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RESEARCH

THE EFFECTS OF 1.5 TESLA CONTRAST-ENHANCED TEMPORAL BONE MRI ON THE AUDITORY FUNCTIONS AND COMPLAINTS OF GERIATRIC PATIENTS WITH TINNITUS

Abstract

Introduction: Temporary hearing threshold shift might develop after noise exposure due to magnetic resonance imaging. We aimed to investigate the effects of acoustic noise during 1.5 Tesla temporal bone MRI on audiometric tests and disturbance self-reports in patients with tinnitus.

Materials and Method: Sixty-three symptomatic ears of 55 patients with persistent tinnitus were included in this study. Sound level recordings of imaging room were made with dosimeter. Two age groups (<65 years and > 65 years) were created. Hearing thresholds were measured before, 24 hours after and 1 month after performing magnetic resonance imaging. Visual analogue scale, tinnitus handicap inventory and the Beck depression inventory were applied to all patients before and 24 hours after the imaging.

Results: The mean intensity of acoustic noise during imaging was recorded as 99.3±3.4 dBA (109.9±4.1 dB). The threshold shifts were statistically higher in patients aged ≥65 than the ones aged <65 for 2000 and 4000 frequencies ($p<0.05$). The mean temporary shifts in tinnitus loudness were 5.00±6.495 dB and 10.17±11.179 dB for the patients with age<65 and age≥65 respectively ($p = 0.018$). While majority of the time dependent effects were significant for audiometric tests; they were insignificant for self-reported questionnaires, except visual analogue scale 5, which was higher in patients aged<65 ($p = 0.012$).

Conclusion: Acoustic noise due to 1.5 Tesla temporal bone magnetic resonance imaging caused hearing threshold shifts and deterioration in intensity and disturbance of the tinnitus especially in elderly. Hearing protection is essentially required for all patients, when it is indicated.

Keywords: Hearing Loss; Magnetic Resonance Imaging; Noise; Quality Of Life; Tinnitus.

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INTRODUCTION

Magnetic resonance imaging (MRI) is widely used in the differential diagnosis of auditory pathologies accompanied by tinnitus, especially in the presence of unilateral, asymmetrical, high-frequency sensorineural hearing loss. In spite of new technology, noise exposure in a high-intensity, wide-frequency range is still experienced in this imaging technique, which is used for the exclusive diagnosis of pathologies such as tumors located in the cerebellopontine angle and internal acoustic canal region (1).

High acoustic noise levels during MRI may temporarily disrupt hearing thresholds and could possibly cause a temporary threshold shift (TTS) that reverses after noise exposure is discontinued (2). The acoustic noise associated with MRI procedures is due to the rapid alterations of currents within the gradient coils. These currents produce significant acoustic noise that manifests as loud tapping, knocking, or chirping sounds and can cause temporary or, sometimes, permanent injury to the cochlea (3,4). Several previous studies have reported an increase in MRI-induced hearing thresholds and even cases of hearing loss (5,6). However, for patients using foam earplugs, the noise generated by a 3T MRI procedure did not cause any TTS during high-frequency hearing measurements in another study (7).

During daily practice, we noticed that some geriatric patients reported that their tinnitus increased immediately after MRI. Therefore, we hypothesized that the auditory functions are disturbed and that complaints regarding tinnitus become more evident after 1.5 Tesla contrast-enhanced MRI of the temporal bone.

The primary aim of this study was to determine the effects of acoustic noise during 1.5 Tesla contrast-enhanced temporal bone MRI on the intensity and frequency of tinnitus and degree of complaints, especially in geriatric patients.

MATERIALS AND METHODS

The present study was conducted in the Department of Otorhinolaryngology and Head & Neck Surgery of a tertiary clinic after approval was received from the ethics committee of the local council (no. FSMEAH-KAEK 2019/1-18). The study was performed in accordance with the most recent version of the Helsinki Declaration. Written informed consent was obtained from all subjects included in the study.

Patients

All patients who presented with a complaint of tinnitus to the outpatient clinic of the otorhinolaryngology department of a tertiary center between February 2019 and August 2019 were prospectively included in this study. After the patients' medical history was taken, physical examinations regarding the ear, nose, throat, head, and neck were performed together with neurological examinations. Routine laboratory tests were conducted to rule out potentially treatable causes of tinnitus. Pure-tone audiometry (PTA) and tinnitus matching (TM) tests for pitch and loudness were used. Contrast-enhanced temporal bone MRI was performed in patients with tinnitus and asymmetric hearing loss of 10 dB or more compared with the other ear at frequencies of 4,000 to 8,000 Hz.

Inclusion criteria

1. Individuals 18–75 years of age.
2. Patients with tinnitus who required investigation via MRI.
3. Patients who were fully capable of communicating with the researchers and obeying simple commands.
4. Patients admitted to outpatient clinics without any morbidity.

Exclusion criteria

1. Patients younger than 18 years and older than 76 years.

2. Patients with MRI requested for reasons other than tinnitus.
3. Patients who were not capable of communicating with the researchers and obeying simple commands.
4. Patients with a history of inner ear pathology and ototoxic drug use.
5. Patients with a tumor in the cerebellopontine angle and internal acoustic canal, peripheral, or central vestibular disease, cardiovascular disease, previous head trauma, neurological disease, metabolic disease, or pregnancy.
6. Bedridden patients.

Initially, 101 patients, who had been free of medical agents that could cause tinnitus or had been prescribed for tinnitus were enrolled in the study. Two patients with vestibular schwannoma and six patients with vascular loop syndrome were excluded following examinations that revealed certain pathologies. One patient with a tinnitus frequency of 250 Hz and two patients with a tinnitus frequency of 500 Hz were also excluded to homogenize the high-frequency tinnitus sample of this research. Thereafter, 57 patients who met the above inclusion and exclusion criteria were selected for inclusion in the study.

Contrast-Enhanced Temporal Bone MRI Procedure

The MRI scan used in this study was performed by a device with a 1.5 Tesla magnetic field density (GE Healthcare SignaTM Explorer, United States). The standardized steps performed for MRI of the temporal bone were as follows: 1) localization (10 sn); 2) Ax T2 prop (full brain) (100 sn); 3) Cor 3D Fiesta (110 sn); 4) Ax 3D Fiesta (110 sn); 5) Ax T1 FSE (Thin) (90 sn); 6) Ax DWI b1000 Prop (185 sn); 7) Cor T1 FSE (90 sn); 8) +C Cor T1 FSE (90 sn); and 9) +C Ax T1 FSE (Thin) (118 sn). All MRI scans of the temporal bone lasted 15 minutes and 5 sn per session. The patients were scanned without any hearing protective equipment during MRI.

Sound Pressure Level Measurements During the MRI Scan

Average sound pressure level (SPL) measurements were gathered in both unweighted (dB) and A-weighted (dBA) decibels for the MRI scans. The sound level recordings were taken with a dosimeter containing a sound level meter and microphone (CEM DT 805 L, Shenzhen, China) that had a sound level measurement range of intensity 30–130 dB and frequency 31.5–8 kHz. The device was mounted within 50 cm of each patient's head position. The background noise in the room before and during the MRI scans was recorded by the calibrated dosimeter.

Audiometric Tests

The results of the PTA and TM tests for pitch and loudness were analyzed for the symptomatic ears. The PTA and TM test results were evaluated on the basis of test results on admission before the MRI (test 1), within 24 hours after the MRI (test 2), and 1 month after the MRI (test 3). Any change of 10 dB or more was accepted as a significant threshold shift.

PTA

The PTA tests were performed blindly in sound-proof booths (AC40, Interacoustics, Middelfart, Denmark) and revealed air and bone conduction hearing thresholds at frequencies of 250, 500, 1,000, 2,000, 3,000, 4,000, and 8,000 Hz for each ear (on admission, within 24 hours after MRI, and 1 month after MRI). A threshold change above 10 dB from baseline recordings was considered significant to define TTS and permanent threshold shift (PTS).

Tinnitus Pitch Matching and Tinnitus Loudness Matching

The tinnitus severity and frequency pairing tests (on admission, within 24 hours after MRI, and 1 month after MRI) were performed blindly in sound-proof booths as well (AC40, Interacoustics, Middelfart, Denmark). Any frequency change and

threshold change above 10 dB from the baseline record was considered significant.

Self-Report Test for the Daily Life Effects of Tinnitus

As tinnitus is a subjective phenomenon and difficult to evaluate; we analyzed disturbances caused by tinnitus according to the VAS, THI, and BDI scales upon admission before the MRI (test 1) and 24 hours after the MRI (test 2) for the symptomatic ears. The third test was not implemented, as 1 month would not have been suitable for relating the daily effects of tinnitus to MRI imaging via subjective self-reports.

VAS Assessment for the Favourability of Tinnitus

To understand the degree of tinnitus-related disturbance or daily life effects of tinnitus, the VAS was used upon admission before the MRI and 24 hours after the MRI (8). All patients were asked to rate their tinnitus from 0 (most favorable) to 10 (least favorable) for each of the five questions listed below:

VAS 1: Please mark the severity/intensity of your tinnitus.

VAS 2: Please mark the frequency/duration of your tinnitus.

VAS 3: Please mark the degree of disturbance caused by your tinnitus.

VAS 4: Please mark the degree of attention deficit caused by your tinnitus.

VAS 5: Please mark the degree of sleep problems caused by your tinnitus.

THI for the Disability Induced by Tinnitus

The validated Turkish version of the THI was used to address the degree of disability experienced by patients due to tinnitus upon admission before the MRI and 24 hours after the MRI (9). The THI was composed of 25 questions, each of which was scored on a scale of 0 to 4. With respect to the functional, emotional, and catastrophic responses due to tinnitus, the minimum total score was 0, and the maximum total score was 100. A test score of 0–16 meant "no or slight handicap", 18–36 meant a "mild handicap", 38–56 meant a "moderate handicap", 58–76 meant a "severe handicap", and 78–100 meant a "catastrophic handicap" (10).

BDI for a Depressive Mood Related to Tinnitus

The BDI was used to determine the extent of patients' depressive symptoms with tinnitus (11). This 21-question multiple-choice self-report inventory was given to the patients upon admission before the MRI and 24 hours after the MRI. The question scoring ranked the severity of each item from zero to three. A score of 0–13 indicated minimal depression, 14–19 mild depression, 20–28 moderate depression, and 29–63 severe depression (11).

Statistical Analysis

The data in the present study were collected and analyzed by using SPSS 20.0 software package (IBM® SPSS® Statistics 20.0, Armonk, NY, U.S.A.). The Shapiro-Wilk test for skewness and kurtosis showed normally distributed data except for the PTA and TM threshold shifts. Numeric variables were presented as mean ± standard deviation, and categorical variables were presented as frequency (n) and percentage (%). The comparisons of the pre- and post-MRI PTA and TM thresholds and VAS, THI, and BDI scores within the same group were performed via a paired-sample t-test. Student's t test was used to compare the PTA and TM thresholds, and Mann-Whitney U test was used to compare the TTS and PTS results between the groups. Repeated-measures analysis of variance (ANOVA) was used for time-dependent measurements to compare the PTA and TM test results and VAS, THI, and BDI scores before and after the MRI scans between the groups. Pearson or Spearman correlation analyses and chi-square or Fisher's exact tests were performed to determine the relationships between the VAS, THI, and BDI

results and PTA and TM results. A two-sided P value of ≤0.05 was deemed significant.

RESULTS

The background noise in the room was 52.8 dBA (58.3 dB) on average. The mean intensity of the acoustic noise during the MRI scan was recorded as 99.3 ± 3.4 dBA (109.9 ± 4.1 dB). Higher noise levels with a peak of 118 dBA (126 dB) were recorded as well, especially when the slice thickness declined and the coronal planes were examined.

A total of 63 symptomatic ears of 55 patients (mean age 56.3 ± 10.3 years, 38 males and 17 female) were included in the analyses before and after the MRI procedure. The patients were divided into two age groups, i.e., <65 years old (n= 33 ears of 29 patients) and ≥65 years old (n= 30 ears of 26 patients). The left ear was symptomatic in 57.58% (19/33) and 53.3% (16/30) of ears in patients aged <65 and ≥65, respectively. Eight patients had bilateral tinnitus.

Moreover, TTS and PTS in the PTA hearing thresholds were observed in 28.6% (18/63) and 23.8% (15/63) of the ears, respectively. The highest threshold shifts within 24 hours after the MRI were observed as 15 dB at 4 kHz and 25 dB at 8 kHz. In one patient, the frequency of tinnitus changed from 2,000 Hz to 4,000 Hz.

One patient (a 70-year-old male) with left-sided tinnitus developed right-sided tinnitus just after an MRI with a loudness of 55 dB at a frequency of 8,000 Hz. The patient developed PTS of 10 dB, 10 dB, and 15 dB for the 2,000, 4,000, and 8,000 Hz frequencies. Additionally, the tinnitus remained persistent with a loudness of 40 dB at an 8,000-Hz frequency 1 month after the MRI.

Another patient (a 57-year-old male) with bilateral tinnitus of 45 dB at 6,000 Hz for the left side and 75 dB at 8,000 Hz for the right side developed a temporary rise of 30 dB and a permanent rise of 20 dB in tinnitus intensity for the right side after the MRI. The loudness of his tinnitus was 65 dB and 70 dB for the left and right ears, respectively, 1 month after the MRI.

Table 1 compares the audiometric measurements before and after 24 hours and 1 month after the MRI, as well as the self-reported questionnaire results before and 24 hours after the MRI between the patients in the two age groups. Almost all PTA thresholds were significantly different between the two age groups, whereas the tinnitus loudness and VAS, BDI, and THI scores were not (Table 1).

Table 2 depicts the comparisons of the mean PTA, TM thresholds, and VAS, BDI, and THI scores across time within each age group and between the two age groups (<65 versus ≥65 years) before and after the MRI scan. Significant deteriorations were observed in the PTA thresholds and tinnitus intensity and related disturbances in the paired-sample t-test, especially in the patients aged ≥65 years. The tinnitus loudness displayed a significant rise from baseline in the symptomatic ear for both groups following the MRI scan ($p < 0.001$). While the time-dependent effects were significant for the PTA thresholds, the TM for loudness thresholds and self-reported tinnitus-related questionnaire scores were not statistically different before and after the MRI scan between the groups (Table 2), except for VAS 5 (item regarding sleep disturbance caused by tinnitus).

The baseline hearing thresholds were significantly different between the two age groups; therefore, analyses of threshold shifts were needed as well (Table 3). The TTSs (PTA threshold on the first day post-MRI minus baseline) and the PTSs (PTA threshold at the first month post-MRI minus baseline) differed statistically between patients aged <65 and aged ≥65 for frequencies of 2000 and 4000 Hz ($p = 0.012$, $p = 0.004$ for 2,000 Hz respectively; $p = 0.006$, $p = 0.004$ for 4,000 Hz respectively). Whereas the mean PTA threshold shifts at 8,000 Hz were not statistically different

Table 1. Comparison of basal and post-MRI audiometric and self-reported questionnaire results between the patients with tinnitus according to the age groups.

	Age<65 years		**Age ≥ 65 years**		
Baseline Audiometry					
	Mean±SD	Minimum-Maximum	Mean±SD	Minimum-Maximum	p*
Air Conductance					
500 Hz	14.24±12.76	5-65	20.33±7.18	10-35	0.025
1000 Hz	14.70±11.86	5-70	24.33±8.58	15-45	0.001
2000 Hz	18.64±13.42	5-60	28.33±10.99	10-50	0.002
4000 Hz	34.85±25.14	5-95	46.00±18.69	15-85	0.052
8000 Hz	42.42±25.04	10-100	57.33±16.85	20-85	0.008
Tinnitus Loudness	49.85±16.56	20-95	50.83±19.08	0-90	0.827
Post-MRI (24 Hours) Audiometry					
	Mean±SD	Minimum-Maximum	Mean±SD	Minimum-Maximum	p*
Air Conductance					
500 Hz	14.24±12.75	5-65	20.33±7.18	10-35	0.025
1000 Hz	14.70±11.86	5-70	24.33±8.58	15-45	0.001
2000 Hz	19.24±13.47	5-60	31.50±11.61	10-55	<0.001
4000 Hz	35.15±26.18	5-95	50.17±21.31	15-90	0.016
8000 Hz	45.30±25.12	10-100	63.83±19.68	20-90	0.002
Tinnitus Loudness	54.85±17.48	30-100	61.00±18.12	35-105	0.175
Post-MRI (1 month) Audiometry					
	Mean±SD	Minimum-Maximum	Mean±SD	Minimum-Maximum	p*
Air Conductance					
500 Hz	14.24±12.75	5-65	20.33±7.18	10-35	0.025
1000 Hz	14.70±11.86	5-70	24.33±8.58	15-45	0.001
2000 Hz	18.64±13.42	5-60	29.83±10.30	10-50	<0.001
4000 Hz	34.70±25.76	5-95	49.00±20.57	15-90	0.019
8000 Hz	44.70±25.52	10-100	63.17±19.63	20-90	0.002
Tinnitus Loudness	52.27±16.34	20-95	56.50±17.92	30-100	0.335
Basal Self-report Tests					
	Mean±SD	Minimum-Maximum	Mean±SD	Minimum-Maximum	p*
VAS 1	4.91±1.99	2-9	4.53±2.40	0-10	0.500
VAS 2	4.82±1.86	2-9	4.33±1.88	0-10	0.308
VAS 3	4.94±2.08	2-9	4.60±2.86	0-10	0.589
VAS 4	3.79±1.83	1-7	3.63±1.87	0-7	0.741
VAS 5	3.55±1.94	1-7	3.17±2.63	0-9	0.515
BDI	3.24±4.58	0-19	4.30±2.78	0-9	0.278
THI	33.33±19.54	0-74	35.67±14.60	11-68	0.596
Post-MRI (24 Hours) Self-report Tests					
	Mean±SD	Minimum-Maximum	Mean±SD	Minimum-Maximum	p*
VAS 1	5.33±2.38	2-10	5.07±2.07	3-10	0.638
VAS 2	5.61±2.34	2-10	5.10±1.37	3-10	0.306
VAS 3	5.82±2.63	2-10	4.93±2.23	2-9	0.157
VAS 4	4.48±1.99	2-8	4.13±2.27	1-9	0.515
VAS 5	4.79±2.40	1-9	3.73±2.52	1-8	0.094
BDI	4.06±5.11	0-21	6.10±3.67	0-12	0.063
THI	37.00±21.85	4-84	40.40±15.83	14-84	0.486

BDI: Beck Depression Inventory, MRI: Magnetic Resonance Imaging, SD: Standard Deviation, THI: Tinnitus Handicap Inventory, VAS: Visual Analogue Scale. p*: Student's T-test.

Table 2. Comparisons of mean thresholds in audiometric tests and mean scores in self-report questionnaires across time within each age group and between two age groups before and after MRI scan.

	Group 1 (Age<65)				Group 2 (Age≥ 65)				
	Baseline (mean±SD)	1st day (mean±SD)	1st month (mean±SD)	p*	Baseline (mean±SD)	1st day (mean±SD)	1st month (mean±SD)	p*	p**
PTA (dB)									
500 Hz	14.24±12.76	14.24±12.75	14.24±12.75	-	20.33±7.18	20.33±7.18	20.33±7.18	-	0.025
1 kHz	14.70±11.86	14.70±11.86	14.70±11.86	-	24.33±8.58	24.33±8.58	24.33±8.58	-	0.001
2 kHz	18.64±13.42	19.24±13.47	18.64±13.42	0.044	28.33±10.99	31.50±11.61	29.83±10.30	0.001	0.001
4 kHz	34.85±25.14	35.15±26.18	34.70±25.76	0.535	46.00±18.69	50.17±21.31	49.00±20.57	0.001	0.024
8 kHz	42.42±25.04	45.30±25.12	44.70±25.52	0.001	57.33±16.85	63.83±19.68	63.17±19.63	0.000	0.003
TM (dB)									
Loudness	49.85±16.56	54.85±17.48	52.27±16.34	<0.001	50.83±19.08	61.00±18.12	56.50±17.92	<0.001	0.385

PTA: Pure Tone Audiometry, TM: Tinnitus Matching; SD: Standard Deviation.
Paired samples T-test, within each group, between the baseline and the first month measurements (p*).
Repeated measures ANOVA (group×time×frequency), between the subject effects (p**).

	Baseline (mean±SD)	1st day (mean±SD)	p*	Baseline (mean±SD)	1st day (mean±SD)	p*	p**
Test							
VAS 1	4.91±1.99	5.33±2.38	0.011	4.53±2.40	5.07±2.07	0.011	0.558
VAS 2	4.82±1.86	5.61±2.34	<0.001	4.33±1.88	5.10±1.37	<0.001	0.288
VAS 3	4.94±2.08	5.82±2.63	0.007	4.60±2.86	4.93±2.23	0.134	0.304
VAS 4	3.79±1.83	4.48±1.99	0.005	3.63±1.87	4.13±2.27	0.007	0.601
VAS 5	3.55±1.94	4.79±2.40	<0.001	3.17±2.63	3.73±2.52	<0.001	0.012
BDI	3.24±4.58	4.06±5.11	<0.001	4.30±2.78	6.10±3.67	<0.001	0.130
THI	33.33±19.54	37.00±21.85	<0.001	35.67±14.60	40.40±15.83	<0.001	0.535

BDI: Beck Depression Inventory, SD: Standard Deviation, THI: Tinnitus Handicap Inventory, VAS: Visual Analogue Scale.
Paired samples T-test, within each group, between the baseline and the first day measurements (p*).
Repeated measures ANOVA (group×time×frequency), between the subject effects (p**).

between the two age groups (p = 0.271, p = 0.363 for TTS and PTS, respectively). The mean TTSs between tinnitus loudness on the first day post-MRI and baseline were 5.00 ± 6.495 dB and 10.17 ± 11.179 dB for patients aged <65 and aged ≥65 respectively; this difference was statistically significant (p = 0.018). However, this significance disappeared for PTSs (2.42 ± 5.019 dB and 5.67 ± 7.739 dB for patients aged <65 and ≥65, respectively) (p = 0.063).

When Table 4 was examined, it revealed that the frequency of TTS and PTS at PTA that occurred from baseline to post-MRI measurements was higher for the geriatric group (36.7% vs. 21.2% for TTS and 33.3% vs. 15.2% for PTS, in patients aged ≥65 and aged <65 respectively), even though the difference was not statistically significant. The results were similar for the TM test for loudness, i.e., the frequency of TTS and PTS was higher for the geriatric group (50% vs. 27.3% for TTS and 26.7% vs. 12.1% for PTS in patients aged ≥65 and <65, respectively).

We defined a level change as follows: at least a one-point increase on a minimum of three items for the VAS; a ≥1 level class change for the BDI (minimal, mild, moderate, and severe); and a ≥1 level class change for the THI with respect to the functional, emotional, and catastrophic classes.

Table 3. Comparison of mean threshold shifts in pure tone audiometry between two age groups of patients with tinnitus.

	Age<65 years		Age ≥ 65 years		
Temporary Threshold Shift					
	Mean±SD	Minimum-Maximum	Mean±SD	Minimum-Maximum	p*
PTA Frequency					
500 Hz	0±0.00	0-0	0±0.00	0-0	1.000
1000 Hz	0±0.00	0-0	0±0.00	0-0	1.000
2000 Hz	0.61±1.66	0-5	3.17±4.64	0-15	0.012
4000 Hz	0.76±2.21	0-10	4.17±5.89	0-20	0.006
8000 Hz	3.33±4.95	0-15	6.33±8.60	0-25	0.271
Permanent Threshold Shift					
	Mean±SD	Minimum-Maximum	Mean±SD	Minimum-Maximum	p*
PTA Frequency					
500 Hz	0±0.00	0-0	0±0.00	0-0	1.000
1000 Hz	0±0.00	0-0	0±0.00	0-0	1.000
2000 Hz	0±0.00	0-0	1.50±2.98	0-10	0.004
4000 Hz	0.30±1.21	0-5	3.00±4.66	0-15	0.004
8000 Hz	2.73±4.16	0-15	5.67±8.28	0-25	0.363

PTA: Pure Tone Audiometry, SD: Standard Deviation. p*: Mann-Whitney U test.

The rates of level changes were 43.3% for the VAS, 10% for the BDI, and 33.3% for the THI for geriatric patients. However, the incidence of self-report test deteriorations was not statistically significantly different between the two patient age groups ($p > 0.05$ for all).

In the correlation analysis, the continuous variables of the PTA thresholds at the 4,000 and 8,000 Hz frequencies were strongly correlated with the VAS (especially VAS 1 and 5), BDI, and THI scores at the 0.01 level of significance (two-tailed). The mean THI score shift was correlated with the mean threshold shift in the PTA at the 2,000, 4,000, and 8,000 Hz frequencies before and after the MRI ($r = 0.319$, $p = 0.012$; $r = 374$, $p = 0.003$; $r = 417$, $p = 0.001$ for TTS at 2,000, 4,000, and 8,000 Hz, respectively, and $r = 0.294$, $p = 0.019$; $r = 350$, $p = 0.005$; $r = 470$, $p < 0.00$ for PTS at 2,000, 4,000, and 8,000 Hz, respectively). Interestingly, the PTA threshold shifts at 8,000 Hz for TTS plus both 4,000 and 8,000 Hz for PTS were correlated with the THI score shifts in the geriatric group, whereas the correlations were significant only for TTS in the PTA at 4,000 Hz in patients aged <65. However, the positive correlations between the THI and TM threshold shifts from baseline were statistically significant in patients aged <65 ($r = 439$, $p = 0.011$ for TTS, and $r = 0.362$, $p = 0.039$ for PTS), in contrast to geriatric patients ($p > 0.05$).

DISCUSSION

The most important outcome of the current study was that geriatric patients were more vulnerable to MRI-related noise induced hearing threshold changes. However, they did not tend to acknowledge this effect in the self-report questionnaires as much, which might be due to their decreased attention to the directed questions and diminished mental cooperation with these subjective tests.

Although the majority of the time-dependent

Table 4. Descriptive analysis regarding the presence of temporary and permanent threshold shifts in audiometric tests and the presence of level changes in self-report questionnaires between the age groups.

		Age Group			
		Age<65 (%)	Age ≥ 65 (%)	n (total)	p
TTS-PTA	absent	26 (78.8)	19 (63.3)	45	
	present	7 (21.2)	11 (36.7)	18	0.175*
	n (total)	33	30		
PTS-PTA	absent	28 (84.8)	20 (66.7)	48	
	present	5 (15.2)	10 (33.3)	15	0.081**
	n (total)	33	30		
TTS-TM	absent	24 (72.7)	15 (50)	39	
	present	9 (27.3)	15 (50)	24	0.064*
	n (total)	33	30		
PTS-TM	absent	29 (87.9)	22 (73.3)	51	
	present	4 (12.1)	8 (26.7)	12	0.126**
	n (total)	33	30		
VAS-difference	absent	22 (66.7)	17 (56.7)	39	
	present	11 (33.3)	13 (43.3)	24	0.414*
	n (total)	33	30		
BDI-difference	absent	33 (100)	27 (90)	60	
	present	0 (0)	3 (10)	3	0.102**
	n (total)	33	30		
THI-difference	absent	26 (78.8)	20 (66.7)	46	
	present	7 (21.2)	10 (33.3)	17	0.279*
	n (total)	33	30		

BDI: Beck Depression Inventory, PTA: Pure Tone Audiometry, PTS: Permanent Threshold Shift, THI: Tinnitus Handicap Inventory, TM: Tinnitus Matching, TTS: Temporary Threshold Shift, VAS: Visual Analogue Scale.
p*: Chi-Square test, p**: Fisher's Exact test.

analyses for the PTA, TM, VAS, BDI, and THI were insignificant and crosstabs for the presence of threshold shifts and level changes were indifferent statistically between two age groups, impairment was observed in the numbers and percentages in the patients aged>65 years after MRI.

Temporal bone MRI is required in patients with unilateral unexplained tinnitus with or without hearing loss, patients with bilateral symmetric and asymmetric hearing loss suspected of retrocochlear pathology, and patients with suspected intracranial tumors. During an MRI scan, various types of noise at different pitches and intensities occur. This leads to symptoms of discomfort for both patients and health care workers, including being unable to communicate, anxiety, claustrophobia, and hearing loss or any kind of acoustic trauma (3–5,12–14).

The sensitivity of the human ear to sound begins at 0 dB (hearing threshold), and disturbance occurs when the SPL exceeds 120–140 dB (pain threshold). In 1.5 Tesla MRI scans, 81–117 dB SPLs

are common and may reach as high as 131 dB for high-speed echo planar imaging (4,15). Both the auditory and vestibular labyrinths may be damaged by high acoustic sound levels. Golz et al. reported that unilateral or bilateral hearing loss might be associated with the abnormal vestibular functions that result from noise (16).

Several otological conditions, especially asymmetric hearing loss, fall under the etiology of tinnitus. Although otological anomalies may be the source of initial tinnitus, it is more likely to continue due to subsequent neural changes in the central auditory system (17,18). While 17% of the general population has been reported to have tinnitus, this rate could be as high as 33% in the geriatric population (19). Presbycusis is responsible for the majority of the etiology of tinnitus, but acoustic trauma also holds a significant place.

In recent years, there has been a growing interest in MRI systems, which has resulted in an increased frequency of requested MRI examinations, which consequently might influence the acoustic characteristics of the inner ear and the incidence of MRI-induced hearing loss or tinnitus (20). The characteristics of the frequency spectra (generally between 0.2 and 1.5 kHz) of acoustic noise generated by MRI depend on the equipment composition and system protocol (21). In particular, Cho et al. (22) found that under loud noise (100 dB), the frequency range occurs in a wide range up to 4 kHz, with a peak at around 2.4 Hz.

The present study also demonstrated that the acoustic noise induced by 1.5 Tesla MRI of the temporal region has a negative impact on the audiometric and self-reported quality measures of tinnitus. Previous studies have reported on depression or anxiety caused by MRI and the bidirectional relationship between such depression and MRI-induced tinnitus (12–14). Furthermore, herein, the MRI noise itself was detected at peak levels of 118 dBA (126 dB) to clearly address the cause-and-effect relationship with post-MRI tinnitus.

In patients with tinnitus, the severity is associated with the severity of anxiety and depression (23). The literature has shown that tinnitus causes more dissatisfaction in older patients, as it may alter sleep patterns and emotional states (24). In this study, sleep disturbances caused by tinnitus (VAS 5) were more evident in patients aged <65, which might be explained by the fact that sleep deprivation could be less tolerable for younger or more socially active people. The numeric values of all VAS scores were higher in patients aged <65 in contrast to the BDI and THI scores, which were higher in geriatric patients. Moreover, the frequency of deterioration on the BDI and THI scales was also higher for the latter group of patients in the present study.

To the best of our knowledge, this is the first study to address the threshold shifts in frequency-specific hearing and tinnitus loudness together with self-reported tinnitus disturbance tests between geriatric and non-geriatric patients. Since exposure to acoustic noise has been found to cause hearing loss, even in a small group of patients, acoustic noise should be assumed to be one of the MRI safety-first parameters. Therefore, hearing protection should be required for all patients, geriatric or not, with the use of earplugs to avoid the undesired effects of this equipment.

CONCLUSION

It may be inferred from this study that 1.5 Tesla contrast-enhanced MRI of the temporal bone might cause deterioration of the hearing and increase tinnitus loudness thresholds and discomfort caused by tinnitus especially in geriatric patients. Therefore, we must consider further the indications of its necessity and take measures to protect the hearing of all patients undergoing an MRI scan.

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