 25-28, 2001, held in Istanbul, Turkey. See also ADM001351 for entire conference on cd-rom.

Abstract

Subject Terms

Report Classification unclassified	**Classification of this page** unclassified
Classification of Abstract unclassified	**Limitation of Abstract** UU

Number of Pages
4

II. METHODS

Animal experiment with guinea pigs was devised to evaluate the effect of tinnitus on the auditory nerves. Salicylate was introduced to the animal based on the Jastreboff's tinnitus model for the simulation of tinnitus conditions. Nerve signals were acquired using electrodes placed inside the round window for the duration of 7 hours. Then, the changes on the signals were compared to verify the effect of salicylate on the auditory nerves quantitatively.

Cochlear Electrical Model

Merits and demerits of the existing model for the auditory system were examined, and then an electrical model which could explain tinnitus phenomena was established. In a shown in Fig. 1, reticular lamina which transmits energy in a cochlear was assumed as a mass, which is different from the previous models. Hair cells, which control the reticular lamina, were connected in series with the reticular lamina.

Anatomically, reticular lamina has considerably small value. However, since the causes for tinnitus is closely related to the malfunction of inner and outer hair cells, reticular lamina is also changed due to the changes on the hair cells. Characteristics of the transfer function for a sound stimulus was interpreted mathematically based on the Allen's method [7-8].

Surgical Procedures

Sound sensitive guinea pigs (300g-450g) were selected for the experiment. After the skin incision along the outer side of the ear, upper part of the processus mastoideus ossis temporalis were punctured. Round window was observed through a microscope. Needle electrodes made with silver wire and Ag/AgCl were inserted through the round window. Since the pathway from inner ear to the outside was

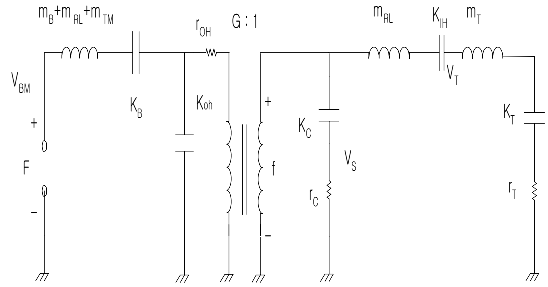

Fig. 1. Two-dimensional electrical cochlear model assuming reticular lamina as a mass

exposed, punctured area was closed with bone cement, inhalt 60g and drala polycarboxylat cement, for a preservation of the duct in the middle ear and the electrodes fixation. Fig. 2 shows the placement of the electrodes for the measurement of nerve signals.

Tinnitus Induction

Before the experimentation, toxicity was tested with diverse kinds of anesthetics (chloralhydrate, ketamin, Penthotal sodium, and urethane) and salicylate to decide the appropriate agents, which could control the steadiness of guinea pigs best for the duration of an experiment. Urethane was selected and guinea pigs were anesthetized with 1g/kg intraperitonial injection. Since the movement of an animal could influence the results of the study, animals were maintained under same condition throughout the experimentation. For inducing the tinnitus, salicylate acid sodium salt (450mg/kg) in 5ml of saline was injected based on the Jastreboff's tinnitus model [9].

Sound Stimulation

Sound stimuli, 500Hz, 1kHz, 2kHz, 4kHz, and 8kHz, were introduced to the one ear with 90dB intensity using sound stimulator (Diagnostic Audiometer, AD229e). Earphone was inserted into the ear canal of guinea pigs. For the reduction of noise from outside, soundproof

Fig. 2. Placement of the electrodes for the measurement of nerve signals from guinea pig

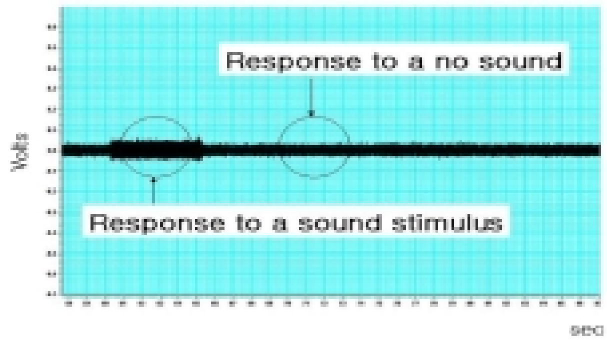

Fig. 3. Auditory nerve signals following sound stimulation

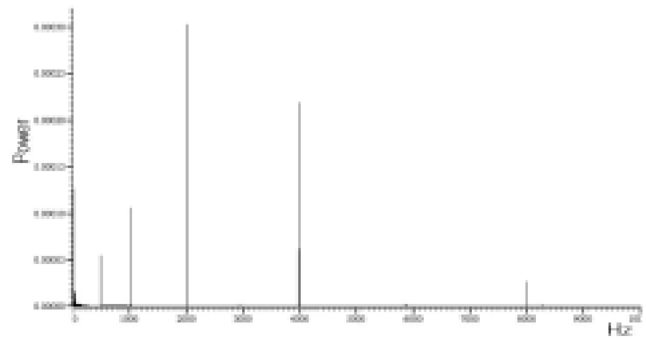

Fig. 4. Power spectrum of the auditory nerve signals, which are 0.5, 1, 2, 4, and 8 KHz

chamber was made in house with double glasses.

III. MEASUREMENTS AND ANALYSIS

Movement of the basilar membrane is caused by the fluctuation of lymph inside the cochlear. Electrodes were placed in the auditory nerve bundles, which is connected to the brainstem, through the round window after puncturing the temporale. So, it might be possible to measure the electrical signals generated from the auditory nerves caused by the oscillation of lymph.

Nerve signals were measured with an amplifier (CED 1401) with the gain of 10,000 and the signals were bandpass filtered from 300Hz to 20KHz. Fig. 3 shows the raw data obtained under different sound simuli, 0.5, 1, 2, 4, and 8 KHz. Then, the signals were analyzed via FFT to obtain power spectrum shown in Fig. 4.

IV. RESULTS AND DISCUSSION

Experiment was designed to find the changes on the auditory nerve signals when certain characteristic frequencies are introduced to the animal. Based on the variations on the nerve signals, hearing threshold could be determined when the electrical stimulation is applied for the treatment of tinnitus.

As shown in Fig. 5, power contents for each frequency component were reduced gradually as time passed after the injection of salicylate. That is, specific hearing loss to a certain sound frequency could occur by the injection of salicylate. Also, from Fig. 6, under no sound stimulation, integrated values for the power contents also decrease as time passed, which implies that tinntius was induced progressively.

Based on these observations, it could be possible to explain the complexity and nonlinear characteristic function of transmission path through the inner ear. It suggests that the cochlear electrical model could be used for the explanation of tinnitus and for the confirmation of the use of electrical stimulation for the treatment of tinnitus.

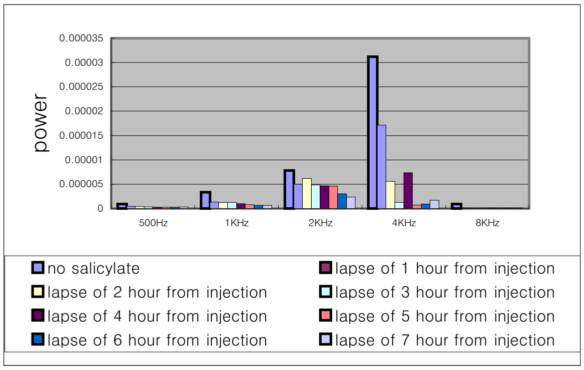

Fig. 5. Variations in power spectral contents for the frequencies of sound stimuli

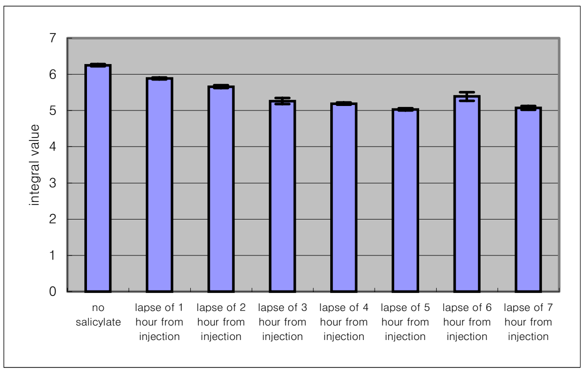

Fig. 6. Variations in integrated power contents with no sound stimulus in chronological order

V. CONCLUSIONS

Prior to the study on the effect of electrical stimulation for the treatment of tinnitus, cochlear electrical model was established. Then, the changes on the auditory nerve signals following simulated tinnitus conditions were investigated to verify the electrical model.

It is concluded that the induction of salicylate caused the variations on the neural responses even without sound stimulation. Also, under the stimulation of sound with different frequencies, power contents varied in a chronological order after the injection of salicylate. Results of this study could be extended to find the effect of the electrical stimulation for the treatment of tinnitus.

ACKNOWLEDGEMENT

This work was supported by grant No. 1999-2-314-002-3 from the Basic Research Program of the Korea Science & Engineering Foundation.

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