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Research Paper

Determination of the relationship between internal auditory canal nerves and tinnitus based on the findings of brain magnetic resonance imaging

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ABSTRACT

This experimental study aimed to investigate a relationship between tinnitus and thicknesses of internal auditory canal and nerves in it. It was performed on brain magnetic resonance images of patients who consulted the ear, nose, and throat clinic with tinnitus complaint. Statistical hypothesis tests and classification experiments were performed on these data to find out structural differences in internal auditory channel components in patients with tinnitus after obtaining cross-sectional areas of nerves as thicknesses. Both the hypothesis tests and classification results showed that the thicknesses of nerves in tinnitus cases were different from those in normal cases. In particular, the hypothesis tests for the superior vestibular nerve and internal auditory channel showed the highest significance, indicating the relationship with tinnitus. The classification results indicated the possibility of classification for tinnitus identification, establishing a computer-assisted diagnostic system to help physicians.
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1. Introduction

Tinnitus is a disorder commonly encountered at ear, nose, and throat (ENT) clinics. It is defined as the perception of noise-like ringing without an external source. The prevalence of tinnitus that can be extremely disturbing is 3%–32% in the general population. Although the examining physician and the patient can hear objective tinnitus such as the ringing or humming sound, the patient only hears subjective tinnitus [1,2]. Some of its symptoms are stress, anxiety, depression, insomnia, and irritability. Although the pathophysiological reasons of tinnitus are poorly understood, it is believed that it is associated with the sensorineural hearing loss of various origins [3–6]. If the peripheral auditory system is damaged, the central auditory neurons receive the weakened auditory input with the affected frequency range. The central auditory system tries to compensate these alterations. In this case, the reason of tinnitus can be considered as a phantom sound because of aberrant plastic reorganization in the auditory center of the brain [4,7].

Subjective tinnitus is more frequently associated with internal auditory canal (IAC) pathology, presbycusis, Meniere's disease, acoustic trauma, ossicle system deformities, and labyrinthitis. In addition, aging or loud noise exposures, which may cause hearing loss, are also related to tinnitus. The pitch of the phantom sound generally corresponding to hearing-loss frequencies may indicate hearing loss. However, it is not always associated with hearing loss with tinnitus [4,8].

Some studies that employed positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) propose that tinnitus generation is in the central auditory system [7,9–11]. The study of tonotopic brain changes with magnetic resonance imaging (MRI) and PET reported no distortion in auditory cortical organization and limbic system responses [7]. Another study carried out with children proposes that MRI would be mandatory for investigating tinnitus [9].

The reason of tinnitus is traditionally considered to reside in the inner ear because tinnitus sound is commonly perceived in the ear [12–14]. Therefore, MRI is recommended to investigate the existence of pathologies inside the canal for identification [15]. The aim of this study was to investigate the internal acoustic canal and the nerves in it. Fig. 1 represents the location of an inner ear in the auditory system. Sound collected by the outer ear is transferred to the middle ear through the ear channel. The middle ear transforms the

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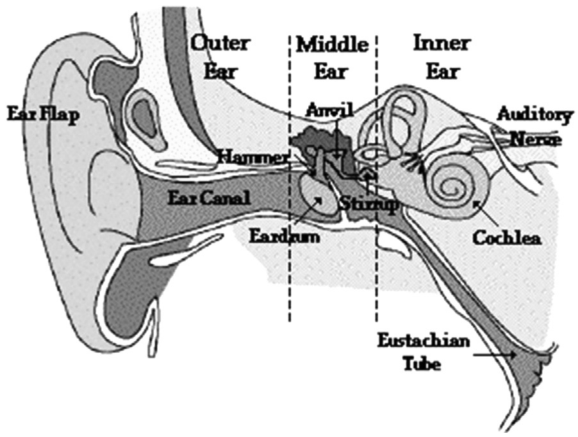

Fig. 1. Three parts of the ear system: inner ear, middle ear, and outer ear [21].

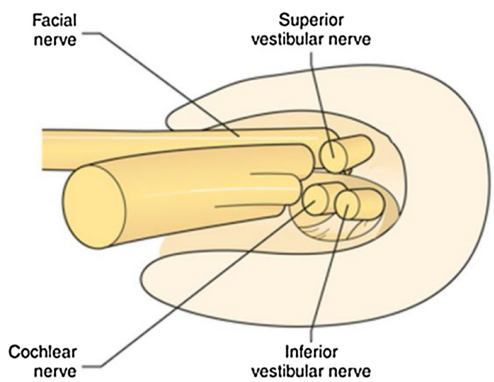

Fig. 2. A schematic diagram of the right IAC: (a) perspective view; (b) cross-sectional view [22].

sound energy into internal vibrations and a compressional wave in the inner ear. Transformation of the internal vibrations into nerve impulses is performed in the inner ear for transferring them to the brain [16–18]. The IAC in the inner ear contains four main nerves carrying the impulses to the brain. A schematic diagram of a right internal acoustic meatus that shows the placement of the nerves in IAC is given in Fig. 2. The nerves that pass through the IAC are the facial nerve (FN), vestibular superior nerve (SVN), inferior vestibular nerve (IVN), and cochlear nerve (CN). Each of the nerves has a constant location in the area of the fundus of IAC [19]. This anatomical knowledge makes it possible to observe structural differentiations. Today, structural forms of IAC and the nerves in it can be visualized using high-resolution techniques. In particular, MRI is more convenient to visualize the structural form and differentiation because the nerves are soft tissues.

MRI monitoring of the auditory pathway has helped obtain valuable findings of the ear origin disorders such as vertigo, maneuver, tinnitus, and hearing loss. In a previous study, important findings were obtained indicating that nerve diameters were related to benign paroxysmal positional vertigo (BPPV) [20]. It was determined that the thicknesses of nerves in IAC were differentiating in BPPV cases. The experience and methods in the previous study have benefited the present study.

This study focused on finding out any relationship between the thicknesses of IAC nerves and tinnitus. The brain MRI images of patients and healthy subjects were used to investigate how the structures of nerves were affected in tinnitus cases. The cross-sectional areas (CSA) of IAC nerves were particularly investigated to determine how the thickness of nerves was affected.

It is assumed that the CSAs have important information about the condition of nerves. After the data collection phase, statistical measurements were used to discover the existence of any relationship between the thickness of nerves and tinnitus. In addition, if a statistical difference exists between healthy volunteers and patients with tinnitus with respect to CSAs, it is possible to establish a computer-aided diagnostic (CAD) system for feature examinations. The possible statistical significance allows a classification system and therefore a CAD system. The possible existence of a statistical significance allows a classification system and therefore to be able to establish a CAD system.

2. Material

The study was performed on those who consulted the ENT clinic with a tinnitus complaint. An otolaryngologist in the ENT clinic diagnosed that the patients had tinnitus definitely. The volunteers for the control group were chosen among the patients who applied to the radiology department. The volunteers in the control group needed brain MRI images for various reasons. The control and patient groups consisted of 23 healthy subjects and 23 patients. The local ethics committee approved this study, which was carried out in accordance with the Helsinki Declaration. The patients with tinnitus, the volunteers in the control group, and the local ethics committee provided the necessary permission. The brain MRI images of the patient and control groups were used to investigate the IAC region and measure its thickness and the thickness of the nerve in it.

Both of the groups had similar demographic characteristics with respect to smoking, hypertension, cholesterol, and so forth. The MR device to obtain the brain images had the power of 1.5 T and an eight-channel high-definition brain coil. An otolaryngologist and a radiologist investigated the IAC canal and the nerves in the MRI images, which were processed using digital image processing techniques. Fig. 3a represents a brain image including the IAC region and the nerves in it as a sample for the collected data. The red square in Fig. 3b shows an IAC region and the nerves. A resolution improvement was performed for detecting the structures adequately after selecting and cropping the IAC region. Fig. 4a shows the cropped original image. Lanczos-2 kernel was used for resolution enhancement [23]. Fig. 4b shows the gray-level image representing the IAC region after resolution enhancement. Then, the obtained gray-level image was converted into a binary image using Otsu's thresholding method [24].

The binary form of the cropped image given in Fig. 4c shows the specific location of the nerves in the IAC region. The white area refers to IAC, and the black areas in the white region refer to the nerves SVN, FN, CN, and IVN from the left top in clockwise rotation. The CSAs of the IAC canal and the nerves could be measured by counting the pixels in each area because a pixel referred to a voxel size. The MRI device provided this information on their produced Digital Imaging and Communication in Medicine (DICOM) Digital images [25]. Therefore, the real size of a tissue in MRI images could be calculated by a simple estimation.

3. Methods

3.1. Statistical measurements for significant difference

The common way to determine any differences among the group data is to use statistical measurements and apply some tests. Many researchers adopt various statistical methods and common-sense techniques to examine the difference between the control and patient groups. Most widely used methods depend on statistical hypothesis tests and correlation calculation. The hypothesis tests

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