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Acoustic characterization of the 1.5 Tesla MRI facility in Mobile Imaging Trailer

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Abstract The Magnetic Resonance (MR) imaging is a very important medical tool for diagnosis of the internal organs of the patient. The major problem associated with MRI is its high noise during operation responsible for anxiety, discomfort and can be harmful for the patient as well as long exposure raises the safety concerns for the operating staffs. This study involves the characterization of the noise in the vicinity of 1.5 Tesla Mobile Imaging Trailer-MRI (MIT-MRI) system, aimed at evaluating the acoustic parameters in the examination room during scanning. The acoustic measurements were carried out using the microphones located inside the MRI examination room for variations of Diffusion Weighted Imaging (DWI) gradient pulse sequences. The sound recordings depicted the waveforms of complex acoustic pulses with high Sound Pressure Level (SPL) spikes of impulse nature. Results revealed equivalent SPL in the MRI examination room exceeds 90 dB(A) and the peak noise was consistently above 101.5 dB(C) and DWI sequence with oscillating gradient (DWI-og) reported peak SPL of 105.9 dB(C). The dominance of the noise is identified in the frequency range of 500–3000 Hz for all scanning sequence. Results indicate that sound levels are high in the mobile scanning facility as compared to the stationary MRI in the hospitals. The noise in the control room and chiller room were also high. Given that these acoustic measurements surpass recommended noise standards, the significance of ear protection is emphasized. These results can be useful in designing the noise reduction strategies to improve the patient comfort and safety.

Keywords: magnetic resonance imaging, mobile imaging trailer, acoustics, noise measurement.

1. Introduction

The Magnetic Resonance Imaging (MRI) is an essential tool for understanding the inner workings of the human body. But this technology presents a challenge of high noise. Exposure to such noise can cause anxiety, discomfort, and potential harm to a patient's hearing, also impairs patient operator communication [1, 2]. For foetuses and infants, MRI induced noise may lead to hearing loss at high frequencies and hinder growth [3, 4]. Along with the discomfort, the noise from MRI is responsible for changes in brain signals by changing the blood oxygenation related signals as seen in the functional MRI scanning [5-7]. Another person inside the examination room attending the physically challenged patient or patient suffering from anxiety due to claustrophobia is more vulnerable to the noise. This necessitates the minimization of the noise during MRI scans. The noisy work condition is also problematic for the operator and poses hazards for them [8-10]. Literature identifies the gradient coils as a major contributor to the noise, whose primary function is to produce dynamic magnetic field for MRI scanning [11-13]. The peak sound pressure level in the MRI system can reach up to 133 dB and is dependent on the scanner magnetic field strength [14-16].

Sound measurement is important for developing the noise reduction strategies and enhancing the patient comfort during the MRI procedure [17, 18]. The major methods for controlling the noise in the MRI includes hardware based, sequence based and protective equipment method. Hardware modifications, although effective, requires extensive changes in the MRI scanner's configuration, making them economically impractical [19]. The sequence-based method focuses on optimising the gradient coil input signals to prevent sudden changes in the function, albeit compromising the scan quality [20]. The protective equipment method encompasses passive and Active Noise Control (ANC) being highly effective but not universally suitable [21-26].

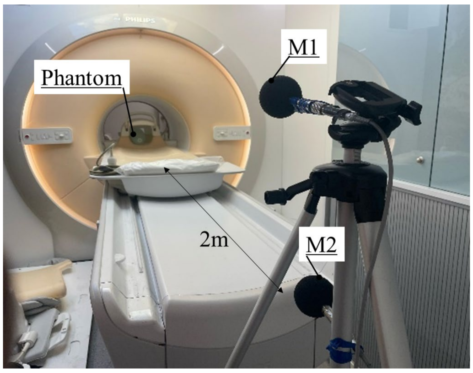
In this study we present the acoustic characterization of the MRI facility built inside the semi-trailer container popularly known as Mobile Imaging Trailers (MIT). The acoustic properties of the MRI examination room inside the conventional hospital-based station and MITs are different because of the size of the room and structural properties. This study focuses on assessment of sound characteristics inside the

MRI examination room, control room and chiller room of the Mobile Imaging Trailer-MRI (MIT-MRI) scanning. The diffusion-weighted sequence which is most frequently used scanning sequence for head and lumbar scanning was considered for evaluation of acoustics inside the examination room. Three variations of this sequence were analysed, namely: Diffusion-Weighted Imaging (DWI), Diffusion-Weighted Imaging with oscillating gradient (DWI-og), and Diffusion-Weighted Imaging Turbo Spin Echo (DWI-TSE). The results will be useful in developing strategies to minimise sound, improve the room acoustics and make MRI scans more comfortable.

2. Materials and methods

The experimentations were conducted on the 1.5 Tesla MRI system (Make: Phillips, Model: Ingenia 1.5 T MR) with the maximum gradient strength of 45.00 mT/m and the slew rate of 200.00 T/m/s. Sound pressure level (SPL) measurement inside the MRI examination room were performed using MRI compatible condenser omnidirectional free field microphones (SVANTEK 7052E and BSWA TECH SV22) of ½ inch diameter, frequency range of 20–20000 Hz with dynamic range of 10–135 dB. During the measurements inside the MRI examination room the microphones M1 and M2 were positioned at height of 30 cm and 2 cm above patient bed and located at 2-meter distance from the isocentre of the MRI scanner respectively. For sound measurements in the control room the microphone M3 was placed at 1 m distance from the partition wall with axis aligned with the MRI scanner. Microphones M1 and M3 were connected to the sound level meters (SLM) SVAN971 (make: SVANTEK) by shielded extension cables. Microphone M2 was connected to SVAN945 sound analyser controlled by the sound measurement system Zoom H6. The SLMs and Zoom H6 were positioned in the MRI control room at a location such that the magnetic field strength is less than 10 Gauss to avoid the influence of the magnetic field on the measurements. The cylindrical bottle phantom filled with doped water was placed inside the MRI cavity to resemble the human head. The experimental setup is presented in the figure 1. The signals recorded from the microphones M1 and M3 were stored and further analysed on computer software SVANPC++, while signal recorded from Zoom H6 were analysed using the software Audacity to investigate frequency characteristics. The measurements were also performed for analysing the characteristics of the acoustics in the chiller room and exhaust of the mobile MRI system.

a)



b)

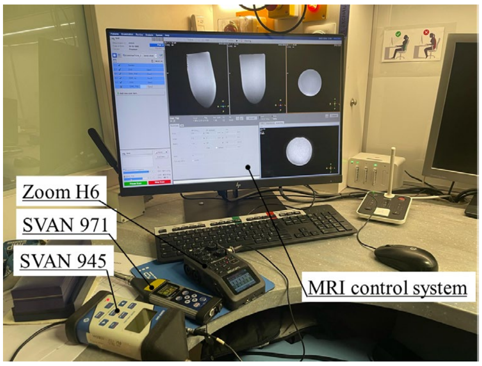


Figure 1. Sound measurement setup: a) inside the examination room, b) setup in control room.

The SPL measurements were conducted for the scanning sequence producing the maximum noise. Literature identifies that the Echo Planer Imaging (EPI) is commonly used scanning sequence which produces maximum noise [27]. In this study the DWI, DWI-og and DWI-TSE were analysed which are based on EPI and commonly used to acquire the scan the patient's head. The characteristics of the scan sequence under study are as shown in Table 1.

The ambient SPL in the MRI examination room when MRI scanning was not ON was considered as a room SPL. The acoustic measurements were performed according the standard guidelines provided by National Electrical Manufacturers Association MS 4 (2010) for measuring SPL in the MRI environment and the setup was complaint to the IEC 61672 class 1 standard for high precision measurements [28, 29]. For each pulse sequence the acoustic measurements were carried out, along with the continuous SPL measurements the equivalent SPL (L_{Aeq}) with A-weighting and peak SPL (L_{Peak}) with no weighting were continuously determined during the scan.

The frequency characteristics of the SPL were measured in 1/3 octave band, which is equivalent to human auditory characteristics. Firstly, the background noise waveform, frequency spectra and spectrogram were analysed to determine the acoustic characteristics of the ambience. The time domain data of the SPL measurement inside and outside the MRI scanner was converted into the frequency domain data by using the Fast Fourier Transform (FFT) technique and frequencies below 20 Hz were eliminated due to unreliable microphone performance in that range.

Table 1. Summary of the scanning sequences used in 1.5 Tesla MRI scanner.

Quantity	Scanning sequence				Unit
	Survey	DWI	DWI-TSE	DWI-og	
Static field strength, B_0	1.5	1.5	1.5	1.5	Tesla
Repetition time, TR	15	2623	3329	2957	milliseconds
Echo time, TE	5.2	83	72	85	milliseconds
Number of slices	3	22	18	22	–
Slice thickness	10	1	1	1	millimetres
Field-of-view	300×300×50	79×79×131	230×196×107	230×230×131	millimetres
Data acquisition matrix size	308×126	64×42	128×97	152×106	–
Number of signal averaged	1	1	4	1	–
Fat saturation	No	Yes	Yes	Yes	–
Meter response time	Fast	Fast	Fast	Fast	–
Duration (T)	18	36	261	36	seconds

3. Results

Before analysing the acoustic characteristic during operation of MRI scanner, the background SPL in the examination room was measured. The background characteristics are shown in the Figure 2. It indicates the background noise measured over the duration, observed to be low and varying between 70 dB and 75 dB. This background noise was mainly due to continuous operation of the helium pump required for magnetization of the static magnet. The secondary contributors were the air handling system and outside noise.

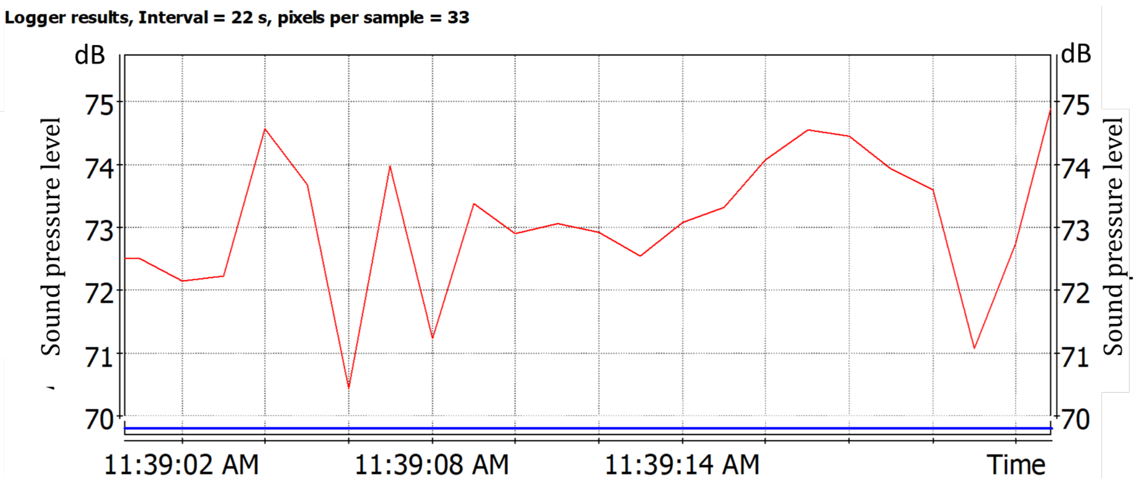


Figure 2. Background noise inside the MRI examination room.

The noise was measured on 1.5 Tesla MRI scanner for three scanning sequences with the microphones placed inside the MRI examination room at 2 m distance from the MRI isocentre. The stored files in the measurement instrument were trimmed using the computer software according to the sequence duration.

The frequency characteristics in the 1/3 octave band indicates that the background noise is dominating the lower frequencies than 1 kHz. The peak amplitudes of the equivalent SPL were identified at the frequencies 25 Hz, 50 Hz, 400 Hz as observed in Figure 3a. The spectrogram from Figure 3b indicates the dominance of the lower frequencies over entire duration of measurements. The highest background SPL was observed to be 75.1 dB which was associated with the 25 Hz frequency.

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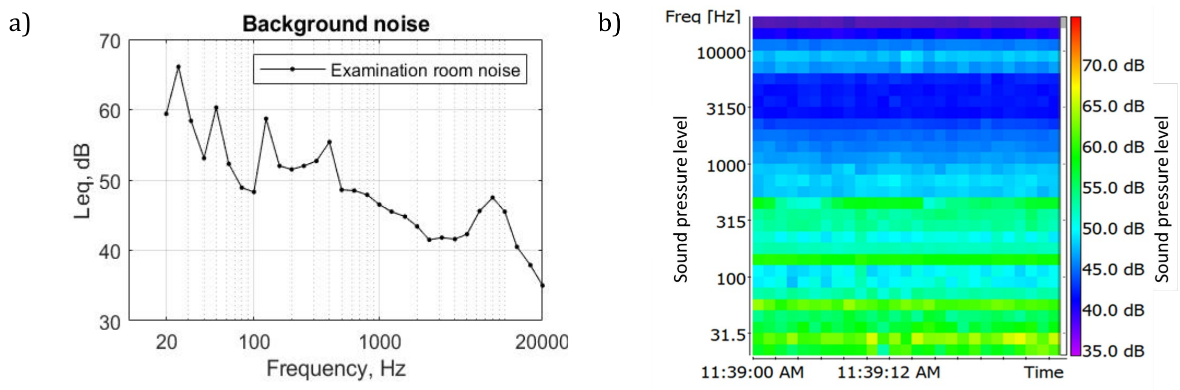

Figure 3. Characteristics of background noise:
a) equivalent SPL in 1/3 octave band, b) spectrogram of background signal.

The time characteristics of SPL inside the MRI examination room are shown in Figure 4, recorded for scanning sequences DWI-og, DWI, DWI-TSE respectively. The figure reveals the complex acoustic pulses with period less than 300 milliseconds in case of DWI TSE and 150 milliseconds for DWI and DWI-og. The frequencies of the high SPL spikes in time domain signals for DWI-og, DWI and DWI-TSE were observed to be 11.66 Hz, 13.33 Hz and 4.66 Hz respectively. The noise from the MRI scanner was observed to be as intense impulse signal.

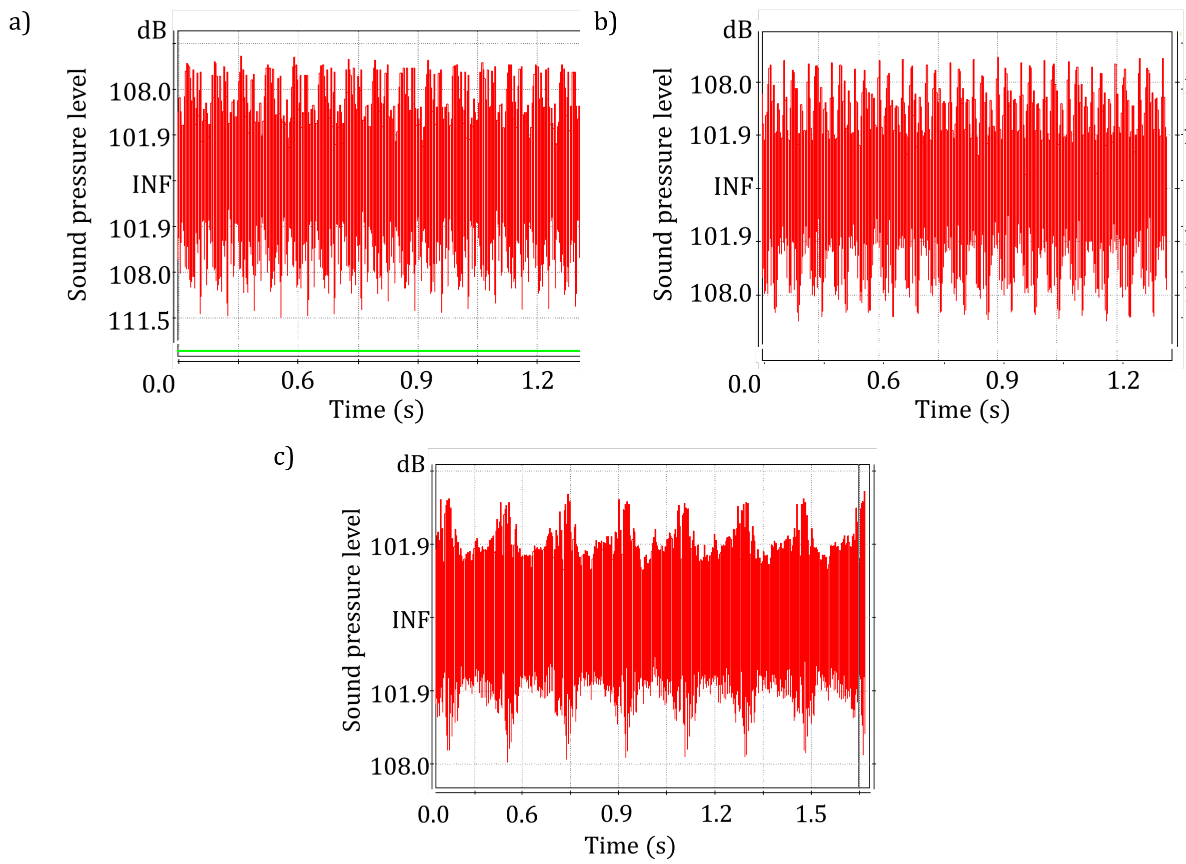

Figure 4. Variation of SPL in time domain recorded for scanning sequences:
a) DWI-og, b) DWI, c) DWI-TSE.

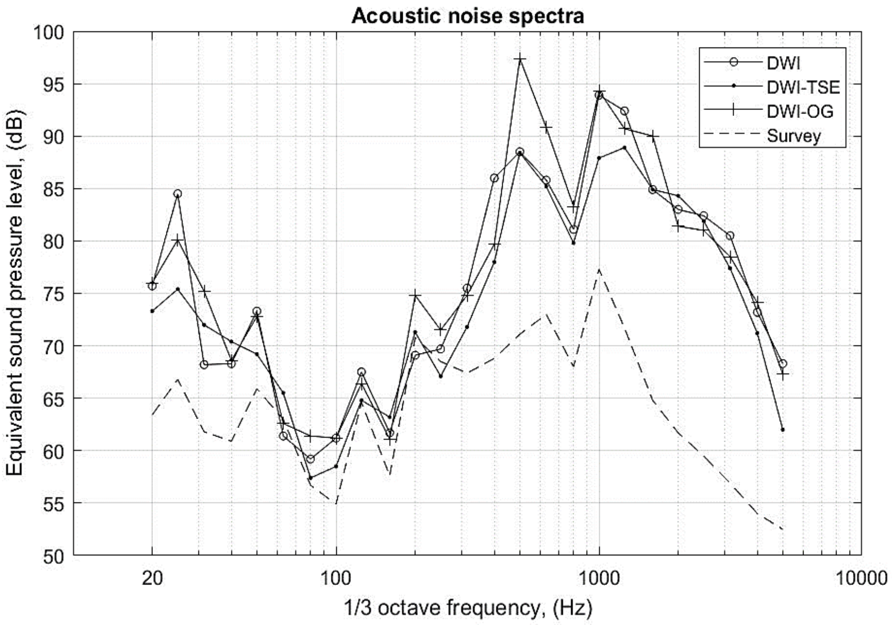

Figure 5. Comparison of equivalent SPL in 1/3 octave band for DWI, DWI-TSE, DWI-og, survey sequences.

Figure 5 depicts the acoustic spectra of the signal for the mentioned scanning sequences. The dominance of signal in the frequency band of 500 Hz to the 3000 Hz was identified from the acoustic spectra with a minor peak at 8000 Hz. The measurements from the microphone operated with the Zoom H6 confirmed the SVAN971 device. The signal recorded with the zoom H6 highlighted the peak amplitudes at the frequencies of 500 Hz, 1096 HZ, 1530 Hz.

The A weighted equivalent SPL over time T ($L_{Aeq,T}$) and C weighted peak SPL (L_{Cpeak}) were measured and statistical parameters such as SPL which was exceeded 90% of the scanning duration (L_{90}), mean SPL (L_{mean}), mode of SPL (L_{mode}) were calculated for the A weighted signal. The results from the measurements and calculation are reported in Table 2.

Table 2. Acoustic parameters inside the MRI examination room for different scanning sequences.

Quantity	Scanning sequence			
	Survey	DWI	DWI-TSE	DWI-og
L_{Cpeak} ,dB	89.9	104.2	101.8	105.4
$L_{Aeq,T}$, dB	76.8	94	90.1	94.2
L_{mean}, dB(A)	83.5	102.8	100.6	104.4
L_{median}, dB(A)	86.8	103.4	100.7	105.6
L_{mode}, dB(A)	87	103.5	100.5	105.7
L_{90}, dB(A)	75.4	102.22	99.1	104

The survey scan is carried out to measure the area of the object under scanning. This scan reported the lowest equivalent SPL over entire spectra. For all DWI scanning sequences, the A weighted equivalent noise level measured during the MRI scanning was above 90 dB and C weighted peaks were consistently recorded above 101 dB. The highest peak was determined to be 105.9 dB (C). The maximum L_{90} of 104 dB (A) was observed for the scanning sequence DWI-og while the lowest was associated with DWI-TSE at 99.1 dB(A). The statistical parameters such as mean, median and mode for all sequences were greater than 100 dB(A). For all scanning sequences the equivalent SPL was greater than 80 dB in the frequency range of 500 Hz to 3000 Hz. The results from the frequency characterization indicated during all the sequences most of the highest peaks were distributed near to the central frequency of 1 kHz. The peak equivalent SPL in the control room was measured to be 87.1 dB (C), while the peak SPL in the chiller room was 95.4 dB (C).

4. Discussion

In the patient care it is required that the patient must not be exposed to the high noise as it may negatively impact the patient health [30]. The World Health Organization (WHO) specifies the sound level inside the hospital facilities should be maintained well below 35 dB of equivalent SPL in the daytime and in the night time to be not more than 30 dB [4]. The MRI is important for the patient to diagnose the internal organs but it has high sound associated with it. This study investigated the noise inside the MRI bore for commonly used scans which highlighted the exposure of patient to the high noise measuring up to 105.9 dB(C), which is confirming to the works reported in the past. The noise is developed majorly by vibration of the gradient coil due to Lorentz forces developed by fast current switching. The air handling equipment and helium pump were the secondary contributors to the total noise. The high noise at the patient head indicates the necessity the use of protective measures for safety of the patient.

Table 3. Comparison of the measured acoustic parameters with the literature.

Reference	Field strength	Scanning sequence	$L_{Aeq,(scan\ time)}$ [dB]	L_{Cpeak} [dB]
This work	1.5 T	DWI	94	104.2
		DWI-og	94.2	105.4
		DWI TSE	90.1	101.8
Morzyński et al. 2011 [31]	1.5 T	Head scan	96.3	115
		Spine lumbar scan	88.1	106.1
Akbar et al. 2023 [32]	3 T	T1 spin echo	100.9	–
	7 T	T1 gradient echo	114.4	–
Yamashiro et al. 2019 [33]	1.5 T	MR Angiography	100.8	111.2
		Comfortone Diffusion Weighted	91.8	108. 6
Yamashiro et al. 2023 [34]	1.5 T	MR Angiography	103	105.9
		T2 weighted	102	113.3
		Diffusion Weighted	100	118
Silva et al. 2016 [35]	1.5 T	Perfusion weighted EPI	100.8	112.8
	3 T	Diffusion Weighted EPI	84.9	99.1
		Perfusion weighted EPI	85.2	98.7
Boulant et al. 2023 [36]	11.7 T	EPI	119	–
Prince et al. 2001 [37]	0.23 T	Fast spoiled gradient echo	–	82
	1.5 T		97.3	–
	3 T		–	118.2
Ravicz et al. 2000 [38]	1.5 T	EPI	97 (2 S window)	123
	3 T		114 (2 S window)	138
Hattori et al. 2007 [39]	1.5 T	Fast Inversion Recovery T1-weighted	89.1	103.4
		Single Shot Echo Planar Diffusion Weighted	99.6	111.7
		MR Angiography	92.3	107.3
	3 T	Fast Inversion Recovery T1-weighted	115.8	128.1
		Single Shot Echo Planar Diffusion Weighted	112.9	130.7
		MR Angiography	112.5	125.7

Table 3 displays the corresponding levels of A weighted equivalent SPL and C weighted peak SPL from the MRI scanner of different strength and scanning sequences reported in previous years. The measurements conducted in this study align closely with findings from other research articles.

In this study, the SPL was measured at a specific distance of 2 m from the MRI scanner. However, it still exhibited a similar SPL to that reported in literature measuring the SPL inside the MRI cavity. This suggests that the actual SPL experienced by patients in this MIT MRI scanner will be higher, as the patient needs to be inside the MRI cavity, which is within the source of the noise, the gradient coil. It can also be inferred that because of the narrow structure of the MIT, there exists strong reflection of the sound inside the examination room. The acoustic metamaterial may be designed particularly to absorb the sound waves in the frequency band of 500 Hz to 3000 Hz. In recent studies have shown the usefulness of the metamaterials for perfect sound absorption in targeted frequencies and reducing the thickness of the absorption panels [40]. Incorporation of laser vibrometer for measuring the surface vibration can be used to identify the correlation between the generated sound and surface vibration. Using such correlation the application of the metamaterial based mechanical vibration reducing panel can be explored to reduce the vibration and sound inside the MIT MRIs.

The higher noise is the problem for the hospital environment and patient health, and it is essential to lower the noise from the MRI scanner not only to from the perspective of safety of the patient but also improve the working environment for the operating staff.

4. Conclusions

This study systematically assessed the acoustic produced by the 1.5 T MRI scanner built inside MIT. A comprehensive analysis of the SPL inside the MRI examination room, control room and chiller room are presented. Measurements were conducted for scans known to produce elevated noise levels. Our results indicate that sound levels are high for this kind of scanning facility as compared to the stationary MRI facilities. The scanning sequences were nearly 20 dB louder than the background. The waveforms of the sound recorded from the MRI scanner were complex pulses showing impulse nature with spikes of very high SPL. The frequencies of spikes varied from 4 Hz to 14 Hz for different scanning sequences. The DWI-og scanning sequence was observed to be the noisiest scanning sequence with C weighted peak SPL of 105.9 dB. The acoustic spectra for all scanning sequence revealed the dominance of the noise in the frequencies ranging from 500–3000 Hz. Within the MRI examination room, the maximum A weighted equivalent SPL reached 94.2 dB in the lower frequency range with peak SPL consistently exceeding 101 dB(C). The C weighted peak SPL inside the control room and chiller room was 87.1 dB and 95.4 dB respectively. The measured SPL levels surpass permissible noise levels as per the WHO. These results carry significant implications for the development of effective noise reduction strategies for MRI scanning facilities in MIT.

Anknowlegment

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Additional information

The authors declare: no competing financial interests and that all material taken from other sources (including their own published works) is clearly cited and that appropriate permits are obtained.

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