A consideration about effect of ear protector in 3-tesla MRI driving sound

Masataka Chikai[1], Kenji Muto[1], Yasuhiro Shimono[1], Kazuo Yagi[2], Yuki Arakawa[2]

[1] Shibaura Institute of Technology, 3-7-5 Kotoku Toyosu, Tokyo 135-8548 Japan, m110092@shibaura-it.ac.jp

[2] Tokyo Metropolitan University, 7-2-10 Higashiogu, Tokyo 116-8551 Japan

INTRODUCTION

MRI equipment generates high level of driving sound, and it was reported that the sound causes temporary potential hearing loss to the patient (Brummett et al. 1988). The MRI driving sound makes the ear protector necessary. Therefore, it is necessary to consider the influence for the patient who uses ear protector.

MRI examination has an important role in medical diagnosis. The 1.5-tesla MRI system for whole body is popular equipment in Japan's hospitals in 2010. The 3-tesla MRI system for whole body was approved in Japan 2005. In Japan, the number of the 3-tesla MRI was 239 in 2010 ('New Medicine in Japan' 2010), because the MRI equipment obtains high quality tomogram (Wada & Ikehira 2007). The equipment utilizes a technology of tomography by the nuclear magnetic resonance (NMR) phenomenon for imaging. The gradient coils and the static magnetic field coil are necessary for imaging. The gradient coils are utilized to decide the imaging surface. The driving sound is generated in MRI examination, because strong force is generated between the static magnetic field coil and gradient magnetic field coils by switching operation of the current of the gradient magnetic field coils. The sound pressure level of 3-tesla MRI exceeds 1.5-tesla MRI on the examination table, its instantaneous sound pressure observed sometimes over 120 dB inside of the bore (Ravicz et al. 2000). The guideline of World Health Organization (WHO 2000) showed that to avoid hearing impairment, impulse noise exposures should never exceed instantaneous sound pressure of 140 dB in adults, and 120 dB in children (WHO 2000). The MRI examination makes the ear protector necessary. We have analyzed A-weighted sound pressure level of the driving sound of 1.5-tesla MRI in the case of using the ear plugs and earmuffs (Takano et al. 2004)]. Recently we measured the driving sound in near field of the equipment (Shimono et al. 2010).

Each part (head, knee, etc.) of the patient is examined in MRI examination. The position of the patient's ear is located outside the bore, in the case of the examination of knee part. However, there is no report which is measuring the driving sound on the table outside the bore. This report is shown the spectrum analysis and equivalent continuous A-weighted sound pressure level (L_{Aeq}) of the driving sound in the case of using the ear protector inside and outside the bore.

MEASUREMENT OF THE DRIVING SOUND ON THE EXAMINATION TABLE

Figure 1 shows the MRI equipment Philips Achieva 3.0-tesla X-series MRI system. The MRI equipment has static magnetic field strength of 3-tesla and maximum slew rate of 200mT/m/ms. Magnetic materials are strongly attracted to MRI equipment, because MRI equipment generates high magnetic field all the time. We utilized non-magnetic microphone, wood and brass for fixation was used in the MRI examination room for measurement of driving sound. This microphone was 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 (Muto & Yagil 2005). Figure 2 shows the measuring points which number of the points was nine. The origin was set to the center of the gantry, y-axis was set to the vertical direction and z-axis was set to the horizontal direction of the table drawing. Five points were set at intervals 10 cm inside the bore in z-axis, and four points were set at intervals 20 cm outside the bore.

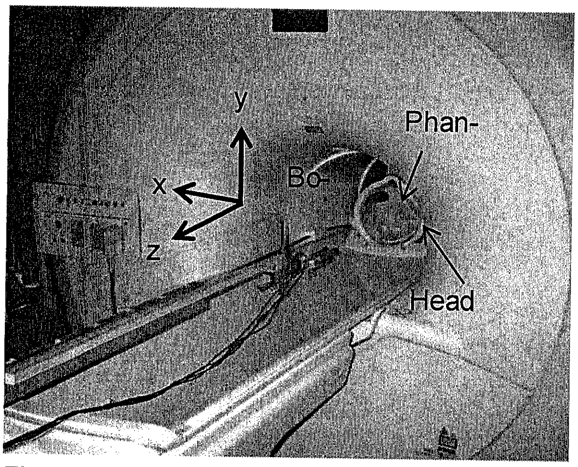

Figure 1: Measuring of the 3T MRI driving sound

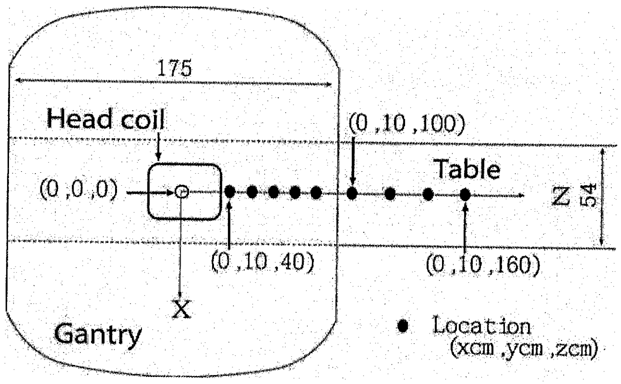

Figure 2: Measuring points (Top view)

The measurement conditions were shown as follows: sampling frequency was 48 kHz, the calibrator was 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 corporation.MRI equipment generated various driving sounds by different imaging methods. Measuring the sounds were the driving sounds of imaging methods in Slice positioning (SP), Reference scan imaging (RS), T2 weighted imaging (T2W) and Echo planar imaging (EPI). Table 1 shows the conditions of the imaging sequences. The sounds of four imaging sequences were analyzed between beginning of the driving sound and 30 seconds.

Table 1: Conditions of imaging sequences for measurement of driving sound. Slice positioning (SP), Reference scan imaging (RS), T2 weighted imaging (T2W), Echo planar imaging (EPI)

	SP	RS	EPI	T2W
TE [ms]	3.1	0.79	70	90
TR [ms]	1.4	4	3800	4000
FOV [mm]	250	450	230	230
Matrix	112×112	96×96	128×128	368×368
Slice thickness[mm]	2.2	3	6	6

The analysis conditions of the driving sound with an ear protector was shown as follows: The ear protector was utilized the earmuff EM-68N made by TRUSCO Corporation. The spectrum of attenuation of the earmuff was measured by Head and Torso Simulator (B&K, 4100D), its spectrum of right and left was averaged three times the measuring. Figure 3 shows sound attenuation performance of the earmuff. The analysis process of L_{Aeq} of the sound that the patient hears is shown Figure 4. The L_{Aeq} was calculated in frequency domain to correct gain of the ECM and to apply spectrum of the sound attenuation of the earmuff. We used Hanning window as time window. The gain in frequency domain of ECM was corrected to flat, frequency characteristic of A-weight was applied to the gain, and the sound attenuation of the earmuff was weighted to the gain.

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, $P_A(t)$ is A-weighted sound pressure and P_0 is reference sound pressure (20 μPa).

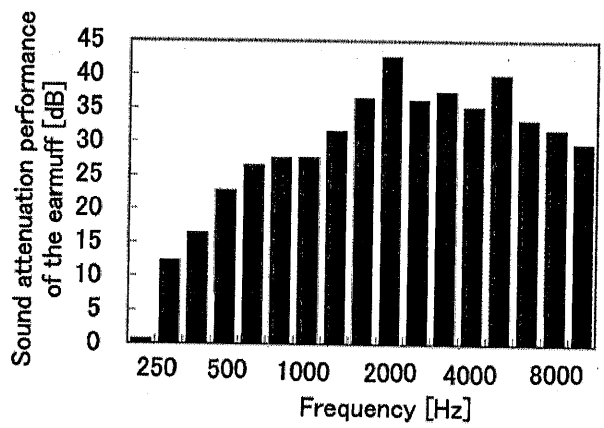

Figure 3: Sound attenuation performance of the earmuff

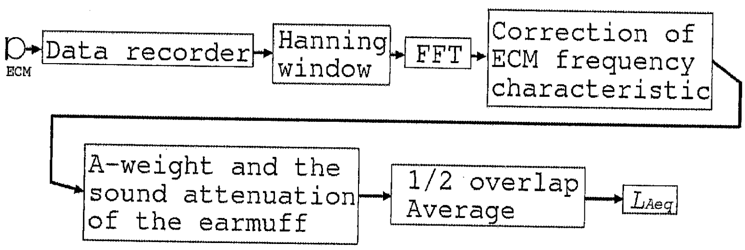

Figure 4: Process of equivalent continuous A-weighted sound pressure level

ANALYSIS

RESULT OF DRIVING SOUND ON THE EXAMINATION TABLE WITH THE EARMUFF

Figure 5 shows the waveform of the driving sound of highest level at nine measurement points. The maximum value of instantaneous sound pressure in SP, RS, T2W and EPI were 124 dB, 115 dB, 117 dB, 123 dB respectively. L_{Aeq} of 30 seconds in SP, RS, T2W and EPI were 115 dB, 105 dB, 107 dB, 112 dB respectively. Figure 6 shows that the spectra of the driving sound were calculated by FFT of 4096 points. The peak frequency of SP, RS, T2W and EPI were 1,278 Hz, 1,000 Hz, 621 Hz and 786 Hz respectively, and sound pressure level (L_P) of SP, RS, T2W and EPI were 110 dB, 99 dB, 105 dB and 109 dB respectively.

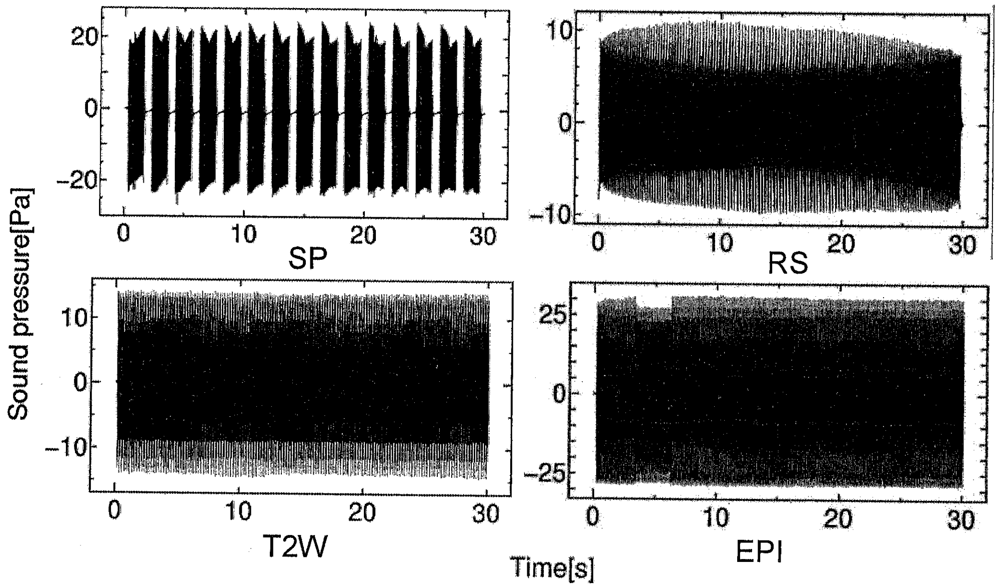

Figure 5: The wave forms of the driving sound

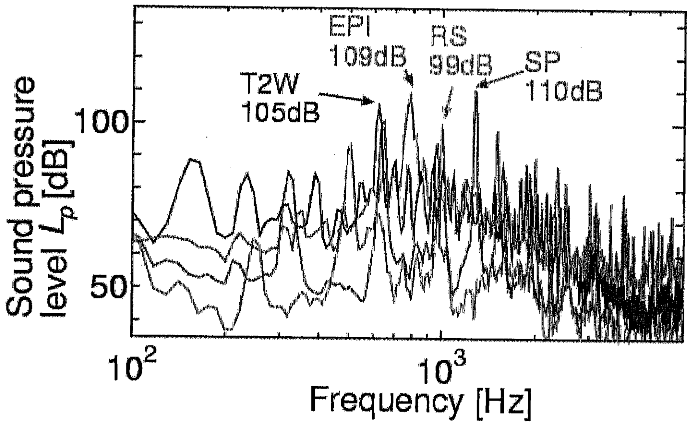

Figure 6: Spectrum analyses of SP, RS, T2W and EPI

Figure 7 shows the result of four kinds of the driving sound with or without the earmuff. The bar shows maximum level and minimum level which were calculated 30 seconds in nine measurement points. The average without the earmuff of SP, RS, T2W and EPI were 109 dB, 102 dB, 103 and 109 dB respectively at the nine points, and they are 77 dB, 70 dB, 81 dB and 82 dB respectively with the earmuff. Because the sound attenuation of the earmuff was depend on frequency, it is important to analyze frequency characteristic of driving sound.

Figure 8 shows 1/3 octave analysis which is the driving sound on the examination table. The spectra which had the characteristic of imaging sequence were constant though the change of a little level was shown with the measuring point. The maximum value of center band frequency of SP, RS, T2W and EPI were 1,250 Hz, 1,000 Hz, 800 Hz and 650 Hz respectively. The maximum value of center band frequency was between 650 Hz and 1,250 Hz, and it was over 27 dB in sound attenuation of the earmuff. The result was effective to protect in the basis of frequency domain of MRI driving sounds. In addition, it is effective to use unpleasant earmuffs together with earplugs. We thought that the ear protector is effective for 3-tesla MRI driving sound as well as the result of 1.5-tesla MRI.

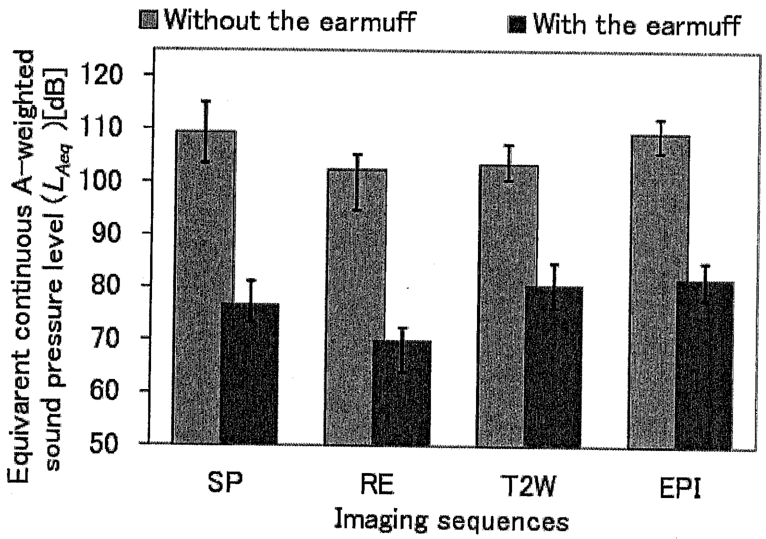

Figure 7: L_{Aeq} of each driving sequences for subject with or without the ear muffs for 30 seconds of the driving sounds. The bar (I) showed maximum value and minimum value of L_{Aeq} in the measurement points of nine

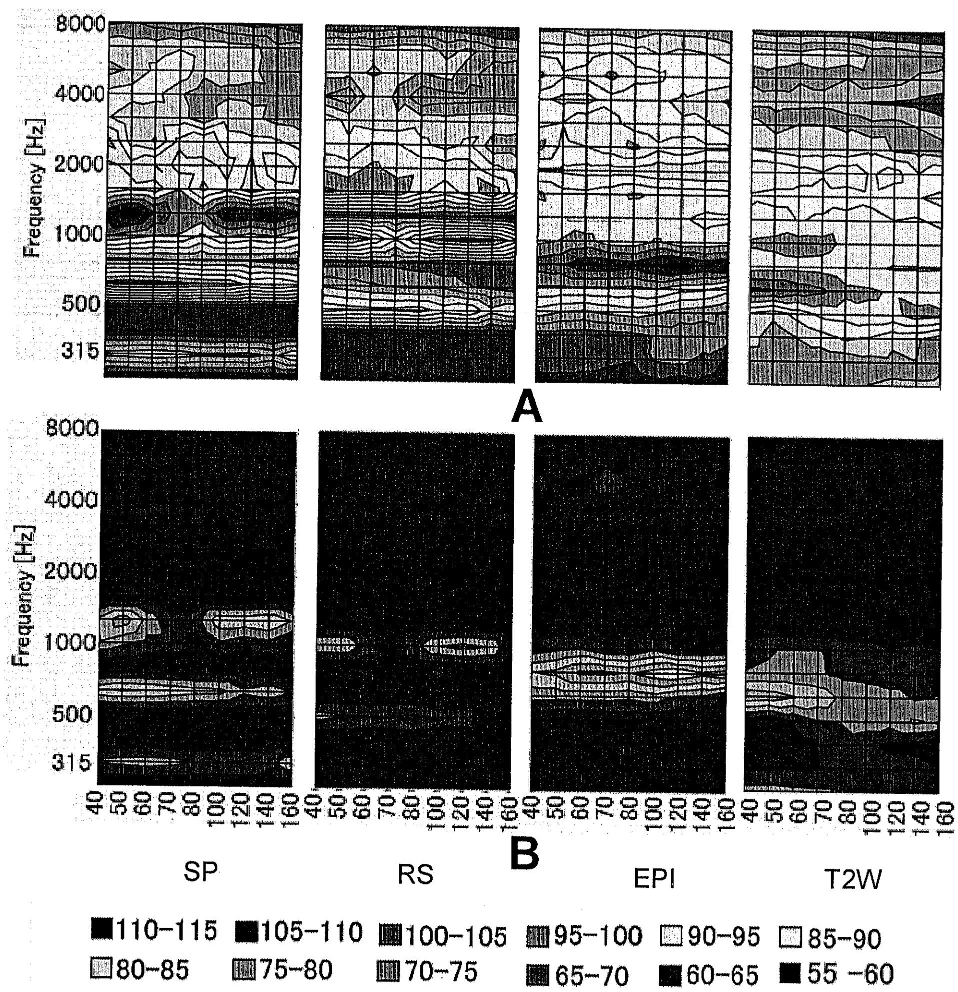

Figure 8: 1/3 octave analysis of Slice positioning (SP), Reference scan imaging (RS), T2 weighted imaging (T2W) and Echo planar imaging (EPI): L_{Aeq} of 30 second. **A**: Analysis of the driving sounds without the earmuff, **B**: Analysis of the driving sounds with the earmuff.

CONCLUSION

The measurement of driving sound at various positions is important for discussion of the MRI sound. This paper showed L_{Aeq} of the MRI driving sound of SP, RS, T2W and EPI which were calculated 30 seconds with or without the earmuff. 1/3 octave analysis was calculated four kinds driving sound which were measurement points of nine on the examination table. MRI driving sound generated various kinds of sound that the sound was depended on imaging sequence. The earmuff was effective to protect in the basis of frequency domain of MRI driving sounds. This result contributes to the transmission system using bone conduction speaker for MRI examination (Saito & Muto 2007).

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