Evaluation of respiration-induced magnetic field disturbance correction of MR thermometry in volunteers and in patients for MR-HIFU ablation of breast cancer: the effects of conscious sedation

Roel Deckers[1], Baudouin Denis de Senneville[1,2], Gerald Schubert[3], Laura G. Merckel[1], H. H.B. Vaessen[4], Maurice A.A.J. van den Bosch[1], Chrit T.W. Moonen[1], and Lambertus W. Bartels[1]

[1]Imaging Division, University Medical Center Utrecht, Utrecht, Utrecht, Netherlands, [2]IMB, UMR 5251 CNRS/Université Bordeaux 1/INRIA, France, [3]Philips Healthcare, Vantaa, Finland, [4]Department of Anesthesia, University Medical Center Utrecht, Utrecht, Utrecht, Netherlands

Target audience: Clinicians and scientist interested in MR-HIFU ablation of breast cancer

Purpose Accurate and precise MR thermometry is of utmost importance during MR-HIFU tumor ablation to ensure safety and reliability. Proton resonance frequency shift (PRFS)-based MR thermometry is currently the standard in clinical applications. However, Peters et al. have shown that respiration induced magnetic field fluctuations can cause significant temperature errors for organs close to the lungs such as the breast[1]. Several correction methods have been proposed including look-up-table (LUT)-based correction and model-based correction[2]. We are currently performing a clinical phase I study to investigate the safety and accuracy of a dedicated MR-HIFU system for the ablation of breast tumors[3]. The purpose of the current study was to evaluate the performance of a LUT-based and a model-based correction method for MR thermometry in healthy free-breathing volunteers and in breast cancer patients undergoing HIFU tumor ablation under conscious sedation.

Methods All experiments were performed on a dedicated breast MR-HIFU system (Philips Healthcare, Vantaa, Finland) integrated with a clinical 1.5-T MRI scanner (Achieva, Philips Healthcare, Best, The Netherlands). Seven healthy female volunteers and four female patients with pathologically proven invasive breast cancer after large-core needle biopsy were included. Segmented Echo Planar Imaging (EPI) was performed for PRFS-based thermometry. Important scan parameters were: TR=70 ms, TE=30 ms, FA =30°, EPI-factor = 23, 4 stacks (3 coronal, 1 sagittal), 1 slice/stack, acquisition voxel size=1.67x1.67x5.0 mm^3, dynamic scan duration=2.2 s. On-line correction of the respiration induced field disturbances was performed by a LUT-based method[4]. During the learning phase the respiratory cycle was monitored continuously by placing a navigator echo on the diaphragm. Subsequently 50 dynamics were acquired during the therapy phase in absence of a sonication. This was repeated three times in the volunteers and 1-3 times in the patients. The same data set was also used for off-line evaluation of a model-based correction method[5]. For switching between the learning phase and therapy phase method specific criteria were used[4,5]. As a measure of performance, the temporal standard deviation (SD) in temperature maps was calculated voxel wise over the 50 dynamics acquired during the therapy phase. The mean SD in an ROI containing the glandular tissue (volunteers) or tumor (patients) was reported. The volunteers were conscious during MR thermometry acquisition, whereas the patients were under conscious sedation. The patients received continuous propofol infusion plus an opioid analgesic for each sonication (#1 and #2) or a combination of propofol and esketamine (#3 and #4). A Mann-Whitney test was used for statistical analysis of difference in mean temperature SD. Values of $p < 0.05$ were considered statistically significant.

Results Figure 1a-b shows the mean temperature SD in a ROI before and after applying the LUT-based or the model-based correction method for volunteers (a) and patients (b). For all volunteers and patients #1 and #2 the application of each correction method significantly improved the precision of the MR thermometry compared to the uncorrected case. Both correction methods decreased the mean temperature SD from 3.7 °C to 1.7 °C (LUT-based) and 1.5 °C (model-based). A small, though significant, difference (0.2 °C) between the two correction methods was observed. For patient #3 and #4 the mean temperature SD was already low (~2 °C) for the uncorrected data and applying the correction methods resulted only in minor or no improvement. In volunteers the average number of images required to complete the learning phase for the LUT-based and model-based correction method were 68 and 23, respectively. In contrast, for patients #3 and #4 almost no difference was observed in the number of images required to complete the learning phase. Figure 1c-d shows the navigator position as function of time for volunteer #6 (c) and patient #4 (d). The respiration of patients under conscious sedation (~6 mm peak-peak) was shallower, based on navigator echo displacement and vital sign monitor data, than the respiration of the volunteers (~13 mm peak-peak). Furthermore, the patients receiving a combination of propofol and esketamine for conscious sedation (i.e. #3 and #4) showed less involuntary motion, based on the dynamic magnitude images of the thermometry sequence, and showed a more regular amplitude and frequency of the respiration.

Conclusion The performance of the LUT-based and model-based correction method to improve thermometry precision was comparable. However, depending on the regularity of the breathing pattern, the learning phase of the model-based approach was up to 3 times shorter. An important observation was that due to the very regular and shallow respiration of patients under conscious sedation the respiration induced temperature error in the breast tumor tissue was already very low without correction. On the other hand, it is known from Peters et al. that the temperature error also depends on the location in the breast[1]. This means that even with sedation correction may be necessary for tumors, which are located more closely to the thoracic wall. In conclusion, the type of conscious sedation used in this study not only reduced artifacts due to involuntary motion, it also improved the quality of MR thermometry.

References [1]Peters et al., JMRI, 2009; [2]Denis de Senneville et al., MRM, 2010; [3]Merckel et al, ISMRM, 2013; [4]Vigen et al., MRM 2003; [5]Hey et al., MRM, 2009
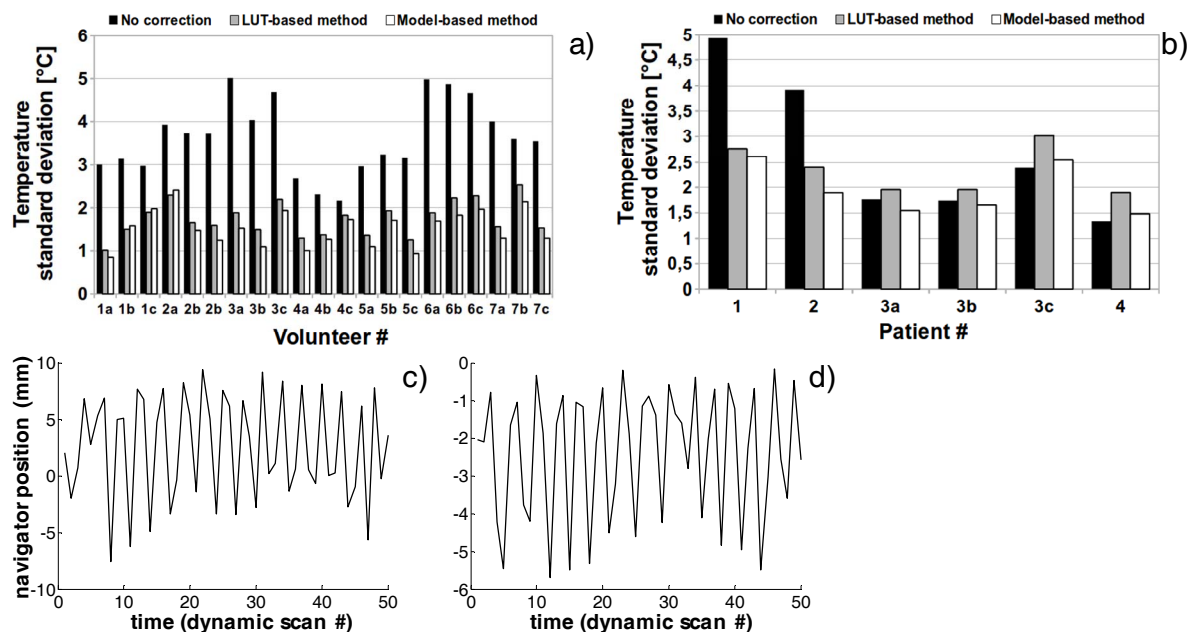
Figure 1: Mean temperature standard deviation before and after applying LUT-based or model-based correction in volunteers (a) or patients (b). Navigator positions as function of time for volunteer #6 (c) and patient #4 (d).

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