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Effect of Sound and Bone Conduction Ultrasound Stimulation on Tinnitus Inhibition

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Original Article

Abstract

Introduction: Tinnitus is a condition where a person perceives a sound without any external source. It is a psychological-auditory phenomenon that affects around 10 to 15% of adults. Due to the complexity of tinnitus and its origins, there are various assumptions and difficulties in treating it. Some treatments include sound stimulation and ultrasonic therapy. This study was conducted to compare the effects of sound stimulation and bone-conducted ultrasound (BCU) stimulation in controlling tinnitus.

Materials and Methods: For this study, 21 patients with persistent tinnitus were selected using convenience sampling method. These patients did not have a curable cause for their tinnitus and did not have conductive hearing loss or retrocochlear lesions. Radiological evaluations were conducted before and after sound and BCU stimulation. These evaluations included audiometry, tympanometry, stapes muscle reflex test, stapes muscle reflex decay test, auditory brainstem responses, and psychoacoustic tinnitus indicators. The psychoacoustic indicators measured included pitch, loudness, maskability, comparison of loudness of tinnitus, and duration of residual inhibition.

Results: The average loudness of tinnitus, measured in dB Sensation level (dBSL), did not significantly decrease (P = 0.080) after receiving sound and BCU stimulation. The mean loudness of tinnitus, as determined by standard-visual criteria, also did not significantly decrease (P = 0.200) after sound and BCU stimulation. However, there was a significant increase in the duration of residual inhibition (RI) after BCU compared to sound stimulation (P = 0.001). The study also found that the maskability of tinnitus and the type of RI did not depend on the type of stimulation used, with a Kappa coefficient of agreement of 0.69.

Conclusion: BCU stimulation of the inner ear may inhibit tinnitus by targeting the basal part of the cochlea, where tinnitus is most likely to occur. BCU stimulation leads to longer inhibition in tinnitus compared to sound stimulation.

Keywords: Tinnitus; Bone conduction; Acoustic stimulation

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Introduction

Tinnitus is the auditory sensation of sound in one or both ears or the head without any internal or external sound stimulus (1). In a large study conducted in Norway, 21.3% of men and 16.2% of women had tinnitus, and 4.4% of men and 2.1% of women reported high intensity tinnitus (2). The results of epidemiological studies have shown a similar prevalence in other European countries, America and Japan, and also in low-income and middle-income Afro-Asian countries. The most common cause of tinnitus is otological disorders. Therefore, it can be said that tinnitus may occur due to disorders of the external ear, tympanic membrane, ossicles, cochlea, and eighth cranial nerve, stem, or cerebral cortex. Some types of tinnitus have a neurological or functional origin with no cause found in ear and central nervous system examinations (4). From the point of view of neuroscience, tinnitus is caused by the imbalance between firing rate patterns in the tonotopic rows of auditory nerve fibers, which does not mean an increase in auditory nerve firings. Tinnitus can be felt even when the auditory nerve is cut (5).

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Research results have reported that about 20% of adults who experience tinnitus need therapeutic interventions (1). Still, despite the numerous clinical studies on tinnitus treatment, no entirely successful method has yet been designed to treat tinnitus (6). Various treatment options are available for tinnitus, including tinnitus retraining therapy (TRT), mask ability, amplification, limiting tinnitus-causing factors and environmental factors (7), and electrical stimulation (8, 9). However, their influence is variable and unknown (10).

Tinnitus is masked by providing an audible masking sound to the ear with tinnitus, and it decreases or disappears within a few seconds to several minutes after the end of masking (11, 12). This continuous reduction or disappearance of tinnitus is called residual inhibition (RI) (11). Recently, RI has been considered a clinical index indicating the degree of tinnitus inhibition (13, 14). Pure sound or noise makers in the frequency range of 0.125-8 kHz are often used to measure RI. Many studies have reported that RI occurs in 60-80% of people with tinnitus using these masks (14, 15). A new trend in tinnitus treatment is using high-frequency maskers, including bone-conducted ultrasound (BCU) (14).

Ultrasound refers to sounds with high frequencies that humans cannot hear through the air (11). In 1948, it was first documented that ultrasound with a frequency of less than 120 kHz can be heard if delivered through the bone (16, 15). The pitch of BCU, regardless of frequency, is similar to a high-frequency sound in the 8-16 kHz range or at the highest frequency audible in people with normal hearing (17, 11). The results have shown that BCU can be heard by people with hearing loss and even some with profound deafness (19, 18). Studies have shown that ultrasound is not transmitted to the cochlea through the middle ear due to poor impedance and can only be perceived through bone conduction (20, 15). Shulman et al., with extensive research in the field of ultrasonic hearing in humans, considered the base of the cochlea in people with normal hearing and hearing loss and the saccule in deaf people as the location of receiving ultrasound and pointed to the positive results of ultrasonic masks in the treatment of tinnitus (22). However, outer hair cells do not play a role in receiving ultrasonic bone stimulation (17). Nishimura et al. stated that the cochlea is the main peripheral organ responsible for ultrasound perception (17). A study concluded that tinnitus is masked by high-frequency audible airway sounds, particularly in the 10-14 kHz range. Ultrasonic perception is associated with the perception of high-frequency airway-audible sounds, and the peripheral region of BCU perception is likely located in the basal turn of the cochlea (16).

In the evaluations to check the maskability of tinnitus, sound stimulation is used, and then, the maskability, loudness of tinnitus, and amount and type of RI are used (23). Considering the characteristics of BCU and its masking effects, especially in high frequencies (16), the present study was conducted to investigate the effect of sound and ultrasonic stimuli on the psychoacoustic characteristics of tinnitus.

Materials and Methods

This interventional study was performed using convenience sampling method. Patients with tinnitus who were not found to have a curable cause for their tinnitus in clinical examination and previous paraclinical examinations by otolaryngology specialists were referred to participate in the research. The exclusion criteria included hearing loss after otoscopy and hearing evaluations, using Auditory Brainstem Response (ABR), stapes reflex, and stapes muscle reflex decay, and suspicion of transcochlear disorders with the opinion of an otolaryngologist. After taking history, an evaluation of loudness and pitch, maskability, and minimum level of masking was conducted. The pitch and loudness matching test was performed in the opposite ear to the ear affected by tinnitus or the ear in which the loudness of the tinnitus sound was lower, and if the loudness was equal in both ears, it was performed in the right ear.

After determining the pitch, a test was performed to rule out the octave mixing problem (comparing the obtained pitch with an octave higher). The loudness of tinnitus is based on its increase compared to the threshold in the tinnitus frequency in decibels of sensation level (dB Sensation level or dB SL). Moreover, the comparative-visual criterion (in the visual comparative measure, the loudness of the tinnitus is valued on an axis from 0 to 10) was determined. To obtain the maskability of tinnitus, narrow band noise at the frequency of tinnitus was presented in the tinnitus-afflicted ear or the earpiece with the higher tinnitus loudness. If the tinnitus loudness was equal in both ears, it was introduced in the right ear. If the tinnitus was maskable, the lowest intensity that led to the masking of the loudness of the tinnitus was considered the minimum masking level (MML). Then, sound stimulation (narrowband noise) of dBSL10+MML was presented in the ear affected by tinnitus for 60 seconds, and other evaluations, including loudness evaluation in terms of dB Sensation level (dBSL), analogical-visual criterion, and evaluation of the type and amount of RI, were performed (22).

The HiSonic-TRD device (Hisonic Inc., Olathe, KS, USA), recommended for tinnitus suppression (24), was used in the third step. First, the best place for ultrasound bone transfer on the mastoid was checked in terms of a better understanding of its sound. Then, 2 bands of frequency sweep and wideband noise (HiSonic-TRD device) with a frequency range of 19.5-24 kHz were used to cover the buzzing. The bandage that provided better masking for the patient was selected. Then, the device's volume was increased until the tinnitus was ultimately masked, and stimulation was supplied for 60 seconds. Then, tinnitus loudness was evaluated in the dBSL scale and comparative-visual criterion and assessment of the type and amount of RI.

The tools used in this research include a hand-held otoscope (HEINE, Germany), audiometer (AD19, Interacoustics, Denmark), tympanometer (AZ7, Interacoustics, Denmark), ABR device (Ep15, Interacoustics, Denmark), and HiSonic-TRD device (USA) to provide ultrasound bone transfer stimulation. Descriptive statistics were used to draw tables, frequency distribution diagrams, variables, and central indicators such as mean, and dispersion indicators such as standard deviation were used. Paired t-test, chi-square test, and Kappa coefficient of agreement were used to compare the results before and after the presentation of stimuli.

Results

The present study was conducted on 21 patients with tinnitus in the age range of 26-65 years, with the average age of 11.48 ± 11.83 years. The participants included 14 men (66.7%), and 7 women (33.3%). Among the patients, the highest frequency was related to the perception of tinnitus bilaterally (15 people, 71.3%). Among all the participants, 2 people (9.5%) had louder tinnitus in the right ear, 4 people had louder tinnitus in the left ear (19.0%), 8 people had equal tinnitus in both ears (0.0 38%), 2 people had tinnitus in the right ear (9.5%), 3 people had tinnitus in the left ear (14.4%), 1 person had tinnitus in both ears and head (4.8%), and 1 person had tinnitus (4.8%). Among the 21 examined patients, 7 people had tinnitus with a whistling sound (33.3%), 3 people had tinnitus with a ringing sound (14.2%), 3 people had tinnitus with a buzzing sound (14.2%), 2 people had tinnitus with a buzzing sound (14.2%), hissing sound (9.5%), 1 person buzzing with whistling and humming (4.8%), 1 person with buzzing and steam whistle (4.8%), and 1 person with buzzing and engine sound (4.8%). The average duration of tinnitus onset in patients was 46.90 ± 58.42 months.

The average frequency of tinnitus in the participants was 6.95 ± 2.50 kHz. 17 people (81%) experienced tinnitus masking using BCU stimulation, and 16 (76%) used sound stimulation. The results of the chi-square test showed that the range of tinnitus using BCU and standard sound stimulation is independent of the type of stimulation (chi-square = 0.002). Moreover, the Kappa coefficient of agreement was 0.69, which expresses the degree of similarity of masking type in each type of stimulation. The mean loudness of tinnitus was lower in terms of dBSL after ultrasound stimulation compared to sound stimulation, but this difference was not significant (P = 0.080) (Table 1).

The comparison of the average loudness of tinnitus after ultrasound versus sound stimulation showed a greater reduction according to the analogical-visual criterion. However, this difference was not statistically significant (P = 0.200). On the other hand, a significant difference was observed between the mean RI of tinnitus after sound and ultrasound stimulation (P = 0.001) (Table 2).

Among the patients, 1 reported a change in tinnitus after BCU stimulation, where the whistling sound turned into a ringing sound. In contrast, another patient heard a waterfall-like sound along with the previous buzzing sound. However, these effects were temporary, and after a few minutes, the tinnitus returned to its original state.

Discussion

A recent study showed that individuals with tinnitus experienced more significant relief when receiving BCU stimulation compared to sound stimulation. Lenhardt et al. surveyed 9 individuals with mild to moderate high-frequency hearing loss and tinnitus using an ultra-quiet device for treatment.

Table 1. Average loudness of tinnitus in terms of dB Sensation level after providing BCU and sound stimulation

Variable	Number	Minimum	Maximum	Mean ± SD	P-value
Loudness of tinnitus after BCU stimulation	21	0	8	2.52 ± 2.83	0.080
Loudness of tinnitus after sound stimulation	21	0	8	3.10 ± 2.11	

SD: Standard deviation

Table 2. Comparison of the average loudness of tinnitus according to the analogical-visual criterion and the duration of residual inhibition after bone conduction ultrasound stimulation and sound stimulation

Variable		Number	Minimum	Maximum	Mean ± SD	P-value
The loudness of tinnitus (visual-comparative criterion)	After BCU stimulation	21	0	9	2.24 ± 2.47	0.200
	After sound stimulation	21	0	8	2.83 ± 2.33	
The loudness of tinnitus (residual inhibition duration)	After BCU stimulation	21	0	900	254.76 ± 415.66	0.001
	After sound stimulation	21	0	1800	133.33 ± 214.83	

SD: Standard deviation

The instrument used digital processing of music with 10-20 kHz modulation, transmitted through a bone conduction transducer to the mastoid. Each person was exposed to the stimulus for 30 minutes a day, twice a week for 4 weeks, at an intensity of 6 dB above their threshold. Hearing evaluations and tinnitus pitch adjustments were conducted before and after the test, and after 2-8 months, all subjects reported an improvement in their tinnitus based on questionnaires. The recovery period ranged from 1 hour to 4 weeks and varied among individuals. The audiograms of patients showed no significant changes after treatment (25).

Lenhardt et al. investigated the effectiveness of the Ultra Quiet device in treating tinnitus. The study included 10 participants with moderate, high-frequency hearing loss and tinnitus in the 6-14 kHz range. The device provided high-frequency pulse patterns above 6 kHz, which were transmitted to the mastoid via the bony pathway. The researchers found 6 out of 10 subjects reported reduced tinnitus loudness 2 months after treatment; 4 patients experienced complete masking, 1 experienced partial masking, and 1 patient experienced tinnitus reduction without masking (26).

Shulman et al. used positron emission tomography (PET) to compare brain metabolism before and after using ultra high frequency (UHF). Their study included 6 participants who underwent 10 to 12 sessions for 5 to 7 weeks (22). All patients underwent a medical-audiological tinnitus protocol, including conventional and high-frequency audiometry, loudness and pitch matching, and minimal masking level evaluations. PET scan showed no significant difference in the response of the right and left hemispheres, temporal, parietal, and frontal lobes, and cerebellum before and after treatment in all the desired regions. However, based on the questionnaires, patients reported varying degrees of improvement in their tinnitus symptoms and a significant decrease in the minimum masking levels (22).

Goldstein et al. conducted a study to investigate the long-term effects of Ultra Quiet treatment on reducing tinnitus, maskability, and RI in 15 patients with tinnitus (27). All patients had severe mental tinnitus of unknown origin, mild to moderate high-frequency hearing loss, and high-frequency tinnitus (except 1 patient who had low-frequency tonal tinnitus). The treatment involved digital processing of music in the range of 6-20 kHz delivered through bone conduction. The first treatment session lasted 30 minutes, while subsequent sessions lasted 60 minutes. According to the patients' reports, 11 patients experienced improvement in tinnitus, while 4 patients experienced improvement in the loudness or severity of tinnitus (27).

In another study, Goldstein et al. found that BCU can mask tinnitus at a frequency range of 20-26 kHz (28). Their results indicated that audible BCU stimulation can be effective in tinnitus masking (28). In addition, they measured the amount of RI caused by BCU with a frequency of 30 kHz and sounds transmitted through the air and bone. They found that the RI caused by BCU stimulation was significantly longer than the RI caused by sound stimulation (12). Poremski and Kostek suggested that ultrasound can be used as one of the tinnitus treatment methods (6). However, its effectiveness varies depending on the signal presented and the place where it is used; while it can mask the tinnitus in some people, it can intensify or eliminate it in others (6).

In a study conducted by Carrick et al., it was reported that applying BCU with a frequency of 500 kHz reduced tinnitus in subjects' heads. The study was conducted on 40 people with tinnitus, 40% of whom experienced a decrease in the loudness of tinnitus (29). However, Rendell et al. re-examined the same paradigm on another 40 individuals and found that 500 kHz BCU failed to inhibit tinnitus (30).

Furthermore, another study found that 500 kHz BCU was ineffective in controlling tinnitus. This is because this amount of ultrasound frequency is beyond the highest limit that can be perceived as sound (12).

The findings of this study are in line with those of previous studies (6, 29), indicating that tinnitus can be suppressed and inhibited more effectively by BCU despite variations in stimulation frequency, device types, and duration of ultrasound exposure. However, the results of this study differ from that of the research conducted by Rendell et al. (30). This difference can be attributed to the ultrasonic frequency used (500 kHz) in their study, which was much higher than that used by other researchers, and thereby, may not have led to hearing improvement or reduced tinnitus (30).

Limitations

No limitation.

Recommendations

Considering the impact of BCU stimulation on tinnitus inhibition, it can be considered as a potential approach for reducing and treating tinnitus. However, since ultrasonic stimulation was only evaluated in one session, it is suggested that its long-term effectiveness as a rehabilitation tool in managing tinnitus be investigated in future research.

Conclusion

After comparing the results of studies investigating tinnitus masking by BCU and sound stimulation, it becomes evident that BCU is more effective in suppressing tinnitus and creates a much longer residual inhibition compared to sound stimulation. As most of the ringing sensations occur in the high-frequency range and the high-frequency receiver and BCU are located in the base screw of the cochlea, the BCU can effectively mask other audible high-frequency sounds.

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Authors' Contribution

Study design and ideation: Nasrin Gohari
Obtaining financial resources for the study: Nasrin Gohari
Scientific and executive support of the study: Nasrin Gohari
Providing equipment and statistical sample: Abdoreza Sheibanizade
Data collection: Abdoreza Sheibanizade
Analysis and interpretation of the results: Nasrin Gohari, Abdoreza Sheibanizade
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Confirmation of the final manuscript for submission to the journal website: Nasrin Gohari, Abdoreza Sheibanizade, Mohammadreza Keyhani
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Conflict of Interest

The authors had no conflicts of interest.

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