Correlation of Lesion Size to Thermal Dose Measured by MR Thermometry in MR-Guided Focused Ultrasound for the Treatment of Essential Tremor

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Introduction

Magnetic resonance guided focused ultrasound (MRgFUS) has shown promising results in the treatment of essential tremor[1,2,3]. The required acoustic energy to produce a lesion, however, varies significantly among patients. Therefore, MR temperature and thermal dose measurement plays a crucial role in monitoring and guiding acoustic parameters. Although MR thermometry and the suppression of tremor symptoms provide valuable feedback for targeting accuracy[4], producing a lesion of proper size is also considered important for durable efficacy. We have observed an increase in size of the lesion several hours after treatment with typically largest lesions observed the following day after treatment. Therefore, it would be useful if thermal dose can be used to predict the ultimate lesion size and thus better define the treatment end point. In this study, we correlated the size of the thermal dose to the lesion size at the follow-up imaging on the first post-treatment day.

Methods

Twenty patients with medication-refractory essential tremor have been treated with a MRgFUS brain system (ExAblate 4000, 650kHz central frequency, InSightec, Tirat Carmel, Israel) and a 3 T MR scanner (MR750, GE Healthcare, Milwaukee, WI, USA). MR thermometry (TR 27.6 ms, TE 12.8 ms, slice thickness 3 mm, FOV 28cm, 256x128, temporal resolution 3.5s) was applied in three orthogonal dimensions separately to measure the focal temperature and the thermal dose. Because of chemical shift artifacts on the frequency encoding direction in the MR thermometry sequence, thermal dose maps measured for each sonication with different encoding directions were not properly aligned spatially. Therefore, the accumulated thermal dose map generated on the ExAblate system was not used. Rather, the thermal dose of the sonication with the maximum energy level (usually the last sonication) was used as the thermal dose measure. Both thermal doses of 240 equivalent minutes (EM) at 43°C and 17 EM were measured. Lesion sizes were measured in T1 images (3D FSPGR, TR 8.3 ms, TE 3.3 ms, slice thickness 1.2 mm) acquired on the first day follow-up.

Results

The maximum acoustic energy applied to produce a lesion varied significantly among twenty patients from ~10,000 J to 40,000 J. The lesion sizes were 5.5±1.5 mm in the left-right (LR) dimension, 4.8±1.1 mm in anterior-posterior (AP), and 6.8±1.6 mm in superior-inferior (SI). The 240 EM thermal dose sizes were 3.8±1.6 mm in LR, 3.3±1.2 mm in AP. The 17 EM thermal dose sizes were 7.0±1.8 mm in LR and 6.0±1.2 mm in AP. The measurement of one case is shown in Fig.1.

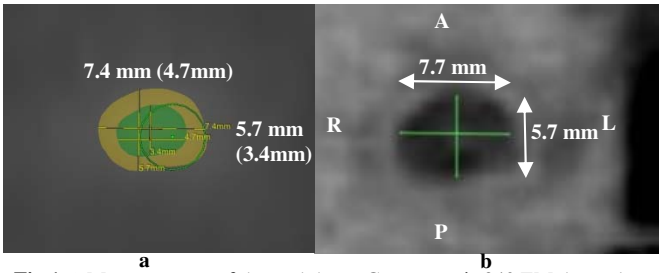

Fig.1 a) Measurements of thermal dose. Green area is 240 EM thermal dose, yellow is 17 EM. b) measurement size of the corresponding lesion on T1 image.

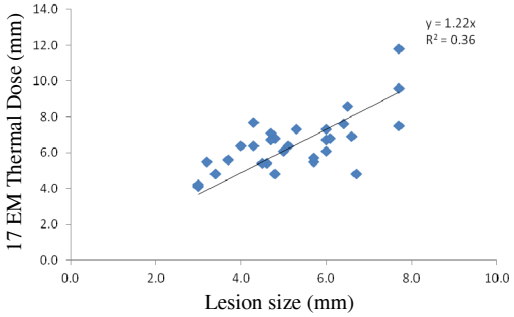

Fig.2 Correlation of lesion size and 17 EM thermal dose.

Discussion

Lesion sizes were in general correlated to the thermal dose and that thermal dose thresholds used in this study can bracket the range of the eventual coagulated tissue volume. However, the thermal dose thresholds used here were established on common tissue types, e.g. on muscles[5]. Based on our measurements, it appears the 240 EM thermal dose underestimated the lesion size, while 17 EM thermal dose overestimated. It has been shown earlier the thermal threshold for permanent damage of brain tissues is lower than muscle[6]. In that study in an animal model they observed tissue damage with a 50% probability at the dose of 17.5 min while damage was always observed at doses above approximately 50 min. We will investigate the thresholds above 17 min to determine if better predictions can be achieved..

The use of thermal dose map of the sonication with the maximum energy is a limitation of our study. This methodology will underestimate the actual accumulated thermal dose in situation where the target location was adjusted during the treatment. This may potentially explain the few data points in Fig.2 by which lesion sizes were larger than the 17 EM thermal doses. Ideally the thermal dose maps of each sonication should be integrated together after correcting the chemical shift artifact on the frequency encoding direction. Since targeting accuracy has been verified in earlier steps at lower energy levels before therapeutic sonications, it is reasonable to assume that the center of the thermal dose area coincides for all therapeutic sonications. Therefore, it is possible to correct for the chemical shift artifacts for the accumulated thermal dose. This will be investigated in future studies.

References

1. Lipsman N et al. Lancet Neurol 2013;12(5):462-8.
2. Elias WJ et al. N Engl J Med 2013;369(7):640-8.
3. Chang WS et al. J Neurol Neurosurg Psychiatry 2014.
4. Moser D et al. Neurosurg Focus 2012 ;32(1):E2.
5. McDannold et al. Radiology 2000; 216:517–523
6. McDannold et al. MRM 2004; 51:913–923.