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Measurement of equivalent continuous A-weighted sound pressure level of driving sound of three tesla MRI equipment

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ABSTRACT

Magnetic resonance imaging (MRI) equipment is important in medical diagnosis. The equipment utilizes a technology of tomography by the nuclear magnetic resonance phenomenon for imaging. Driving sound of MRI equipment is loud and it is caused by using the gradient magnetic field controlled by imaging sequence. It generates loud sound which depends on imaging sequence. The sound pressure level of the driving sound is over 100 dB sometimes and it makes the ear-protector necessary. There are some researches of the driving sound. In this paper, this paper shows the measurement result of equivalent continuous A-weighted sound pressure level of distribution in the three tesla MRI equipment which is Philip Achieva 3.0T X-series. Number of measurement point is 21 on the table; the 15 points located inside of the bore and the 6 points located outside of the bore. Imaging sequences of the measurement sound are slice positioning, T2 weighted imaging (T2W) and Echo planar imaging (EPI). The measurement data length is 30.04 seconds. The result showed that the driving sound of each imaging sequences on the table was loud. The maximum equivalent continuous A-weighted sound pressure level (L_{Aeq}) of slice positioning, T2W and EPI were 114.7 dB, 106.0 dB, 114.3 dB respectively. These values were larger than driving sound of 1.5 tesla MRI equipment. The maximum value of instantaneous sound pressure was 123.9 dB in the three sequences of the 3 tesla MRI equipment. So, it shows the instantaneous value is important parameter.

INTRODUCTION

Back ground

MRI examination is important in medical diagnosis for internal body. Imaging part is set inside of the equipment's bore at MRI examination. Three tesla MRI system for whole body was approved in Japan in 2005. Magnetic field strength becomes more high for improve signal-to-noise ratio. Signal-to-noise ratio improves in proportion to the high magnetic field strength. Therefore, three tesla MRI can obtain high quality tomogram of cortical structure, internal structure of hippocampus, etc [1]. In recent year, development of the 11.7 tesla MRI system for human body was provided in 2005 [2]. It is expected that the 11.7 tesla MRI come to get a tomogram of nerve activity. However, driving sound is generated at the MRI examination by Lorentz force. The gradient coils are utilized to decide the position of imaging part. Strong force is generated between the static magnetic field coil and gradient magnetic field coil by switching operation of the current of gradient magnetic field coils. Sound pressure level (SPL) of MRI equipments driving sound is over 100 dB sometimes.

The influence of the 1.5 tesla MRI for potential hearing loss of the patient was researched by Brummet [3]. As for the 1.5 tesla MRI, it was reported that patients of 43% was suffered a temporary potential hearing loss without ear protection. The paper by Hattori [4] reported that the sound pressure level of 1.5 tesla MRI exceed sound pressure level of 3 tesla MRI at the anatomical ear site of patient's head inside of the bore. The four tesla MRI was measured of driving sound, and it was estimated by W. LI [5], and active noise control was proposed for sound proofing by Mingfeng [6]. However, those were only a measurement in close of head position of head in the bore of MRI equipment in the researchs.

Purpose

MRI examination is not only head part but also abdomen part. In case of abdomen part examination, patient lies on the table and puts out the head outside of the bore. Therefore, SPL research on driving sound is important not only inside but also outside of MRI equipment. We have been measuring the distribution of the equivalent continuous A-weighted sound pressure level (L_{Aeq}) [7, 8], and the sound intensity [9]. This report shows the distribution of L_{Aeq} of inside and outside of the bore in the 3 tesla MRI equipment.

MEASUREMENT OF DRIVING SOUND OF 3 TESLA MRI EQUIPMENT

Because of MRI equipment of high magnetic field, magnetic materials are strongly attracted to the MRI equipment. Non-magnetic microphone, wood and brass for fixation was used in the MRI examination room for measurement of driving sound. This microphone is omnidirectional microphone of electret condenser microphone (ECM) which is made by AZDEN Corporation. The vibrating membrane is polyester, the back electrode is brass, field effect transistor (FET) is 2SK123, and the cover is aluminum and resin [8]. The gain of frequency characteristic is flat in 2 kHz or less. Figure 1 shows the frequency characteristic of the ECM. Figure 2 shows the MRI equipment Philips Achieva 3.0 T X-series MRI system for measurement of driving sound with these instruments. There is the head coil and phantom at the center of gantry. This phantom is pseudo object of human body for the MRI equipment driving. Number of measurement points are 21 as shown in figure 3. The origin is the center of the gantry, y-axis is the direction of height and z-axis is the direction of table drawing. Driving sound was measured with the sound intensity probe in 10cm intervals inside of the gantry, and 20cm intervals outside of the gantry. Sampling frequency for recording is 48 kHz. The calibrator for calibration of sound pressure is NC-74 (calibration level 94 dB, calibration signal frequency 1,000 Hz) and NC-72 (calibration level 114 dB, calibration signal frequency 250 Hz) made by RION.

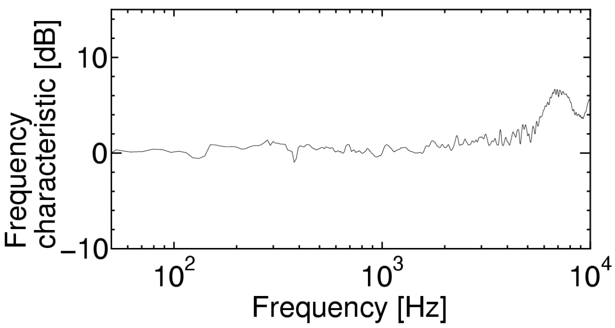


Figure 1. Frequency characteristic of the ECM

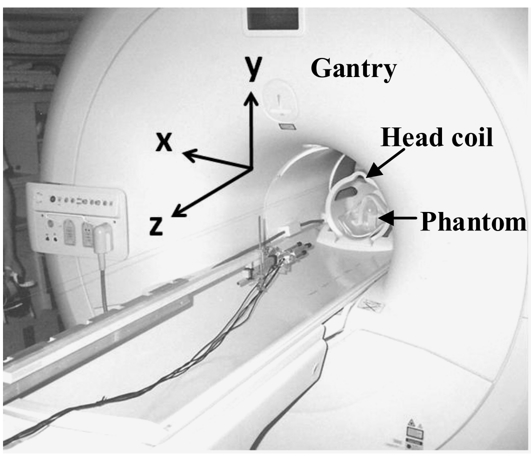


Figure 2. Measurement of MRI driving sound

The driving sounds of measurement are the sounds in the typical imaging sequences which are slice positioning, echo planar imaging (EPI) and T2 weighted imaging (T2W). The conditions of imaging sequences for measurement of the driving sounds are shown in Table 1.

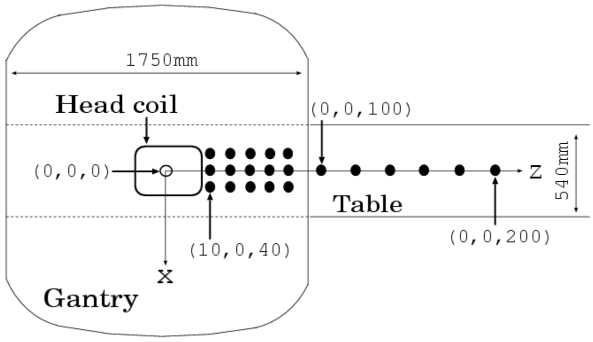


Figure 3. Masurement points on the table of MRI equipment (top view)

Table 1. The Conditions of imaging sequences for measurement of driving sound

	Slice positioning	EPI	T2W
TE [ms]	1.4	85	90
TR [ms]	3.1	3000	4000
FOV [mm]	250	230	230
Matrix	112×112	128×128	368×368
Slice thick ness [mm]	2.2	6	6

TR=repetition time, TE=echo time, FOV=field of view

The equivalent continuous A-weighted sound pressure level L_{Aeq} is given as follows;

$$L_{Aeq} = 10\log_{10}\{\frac{1}{T}\int_{t_1}^{t_2}\frac{P_A^2(t)}{P_0^2}dt\}.$$

Where, $T = t_2 - t_1$ is observation time, of A-weighted sound pressure is $P_A(t)$ and P_0 is reference sound pressure (20 μ Pa). The L_{Aeq} of three kinds of imaging sequences were measured at the time of driving sound between beginning and 30.04 seconds. The processed of measurement is shown by figure 4.

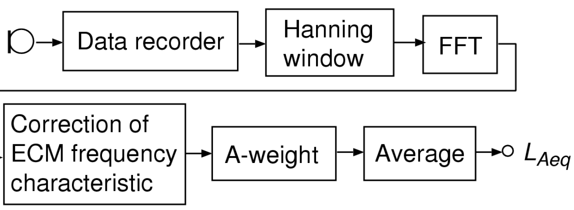
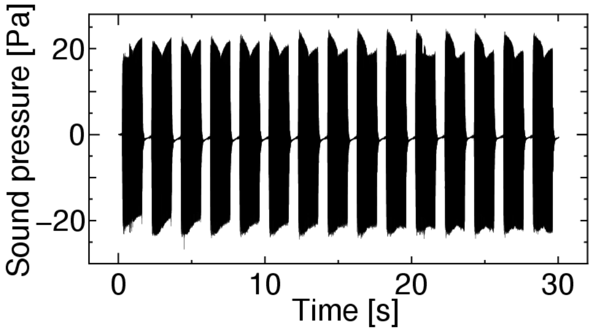


Figure 4. Process of equivalent continuous A-weighted sound pressure level

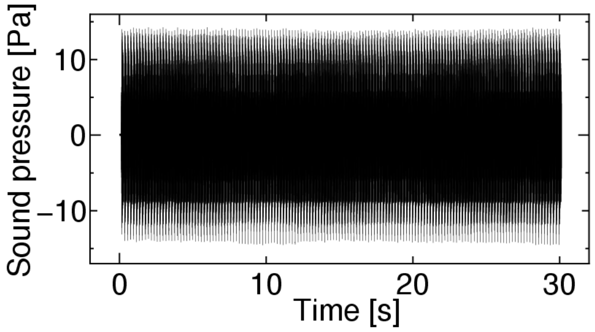
The time window function is hanning window, data length of FFT was 16384 points (0.34s). The gain in frequency domain of ECM was corrected to flat, and it was applied to the frequency characteristic of A-weight. Averaged value of L_{Aeq} was calculated 88 times (30.04s) without overlap.

MEASUREMENT RESULT OF DRIVING SOUND OF 3 TESLA MRI EQUIPMENT

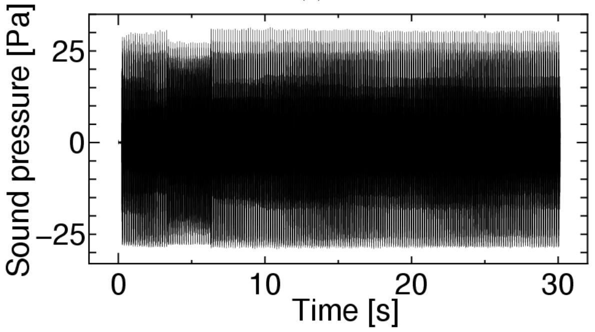
The distribution of L_{Aeq} in the three tesla MRI was measured by the non-magnetic ECM. Figure 5 shows the waveform of slice positioning, T2W and EPI sequence. The maximum value of instantaneous sound pressure of slice positioning, T2W and EPI were 122.1 dB, 117.1 dB and 123.9 dB respectively.



(a) Slice positioning



(b) T2W



(c) EPI

Figure 5. The waveform of driving sound at the sequences: (a) slice positioning at the (0, 0, 50), (b) T2W at the point (0, 0, 40), (c) EPI at the point (-10, 0, 70).

The averaged value of L_{Aeq} of the driving sounds was calculated some times per point of z-axis. For example, the L_{Aeq} of the points (10, 0, 40), (0, 0, 40) and (−10, 0, 40) were averaged. Figure 6 shows the distribution of L_{Aeq} in slice positioning. The averaged maximum value of L_{Aeq} was 110.4 dB at the location 140 cm. Bars show 95% confidence interval of L_{Aeq} of each location. The confidence interval was ±2.2 Pa (at the location 50 cm) or less. Figure 7 shows the distribution of L_{Aeq} in T2W. The averaged maximum value of L_{Aeq} was 103.7 dB. The confidence interval was ±0.3 Pa (at the location 40 cm) or less. Figure 8 shows the distribution of L_{Aeq} in EPI. The averaged maximum value of L_{Aeq} was 111.0 dB. The confidence interval was ±1.9 Pa (at the location 40 cm) or less. The distribution of the L_{Aeq} in the three imaging sequences was between 95.0 dB and 114.7 dB. The L_{Aeq} outside of the bore was high as well as the L_{Aeq} inside of the bore.

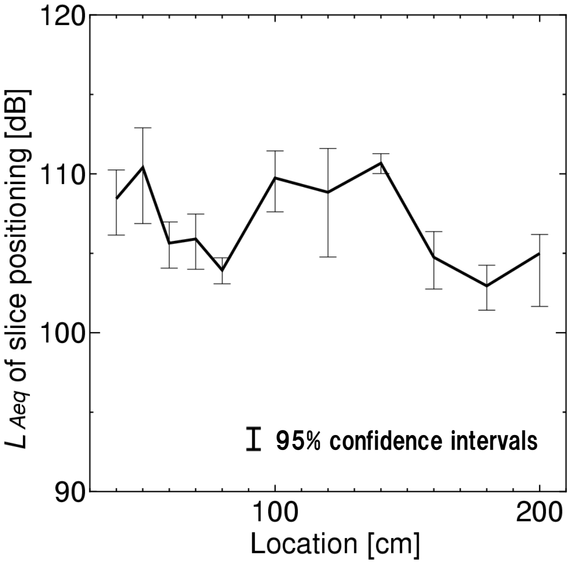


Figure 6. The distribution of L_{Aeq} of slice positioning

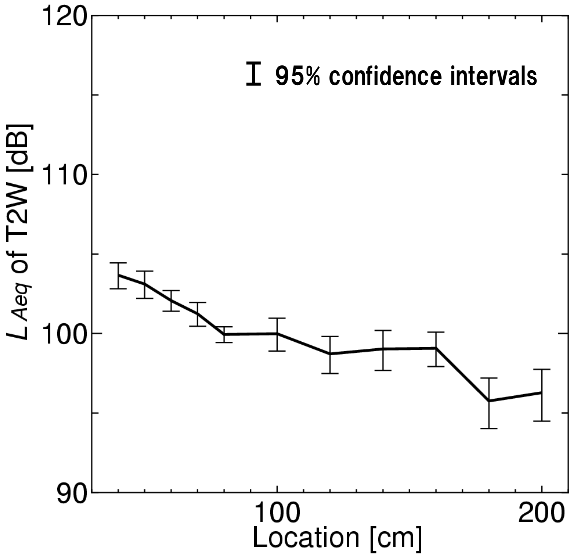


Figure 7. The distribution of L_{Aeq} T2W

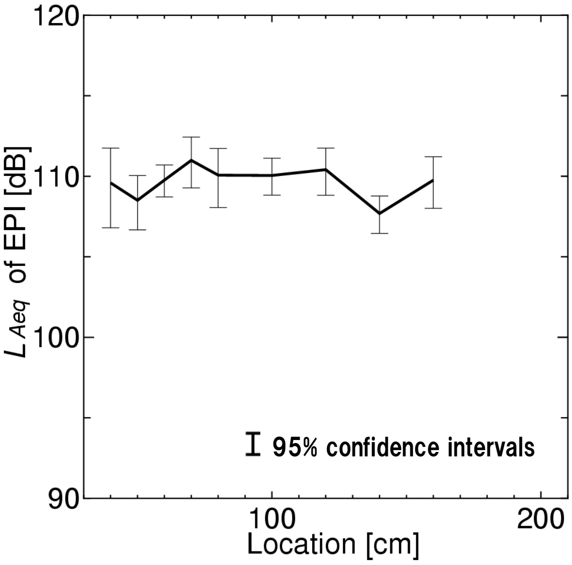


Figure 8. The distribution of L_{Aeq} of EPI

We have been measuring the distribution of the L_{Aeq} of the 1.5 tesla MRI [8]. Figure 9 shows the distribution of L_{Aeq} in the Signa Horizon LX 1.5 tesla MRI equipment of the whole body of GE Yokogawa Medical Systems. This result was measured at 20cm intervals of z-axis from center of the bore. The maximum value was observed 104.8 dB of T2W at the location 100cm. The maximum value of the driving sound of the 3 tesla MRI equipment was larger than the maximum value of the driving sound of the 1.5 tesla MRI equipment.

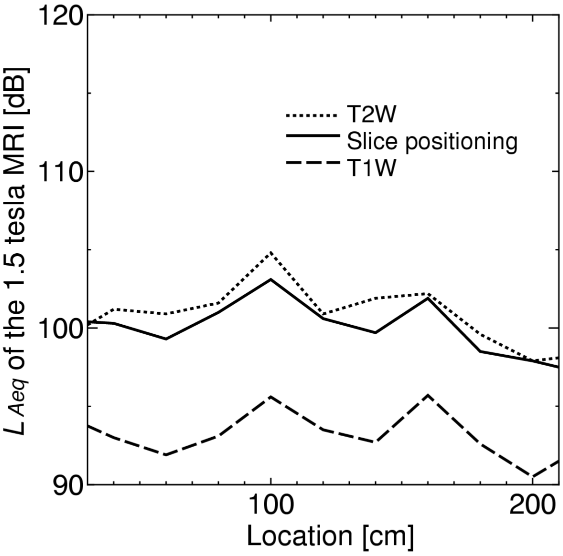


Figure 9. Distribution of L_{Aeq} on the examination table of the 1.5 tesla MRI equipment

The detail of the measurement points shows that the maximum value of L_{Aeq} of slice positioning was 114.7 dB at the point (0, 0, 50) in the 3 tesla MRI. The maximum value of L_{Aeq} of T2W was 106.0 dB at the point (0, 0, 40). The maximum value of L_{Aeq} of EPI was 114.3 dB at the point (–10, 0, 70). The other loud, the maximum value of instantaneous sound pressure of EPI was 123.9 dB which was larger than the maximum value of L_{Aeq}. The guideline of World Health Organization (WHO) is shown that to avoid hearing impairment, impulse noise exposures should never exceed instantaneous sound pressure of 140 dB in adults, and 120 dB in children. It is important to utilize not only L_{Aeq} but also maximum value of instantaneous sound pressure for measurement of MRI driving sound.

CONCLUSION

This paper showed that the distribution of L_{Aeq} of the 3 tesla MRI inside of the bore and outside in 21 points of location, and maximum value of instantaneous sound pressure in three imaging sequences. The L_{Aeq} outside of the bore was as high level as the L_{Aeq} inside of the bore depending on sequences. The instantaneous sound pressure exceeded over the guideline of WHO for children. It is thought that not only measurement of L_{Aeq} but also various measurement methods are necessary. We will plan for measurement of sound intensity at various locations for analysis of propagation appearance of the driving sound.

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