EXAMINATION OF AUDITORY EFFECTS OF NOISE EXPOSURE DURING MAGNETIC RESONANCE IMAGING

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Abstract

The purpose of this study was to determine if there is any noise induced Threshold Shift resulting from the noise exposure for the various Magnetic Resonance Imaging examinations. A total of 17 adult patients (34 ears) were scheduled for MRI studies anticipated to require atleast 20 mins of imaging time were included in this study. Screening OAE test was done & baseline pure tone air & bone conduction thresholds were determined employing a step size of 2dB for each ear. The MRI instrument under the present study is a General Electrical Sigma Contour 0.5 Tesla device. The post MR imaging audiometric threshold estimation was done as soon as possible after the completion of MRI study. Statistical analysis using the paired 't' test shows that there was a significant increase ($p < 0.001$) in the air conduction thresholds at 4 kHz and at 8kHz ($p < 0.001$) after. 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. The parents study shows that the noise exposure during an MRI scan has an effect on the human auditory system and has been found to cause significant noise induced threshold shift at 4 kHz and 8 kHz. Noise and its auditory and non-auditory effects are proven in the literature. Since the present study revealed significant noise induced Threshold Shift, there is a need for effective Ear Protective Devices usage during MRI procedures to reduce long-term auditory effects.

Key words: MRI, noise induced threshold shift, pure tone audiometry

The introduction of Magnetic Resonance Imaging (MRI) has resulted in a tremendous advance in the technology of medical diagnosis. However with all positive advances there are normally some negative aspects. One of the potentially adverse aspects of MRI is that the equipment is extremely noisy. Many patients complain of noise, which is so loud that some children are frightened by it; some tinnitus sufferers claim that it makes their tinnitus more, such loud sounds are not only an annoyance to the patients undergoing MRI, but they have the potential of adversely affecting the patients hearing. It is a well-known fact that loud sounds can induce a hearing loss. The hearing loss can be permanent if the sound is sufficiently intense and the exposure sufficiently long. Less intense sounds or shorter periods of exposure will result in a reversible hearing loss.Since the first Magnetic Resonance Imaging (MRI) concept was devised, gradient coils and gradient pulsing has been the basic imaging book for decades. This basic gradient pulsing in conjunction with the magnetic field in MRI produces what is called acoustic noise.

Ever since the appearance of clinical MRI scanners, it has been one of the most disturbing obstacles for MRI patients scanning, especially for psychiatric patients and small children (Quirk, Letendre, Ciottone, & Lingley, 1989; Brummett, Talbot, & Charuhas, 1988; Hurwitz, 1989).

There have been some attempts to reduce the noise by using the antiphase noise cancellation technique (Goldman, Grossman, & Friedlander,

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1989) and the Lorentz force cancellation technique (Mansfield, Chapman, Botwell, Glover, Coxon, & Harvey, 1995). Most of these techniques have not been very successful and significant sound noise still remains. A simpler and perhaps more ideally used technique is the use of ear plugs but this method seems to protect only against sound transmitted by the auditory canal to the ear and does not protect against the sound transmission through bone conduction mode. In fact, patients still experience loud sound noise even after wearing ear plugs since ear plugs suppress only the high-frequency sound noise within audible frequency band (Mansfield et al., 1995).

Although studies have been reported on noise during MRI procedures and its' effects, it is felt that a more quantitative physical analysis of sound noise produced by recently variable MRI systems would be an important asset for future research on this important problem, especially in connection with the newly developing functional MRI and other cognitive science research.

Review

Acoustic noise levels during Echo Planar Imaging (EPI) have been reported to increase significantly pure tone hearing thresholds in the optimal frequency hearing range between 0.1 to 8 kHz. These effects vary across the frequency range. The threshold changes according to the characteristics of the sequence-generated acoustic noise. Notably, if may be possible to take into account the MR system-induced auditory activation by using a control series of scans in task paradigms. Experimental results have been reported for mapping auditory activation induced by MR system-related acoustic noise.

The ear is highly sensitive wide-band receiver. The human ear does not tend to judge sound powers in absolute terms but assesses how much greater one power is than another. Combined with the very wide range of powers involved, the logarithmic decibel scale, dB, is used when dealing with sound power.

Since the ear is not equally sensitive to all frequencies, data may be weighted using the dB (A) measurement scale, which biases the meter to respond similarly to the human ear. The quality or efficiency of hearing is defined by the audible threshold, that is, the SPL at which one can just begin to detect a sound.

Noise is defined in terms of frequency spectrum (in Hz), intensity (in dB), and duration (in minutes). Noise may be steady state, intermittent, impulsive, or explosive. Transient hearing loss may occur following loud noise, resulting in a Temporary Threshold Shift (TTS) (shift in audible threshold). Brummett, Talbot, & Charuhas, (1988) have reported temporary shifts in hearing thresholds in 43% patients scanned without ear protection and also in those with improperly fitted protection. Recovery from the effects of noise should be exponential and occur quickly. However, if the noise insult is severe, full recovery can take up to several weeks. If the noise is sufficiently injurious, this may result in a Permanent Threshold Shift (PTS) (i.e., permanent hearing loss) at specific frequencies.

MRI-related acoustic noise:

The gradient magnetic field is the primary source of acoustic noise associated with MR procedures (Goldman, Grossman, & Friedlander, 1989; Hurwitz, Lane, Bell & Brant-Zawadzki, 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.

Gradient magnetic field-induced noise levels have been measured during a variety of pulse sequences for clinical MR systems with static magnetic field strengths ranging from 0.35 to 1.5 T

(12-21) and one 2.0 T research system. Hurwitz et.al., (1989) reported that the sound levels varied from 82 to 93 dB on the A-weighted scaled 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. 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.

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

Table 1: Permissible Exposure Levels to Acoustic Noise

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 MR 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.

Need for the study

The sensitivity of the ear is frequency dependent. Peak hearing sensitivity occurs in the region of 4 kHz; and is also the region where the potential maximum hearing loss will occur which change spreading into neighbouring frequencies. Recovering from the effects of noise exposure during an MRI should be exponential and quick (Brummet et al., 1988). However if the noise insult is severe, full recovery can take up to several weeks.

Gradient magnetic field –induced noise leads have been measured during a variety of pulse sequences for clinical MR systems with static magnetic field strengths ranging from 0.35Tesla to 1.5Tesla. Hurwitz et. al. (1989) reported that the sound levels varied from 82 to 93 dB (A) and from the 84 to 103 dB on a linear scale.

Aim of the study

The purpose of this study was to determine if there is any noise induced Threshold Shift resulting from the noise exposure for the various MR imaging examinations.

Method

1. Instruments used:
   - MAICO MA 53 audiometer with Telephonics TDH 49
   - P headphones & Radio ear B-71 bone vibrator
   - MAICO ERO SCAN OAE Test system
   - General Electric Sigma Contour 0.5 Tesla MRI device
2. Participants:

   A total of 17 adult patients (34 ears) who were scheduled for MRI studies anticipated to require at least 20 mins of imaging time were included in this study. Informed consent was obtained from all patients after the nature of the procedure was fully explained.
3. 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 the each patient to check the status of the external auditory meatus & 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 & bone conduction thresholds were determined employing a step size of 2dB for each ear using the MAICO MA-53 audiometer with TDH 49P headphones & 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 & 8 kHz. All the subjects had normal hearing air conduction thresholds (20 dBHL or below across frequencies 250 Hz to 8 kHz).
- The MRI instrument under the present study is a General Electric Sigma Contour 0.5 Tesla device. The average of noise exposure ranged from 30 mins to 1 hour 30 mins depending on the type of scan (determines the number and type of sequences for it) & patient's status; the time taken for the MRI of pelvis is found to be approximately 80 mins for 8 sequences, for knee is 40 to 60 mins for 6 sequences, for spine is 30 to 45 mins for 5 sequences, for shoulder is 60 to 90 mins & for brain is 30 to 45 mins for 5 sequences.

Out of the 17 subjects 5 had pelvis scan, 2 had knee scan, 6 had spine scan, 3 had shoulder scan & 1 had brain scan.

- The post MR imaging audiometric threshold estimation was done as soon as possible after the completion of MRI study. The average time taken to initiate the test after the termination of the MRI was approximately 5-10 mins.
- 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 revealed that average Leq levels were 129 dBSPL for 20 mins. 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 34 ears are as shown in Table 2.

Frequency	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz
Mean (dBHL)	14.53	14.18	14.53	14.18	14.06	14.47
SD	3.98	3.69	4.96	3.83	4.76	6.88

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

Frequency	250 Hz	500 kHz	1 kHz	2 kHz	4 kHz	8 kHz
Mean (dBHL)	15.94	15.27	14.09	15.00	22.65	20.47
SD	4.94	4.19	5.18	5.00	5.90	7.25

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

Frequency		250 Hz		500 Hz		1 kHz		2 kHz		4 kHz		8 kHz	
Scan	Duration	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Spine	45 min	1.5	3.09	0.67	4.03	-1.5	2.28	2.33	3.4	8.17	4.13	7.33	4.46
Pelvis	80 min	-1.6	3.10	0.4	4.20	-0.6	3.41	0.8	0.8	7.8	3.11	2.4	4.41
Knee	60 min	3	5.03	1.5	4.43	2.25	2.63	3	6.22	9	5.77	7.5	2.52
Brain	45 min	1	1.41	0	5.66	-1	1.41	-2	0	10	5.66	7	7.07
Shoulder	90 min	5.33	5.16	2.83	5.67	1	7.13	-1	4.85	9.67	5.57	6	2.53

Table 4: Mean & S.D. of difference in thresholds (dBHL) between pre & post MRI for the different scan procedures.

The Mean and S.D. of difference in thresholds between the pre and post MRI thresholds are tabulated above for the different scan procedures (Table 3).

The Mean and S.D. of difference in thresholds between the pre and post MRI thresholds are tabulated above for the different scan procedures (Table 4).

The mean values between the pre and post MRI thresholds 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 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 shows.

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 10-30dB, 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 MR procedures (Bandettini, Wong, Hinks, Tikofsky, & Hyde, 1992). Passive noise control techniques of using Ear Protective Devices (EPD) provide poor attenuation of noise transmitted to the patient through bone conduction.

Conclusion

The presents study shows that the noise exposure during an MRI scan has an effect on the human auditory system and has been found to cause significant noise induced threshold shift at 4 kHz and 8 kHz. Noise and its auditory and non-auditory effects are proven in the literature. Since the present study revealed significant noise induced Threshold Shift, there is a need for effective Ear Protective Devices usage during MRI procedures to reduce long-term auditory effects.

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