

Original Article

Does 3 Tesla Magnetic Resonance Imaging Have Adverse Effect on Cochlear Functions?

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OBJECTIVE: The aim of this study was to investigate the effects of 3 Tesla (3T) magnetic resonance imaging (MRI) noise on cochlear functions.

METHODS: The distortion product otoacoustic emission (DPOAE) test was applied to patients who were scheduled to have 3T MRI in the tertiary care center. Patients who revealed emission amplitudes at all frequencies (1, 1.5, 2, 3, 4, 6, and 8 kHz) in the DPOAE test before MRI were included in the study. After MRI, the DPOAE test was performed twice on 17 patients (33 ears) (immediately after MRI and 30 minutes after MRI). The changes in the results of the tests taken before MRI (pre-MRI), immediately after MRI (post-MRI 1), and at 30 minutes after MRI (post-MRI 2) in the DPOAE amplitudes at all frequencies were compared statistically.

RESULTS: There was a significant difference between pre-MRI, post-MRI 1, and post-MRI 2 measurements at 3, 6, and 8 kHz. In pairwise comparisons; post-MRI 1 was statistically lower than post-MRI 2 at 3 kHz, and post-MRI 1 was statistically lower than pre-MRI and post-MRI 2 at 6 and 8 kHz. In addition, post-MRI 2 was significantly lower than pre-MRI at 8 kHz.

CONCLUSION: According to these results, 3T MRI noise does not have any permanent negative impact on hearing functions. It can only cause DPOAE amplitude changes at high frequencies. This is a clinically negligible effect. Therefore, it can be considered that the 3T MRI examination with protective headphones does not cause any adverse side effects in terms of hearing functions.

KEYWORDS: Distortion product otoacoustic emission, magnetic resonance imaging, noise, noise-induced hearing loss, outer hair cell, sensorineural hearing loss

INTRODUCTION

Noise exposure is one of the most common causes of sensorineural hearing loss (SNHL).¹ Noise-induced hearing loss (NIHL) can develop due to acute or chronic noise exposure. Chronic NIHL occurs with exposure to noise, not of a very high level but over a period of many years, and is often seen as an occupational consequence. Acute NIHL occurs after short-term exposure to very loud noise and usually presents with temporary threshold shift (TTS).² A permanent threshold shift (PTS) may occur depending on the duration and the severity of the noise.³

Magnetic resonance imaging (MRI) is one of the methods which is commonly used for screening soft tissues. The disadvantages of the investigation are the long test time and high levels of noise exposure during imaging.⁴ Although headphones and earplugs are used to reduce noise during MRI, patients are still exposed to very loud sounds.⁵ It is accepted that the noise exposure during MRI does not have a negative effect on hearing functions.⁶ However, it has been reported that MRI noise exposure may cause TTS and occasionally, permanent SNHL.^{7,8}

The aim of this study was to present distortion product otoacoustic emission (DPOAE) measurements which show the functions of the outer hair cells (HC) which are first affected by the noise of 3 Tesla (3T) MRI, to reveal the changes occurring in the inner ear

due to 3T MRI noise, and to investigate whether these changes are temporary or permanent.

METHODS

Approval for the study was obtained from the Clinical Research Local Ethics Committee of the tertiary care center prior to this prospective clinical trial (Decree no: OMU KAEK 2017/109). The study included patients aged 18-65 years, who were scheduled to undergo 3T MRI examination (Philips Ingenia; Philips Healthcare, the Netherlands) in the tertiary healthcare center between March 2017 and December 2018. The patients were informed about the study and informed consent forms were obtained from the volunteers. Patients who had tinnitus, hearing loss, or abnormal otoscopic examination findings were excluded from the study. DPOAE was applied to the patients before MRI (pre-MRI). The DPOAE measurements were taken at 1, 1.5, 2, 3, 4, 6, and 8 kHz. Patients with emissions obtained at all frequencies were included in the study and the others were excluded. Throughout, the time in the MRI unit and the duration of the MRI examination were recorded. All patients wore standard protective headphones during MRI. The DPOAE tests were performed 2 times after MRI; immediately after MRI (post-MRI 1) and 30 minutes after MRI (post-MRI 2). The pre-MRI, post-MRI 1, and post-MRI 2 test results were statistically compared at each frequency, one by one.

Distortion Product Otoacoustic Emission Measurements

The values of DPOAE were recorded using a computer-based DPOAE analyzer (Grason-Stadler Inc., Eden Prairie, MN, USA) (GSI AUDERA) with primary tone levels of 65 dB sound pressure level (SPL) (L1) and 55 dB SPL (L2) and a frequency ratio f_2/f_1 of 1.22. Distortion products were measured at $2f_1-f_2$. The DPOAE values were measured at all frequencies (1, 1.5, 2, 3, 4, 6, and 8 kHz) and were recorded. The pre-MRI, post-MRI 1, and post-MRI 2 measurements were all taken twice and the arithmetic average of the 2 measurements was calculated.

Statistical Analysis

Data obtained in the study were analyzed statistically using IBM SPSS version 22 software (IBM SPSS Statistics for Windows, version 22.0. Armonk, NY, USA). Continuous variables were presented as mean \pm standard deviation values. The normality of the dependent variables in each combination of the related groups was confirmed using the Shapiro-Wilk test of normality. Statistically significant differences between the groups were analyzed using repeated measures ANOVA for data which showed normal distribution or the Friedman test for non-normal distributions. Mauchly's test of sphericity was used to check the assumption of sphericity. If the Mauchly's test statistic was significant, the Greenhouse-Geisser or Huynh-Feldt correction was used. If the main/interaction effect was significant, Bonferroni correction was applied for multiple comparisons. The statistical level of significance for all tests was $P < .05$.

RESULTS

A total of 17 patients and 33 ears were included in the study (in one ear, DPOAE values could not be determined because the probe could not be worn correctly). The youngest patient was 25 years old, and the oldest one was 60 (mean: 39.11). The test durations ranged from 25 to 60 minutes, with an average of 36.23 minutes. The detailed data of the patients (age, sex, duration of MRI, and reason for MRI) have been shown in Table 1. Mean DPOAE amplitudes in pre-MRI were 7.7 dB at 1 kHz ($SD = 0.9$), 12.3 dB at 1.5 kHz ($SD = 1.04$), 13.6 dB at 2 kHz

Table 1. Detailed Data of the Patients

Patient Number	Age	Sex	Duration of MRI (Minutes)	Type of MRI
1	27	Female	55	Brain
2	31	Female	40	Brain
3	27	Female	52	Brain
4	34	Female	29	Pelvis
5	48	Female	27	Pelvis
6	26	Female	25	Abdomen
7	30	Male	28	Paranasal sinus
8	35	Female	41	Cardiac
9	44	Male	45	Cardiac
10	42	Female	38	Abdomen
11	37	Male	27	Brain
12	60	Female	31	Brain
13	43	Female	29	Brain
14	37	Female	36	Lumbar spine
15	35	Male	43	Brain
16*	57	Male	45	Brain
17	52	Female	25	Hypophysis

*The patient whose DPOAE values could not be determined in one ear.

($SD = 1.06$), 13.7 dB at 3 kHz ($SD = 0.96$), 13.8 dB at 4 kHz ($SD = 1.05$), 12.3 dB at 6 kHz ($SD = 1.33$), and 7.4 dB at 8 kHz ($SD = 2.62$) (Table 2, Figure 1). The post-MRI 1 and post-MRI-2 DPOAE amplitude averages are given in Table 2. Significant differences were observed between the groups (pre-MRI, post-MRI 1 and post-MRI 2) at 3, 6, and 8 kHz. In pairwise comparisons at 6 kHz, there was a significant difference between pre-MRI and post-MRI 1, and between post-MRI 1 and post-MRI 2. The post-MRI 1 value was statistically significantly lower than pre-MRI and post-MRI 2. At 8 kHz, a statistically significant difference was observed among all the groups. The post-MRI 1 value was statistically significantly lower than pre-MRI and post-MRI 2, and post-MRI 2 was significantly lower than pre-MRI. At 3 kHz, there was a significant difference only between post-MRI 1 and post-MRI 2. The post-MRI 1 value was statistically significantly lower than the post-MRI 2 value. There was no significant difference between the groups at other frequencies (1, 1.5, 2, and 4 kHz). The P -values of the paired comparisons between the groups are given in Table 3.

Table 2. Distortion Product Otoacoustic Emission Measurements (dB Sound Pressure Level)

	Pre		Post 1		Post 2	
	Mean	SD	Mean	SD	Mean	SD
1 kHz	7.703	0.923	7.258	0.969	6.861	0.952
1.5 kHz	12.309	1.041	11.127	1.049	12.206	1.097
2 kHz	13.621	1.066	13.256	1.013	13.255	1.066
3 kHz	13.742	0.968	12.176	1.067	14.076	0.984
4 kHz	13.812	1.050	12.897	1.130	13.836	1.059
6 kHz	12.348	1.339	10.848	1.532	12.161	1.495
8 kHz	7.400	2.621	3.103	0.638	4.627	0.517

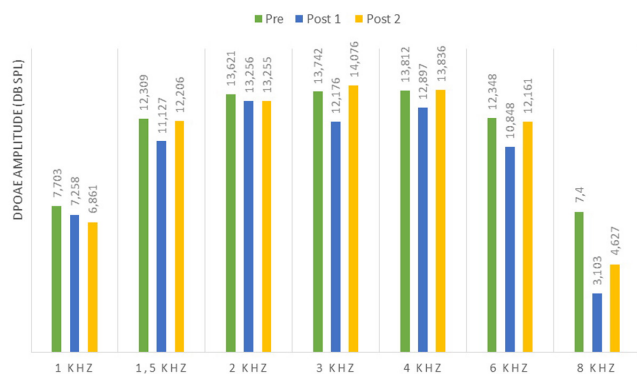


Figure 1. Graph showing the changes in the test results before and after 3 Tesla magnetic resonance imaging.

DISCUSSION

Noise-induced hearing loss develops as a consequence of oxidative stress to sensory HC in the cochlea.⁹ While temporary damage occurs in HC stereocilia and synapses in TTS, there is permanent damage in PTS.¹⁰ The mechanism of HC damage is a complex pathway, which is in the form of apoptotic and/or necrotic cell death induced by the activation of intracellular stress pathways with the accumulation of reactive oxygen radicals.¹⁰ The mechanical effect created by the noise is the trigger point of this chain of events.¹⁰

Otoacoustic emissions (OAE), which actively reflect from the cochlea and are measured in the external auditory canal, were first defined by Kemp et al.¹¹ OAEs are transmitted from the cochlea through the middle ear and tympanic membrane to the external ear canal. The acoustic energy generated in the external ear canal as a result of the non-linear interaction of the primary simulated pure-sound frequency (f1, f2) in the cochlea is called the DPOAE. The measure of DPOAE is especially used to evaluate the functions of outer HC in the organ of Corti,¹² and is an objective, non-invasive, inexpensive, and short-term test that is useful in demonstrating cochlear functions.^{11,13} In addition, it is a reliable test for acute NIHL as it shows the functions of the outer HC objectively. However, it has been reported that DPOAEs are correlated with pure-tone audiometry.^{14,15} Therefore, the DPOAE test was preferred for the evaluation of hearing status in the current study.

Gradient coils, which determine where the signal comes from in MRI to provide the imaging sections, is also the main source of noise during the MRI examination.¹⁶ The greater the strength of the magnetic field, the greater the intensity of the noise produced by the

device, increasing in direct proportion.¹⁶ There are some studies in the literature which have determined and standardized the level of noise generated during MRI. Hattori et al.⁵ found this value to be between 126 and 131 dB in a study for the detection of noise in 3T MRI. However, Ravicz et al.¹⁶ reported noise peak levels as 123 and 138 dB for 1.5 T and 3.0 T MRI, respectively. These are loudness values that can cause temporary or permanent impairments in cochlear functions.³ In addition, the frequency of MRI noise is generally below 4 kHz (usually lower than 2 kHz), which is within the frequency range where speech sounds are concentrated.^{17,18}

There are many studies which have been conducted to reveal the effect on cochlear functions of noise exposure during MRI. Based on these studies, various earplugs and protective headphones have been developed to minimize the effect of exposure. Radomskij et al.⁸ compared hearing loss after MRI examination between 2 groups of patients wearing/not wearing ear protectors. The OAE amplitude changes before and after MRI were examined, and a decrease in OAE amplitudes after testing was observed in the group that did not use ear protection. Thus, the importance of using effective ear protection during the MRI scan was emphasised.⁸ Wagner et al.⁶ evaluated the cochlear functions of 126 patients with protective headphones by measuring DPOAE and pure-tone audiometry before and after MRI. No significant TTS or reduction in DPOAE amplitude averages were observed. Accordingly, it was stated that MRI examination with ear protection had no negative effect on cochlear functions. However, in an experimental study on dogs in which DPOAE values were measured, Venn et al.¹⁹ reported that MRI noise caused a decrease in frequency-specific cochlear functions.

Before the MRI procedure, patients are asked whether they have any orthodontic braces, pacemakers, pumps, stents, steel-containing orthopedic prostheses, implanted hearing aids, or psychogenic conditions such as claustrophobia.^{20,21} When the informed consent forms obtained from patients before MRI were examined, it was seen that hearing loss due to high sound exposure was not included.²² Although it is accepted that MRI noise can cause anxiety and psychological symptoms, it is thought that it will not pose a risk for the development of hearing loss.^{6,23} Nevertheless, TTS can be seen after MRI. For example, Jin et al.²⁴ reported that 3T MR neuroimaging examination with approximately 103.5–111.3 dB acoustic noise lasting 51 minutes may cause TTS in healthy volunteers with hearing protection. A study by Bahaloo et al.²⁵ revealed that 1.5 T MRI noise during head and neck MRI may cause TTS without PTS. Nonetheless, there are also rare cases of PTS after MRI examination. Mollasadeghi et al.¹⁸ reported that bilateral SNHL developed after 1.5 T MRI without hearing-protective equipment lasting 25 minutes in a patient who had no previous hearing complaints, and no improvement was observed in the 3-month observation period. In our study, the duration of the MRI test in all patients was at least 25 minutes. When evaluated in terms of duration, it was sufficient to evaluate the effect of noise exposure on hearing functions.

MRI examination may be performed to evaluate some conditions such as sudden SNHL or asymmetric hearing loss.^{26,27} It is necessary to determine whether 3T MRI causes hearing loss, because performing a procedure with a risk of hearing loss on a patient who already has hearing loss is contradictory. However, in non-otolaryngology clinics, is performing a hearing test necessary before MRI of patients who are

Table 3. P-Values of Pairwise Comparisons (Wilcoxon Signed-Rank Test for 1, 6, 8 kHz, ANOVA for 1.5, 2, 3, 4 kHz)

	Pre–Post 1	Pre–Post 2	Post 1–Post 2
1 kHz	0.129	0.075	0.929
1.5 kHz	0.473	1.000	0.557
2 kHz	1.000	1.000	1.000
3 kHz	0.190	1.000	*0.041
4 kHz	0.626	1.000	0.297
6 kHz	*0.001	0.808	*0.003
8 kHz	*0.000	*0.021	*0.000

Bold values indicates statistical significance ($P < .05$).

planned to undergo 3T MRI examination? Should it be questioned whether there is hearing loss? If 3T MRI is likely to cause NIHL, this will pose a serious risk to public health. The current study was designed to answer all these questions.

From a review of literature in English, no study could be found which investigated the effect of 3T MRI noise on the outer HC in the cochlea. Although similar clinical and experimental studies have been previously performed with 1 or 1.5 T MRI, this study is the first to evaluate cochlear functions after 3T MRI. The need for this study has arisen due to the widespread use of 3T MRI in recent years, with noise values higher than 1 and 1.5 T MRI.^{5,16} The results of the study showed that significant differences were observed between the DPOAE amplitudes performed before and after MRI at 3, 6, and 8 kHz. The significant difference between post-MRI 1 and post-MRI 2 at 3 kHz shows that there is an effect on cochlear functions immediately after MRI, but this effect improved after half an hour of rest. At 6 kHz, immediately after MRI, the DPOAE amplitudes decreased significantly when compared to those measured before MRI, but they returned to normal half an hour after the MRI examination. The DPOAE amplitudes which showed a significant decrease immediately after MRI, increased after half an hour of rest only at 8kHz, but did not reach pre-MRI values. When interpreting these results, it can be said that MRI noise has an effect on the functions of the outer HC at high frequencies. In addition, 30 minutes after MRI, the increase of decreased amplitudes can be interpreted as the temporary nature of this effect. 3T MRI noise can be considered as having no clinically adverse effect on hearing functions, as speech sounds are at the same low frequencies.

There are some limiting factors of the study. A retest is required at least 24 hours later, to interpret whether changes in DPOAE amplitudes are permanent.²⁸ In the current study, the last test was performed half an hour after MRI to assess the return to normal of amplitude loss, due to the difficulty in access to patients after 1 day. In addition to this, we would have to measure sound pressure levels inside the protective headphone to evaluate the noise that patients are exposed to during MRI, but we did not have the necessary equipment. The final limitation is the small number of participants. Exclusion of patients due to the absence of emissions at some frequencies in the pre-MRI test, and the insufficient number of voluntary participants were reasons for this limitation. Further studies with more participants and more data may yield more valuable results on this subject.

CONCLUSION

According to the results of this study, as long as protective headphones are used, 3T MRI noise does not cause any hearing impairment that could result in clinical loss of hearing functions. The current study shows that the noise of 3T MRI, which has become the frequently preferred technique for the evaluation of soft tissue diseases in recent years, causes variations in DPOAE amplitudes, but does not create a permanent effect on cochlear functions.

Ethics Committee Approval: The Approval for the study was obtained from the Clinical Research Local Ethics Committee of Ondokuz Mayıs University prior to this prospective clinical trial (Decree no. OMU KAİK 2017/109).

Informed Consent: The patients were informed about the study, and informed consent forms were obtained from the volunteers.

Peer Review: Externally peer-reviewed.

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