Auditory effects of noise exposure during magnetic resonance imaging

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INTRODUCTION

Various types of acoustic noise are produced during the operation of MR systems. The problems associated with acoustic noise for patients and healthcare workers include simple annoyance, difficulties in verbal communication, heightened anxiety, temporary hearing loss, and potential permanent hearing impairment (Brummett et al. 1988; Quirk et al. 1989; Laurell 1992; Philbin et al. 1996; Kanal et al. 1988, 1990; Shellock & Kanal 1991; Shellock et al. 1992). Acoustic noise may pose a particular hazard to specific patient groups who may be at increased risk. Patients with psychiatric disorders and elderly and pediatric patients may be confused or suffer from heightened anxiety (Quirk et al. 1989). Sedated patients may experience discomfort due to high noise levels. Certain drugs are known to increase hearing sensitivity (Laurell 1992). Neonates with immature anatomical development may have an increased response to acoustic noise. For example, significant alterations in vital signs of newborns have been reported during MRI examinations, which may be attributed to acoustic noise (Philbin et al. 1996).

Acoustic noise levels during echoplanar imaging (EPI) have been reported to increase significantly pure tone hearing thresholds in the optimal frequency hearing range (i.e., 0.1–8 kHz) (Ulmer et al. 1998). These effects vary across the frequency range. The threshold changes according to the characteristics of the sequence-generated acoustic noise (Ulmer et al. 1998). The gradient magnetic field is the primary source of acoustic noise associated with MR procedures (Goldman et al. 1989; Hurwitz et al. 1989). This noise occurs during the rapid alternations of currents within the gradient coils. These currents, in the presence of a strong static magnetic field of MR system, produce significant (Lorentz) forces that act upon the gradient coils. Acoustic noise, manifested as loud tapping, knocking, or chirping sounds, is produced when the forces cause motion or vibration of the gradient coils as they impact against their mountings which, in turn, also flex and vibrate. Alteration of the gradient output (rise time or amplitude) caused by modifying the MR imaging parameters will cause the level of gradient-induced acoustic noise to vary. This noise is enhanced by decreases in section thickness, field of view, repetition time, and echo time. The physical features of the MR system, especially whether or not it has special sound insulation, and the material and construction of coils and support structures also affect the transmission of the acoustic noise and its subsequent perception by the patient and MR system operator. Hurwitz et al. (1989) reported that the sound levels varied from 82 to 93 dB on the A-weighted scale and from 84 to 103 dB on the linear scale. Table 1 shows the relationship between the noise duration and recommended permissible sound levels for occupational exposures.

Table 1: Permissible exposure levels to acoustic noise

Noise duration / day (hours)	Sound level (dB A)
8	90
6	92
4	95
3	97
1.5	100
1	102
0.5	105
0.25	115

The U.S. Food and Drug Administration indicates that the acoustic noise levels associated with the operation of MR systems must be below the level of concern established by pertinent federal regulatory or other recognized standards setting organizations. If the acoustic noise is not below the level of concern, the manufacturer of the MR system must recommend steps to reduce or alleviate the noise perceived by the patient. No recommendations exist for non-occupational or medical exposures. In general, the acoustic noise levels recorded by various researchers in the MR environment have been below the maximum limit permissible by the Occupational Safety and Health Administration (OSHA) of the United States. This is particularly the case when one considers that the duration of exposure is one of the most important physical factors that determine the effect of noise on hearing. These recommended limits for acoustic noise produced during MRI procedures are based on recommendations for occupational exposures that are inherently chronic exposures with respect to the time duration. Of note is that comparable recommendations do not exist for non-occupational exposure to relatively short-term noise produced by medical devices.

AIM

To determine if there is any noise induced threshold shift resulting from the noise exposure from Magnetic Resonance Imaging (MRI).

METHOD

Instruments used

- MAICO MA 53 audiometer with Telephonics TDH 49P headphones and Radio ear B-71 bone vibrator
- MAICO ERO SCAN OAE Test system
- MRI instrument used were General Electric Sigma Contour 0.5 Tesla and General Electric 1.5 Tesla HDxt

Participants

A total of 30 adult participants (17 for 0.5 Tesla MRI and 13 for 1.5 Tesla MRI) who were scheduled for MRI anticipated to require at least 20 min of imaging time were included in this study. Informed consent was obtained from all patients after the nature of the procedure was fully explained.

Procedure

All the subjects with positive history of ear pathology, medical history for otological damage, noise exposure or the use of any ototoxic drugs were excluded from this study. An otoscopic examination was performed on each patient to check the status of the external auditory meatus and the tympanic membrane. Then, a screening OAE test was done using ERO SCAN, Etymotic Research, MAICO OAE Screening instrument to check the status of the outer hair cells of the cochlea. All the evaluations were carried out in a quiet room with ambient noise within permissible limits as per ANSI (1977) using biological calibration. Then the baseline pure tone air and bone conduction thresholds were determined employing a step size of 2 dB for each ear using the MAICO MA-53 audiometer with TDH 49P headphones and Radio ear B-71 bone vibrator. The bone conduction thresholds were also found out to rule out any middle ear condition noticed through the Air Bone Gap (ABG). The test frequencies were 250 Hz, 500 Hz, 1 kHz, 2 kHz, 4 kHz and 8 kHz. All the subjects had normal hearing air conduction thresholds (20 dBHL or below across frequencies 250 Hz to 8 kHz). The first MRI instrument used in the present study is a General Electric Sigma Contour 0.5 Tesla device. The average of noise exposure ranged from 30 min to 1 hour 30 min depending on the type of scan (determines the number and type of sequences for it) and patient's status; the time taken for the MRI of pelvis is found to be approximately 80 min for 8 sequences, for knee is 40 to 60 min for 6 sequences, for spine is 30 to 45 min for 5 sequences, for shoulder is 60 to 90 min and for brain is 30 to 45 min for 5 sequences. Out of the 17 subjects 5 had pelvis scan, 2 had knee scan, 6 had spine scan, 3 had shoulder scan and 1 had brain scan.

The second MRI instrument used in the present study is General Electric 1.5 Tesla HDxt. The participants who were scheduled for brain scans were only taken up because ear muff could be provided for all the other types of scan in this MRI instrument except for brain scans since it would distort the scan image. The time taken for the brain scan was approximately 20-30 min which all 13 participants were scheduled for. The post MR imaging audiometric threshold estimation was done as soon as possible after the completion of the MRI study. The average time taken to initiate the test after the termination of the MRI was approximately 5-10 min. Mean, Standard Deviation (S.D.) of the pre, post and between different MRI procedures were calculated. Further to estimate if the mean difference is significant, paired 't'-test was used using SPSS version 5.

RESULTS AND DISCUSSION

The literature reveals that various studies have found that the noise levels during the MRI procedure causes Temporary Threshold Shift. Noise levels in the scanning room were done using Brüel & Kjær Sound Level Meter and revealed that average L_{eq} levels were 129 dBSPL for 20 min. The hearing thresholds obtained pre and post MRI procedure are presented and discussed below. The mean and Standard Deviation (S.D.) for baseline AC thresholds of the 17 participants (34 ears) for 0.5 T MRI and 13 participants (26 ears) for 1.5 T MRI are as shown in Table 2.

Table 2: Mean and S.D. for pre MRI AC thresholds

MRI instrument used	Frequency (Hz)	250	500	1 k	2 k	4 k	8 k
0.5 T	Mean (dBHL)	14.53	14.18	14.53	14.18	14.06	14.47
	S.D.	3.98	3.69	4.69	3.83	4.76	6.68
1.5 T	Mean (dBHL)	12.46	11.84	14	13.69	14	14.46
	S.D.	2.02	2.37	2.16	1.60	2.16	1.66

The mean and S.D. of difference in thresholds between the pre and post MRI thresholds are tabulated above for the different scan procedures are as shown in Table 3.

Table 3: Mean and S.D. for post MRI AC thresholds

MRI instrument used	Frequency (Hz)	250	500	1 k	2 k	4 k	8 k
0.5 T	Mean (dBHL)	15.94	15.27	14.09	15	22.65	20.47
	S.D.	4.94	4.19	5.18	5	5.90	7.25
1.5 T	Mean (dBHL)	12.15	12.30	14.76	14.46	21.07	21.38
	S.D.	2.23	2.13	2.08	2.02	2.39	3.30

The mean values between the pre and post MRI thresholds (for both 0.5 T and 1.5 T MRI) shows a difference at 4 kHz and 8 kHz, and to check if there is a statistical significant difference, paired 't'-test was performed and it was observed there was a significant increase ($P < 0.001$) in the air conduction thresholds at 4 kHz and at 8 kHz ($P < 0.001$) after MRI. The frequencies from 250 Hz to 2 kHz did not show any statistically significant difference after exposure to acoustic noise of MRI. This shows that there is a noise induced Threshold Shift in the normal hearing subjects after the MRI which suggests that the noise exposure during the MRI has damaging effects on the auditory system. These findings can be correlated to the finding of Brummett et al. (1998) where in a total of 14 adult patients were subjected to MRI study of 0.35- Tesla equipment, wherein significant threshold shifts of 15 dB or above were found in frequencies 560 Hz, 4 KHz, 6 KHz and 8 KHz in 43 % of patients. Ear plugs, when properly used can abate noise by 10-30 dB, which is usually an adequate amount of sound attenuation for the MR environment. The use of disposable ear plugs has been shown to provide a sufficient decrease in acoustic noise that in turn would be capable of presenting the potential temporary hearing loss associated with MRI procedures (Bandettini et al. 1992). Passive noise control techniques of using Ear Protective Devices (EPD) provide poor attenuation of noise transmitted to the patient through bone conduction.

CONCLUSION

Noise originating from MRI easily reaches sound pressure levels 110 dB and higher (Moelker et al. 2003), a peak L_{eq} of 119 dBSPL was found in the current study and such high levels of noise may damage the auditory system (29 CFR 1910.95, Occupational Noise Exposure). In our study we found that noise exposure during MRI could potentially damage the human auditory system causing a significant noise induced threshold shift at 4 kHz and 8 kHz. Thus, there is a need for effective hearing

protective devices and also the necessity to reduce the generation of acoustic noise during MRI through hardware modifications of the scanner and room acoustics, in order to prevent long-term auditory effects.

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