Abstract

Magnetic resonance thermometry: a preliminary study

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Purpose: In this thesis the work performed at the Ente Ospedaliero Cantonale (EOC) in Bellinzona for the implementation of magnetic resonance thermometry (MRT) is presented. The EOC Radiation-Oncology clinic has recently integrated its therapeutic offer with mild hyperthermia treatments (HT) combined with radiotherapy. The HT for deep seated tumors is delivered with the ALBA 4D system from MedLogix providing focused radiofrequencies (RF) at 70 MHz. HT treatments outcome depends on heating parameters such as the temperature obtained in the tumor and the heating rate. Therefore, quality assurance (QA) measurements for assessing the performance of the HT have to be implemented. In this work preliminary measurements for investigating the feasibility of MRT to assess the quality of HT in the EOC Radiation-Oncology clinical setting were performed. Specifically, the proton resonance frequency (PRF) shift MRT method was applied in this work. This method relies on the concept that the resonance frequency of hydrogen nuclei (protons) in water molecules changes as the temperature varies, which is due to alterations in the local magnetic field. A gradient-recalled echo (GRE) imaging sequence can be used to measure the phase change caused by the temperature-dependent shift in the resonance frequency. The phase difference images are proportional to the temperature variations. However, accurate thermometry is challenging as many confounding factors, such as magnetic field drift, field inhomogeneity and background noise, have to be taken into account in the phase shift analysis. In particular, the influence of the magnetic field drift becomes important when performing long-term dynamic scans. The initial phase of this study consisted in conducting preliminary measurements to understand and characterize the magnetic field drift that impacts the phase images. Two methods for drift correction were explored and compared to the resulting temperature measurement. The first method "Oil reference probes" consists in utilizing oil probes during the data acquisition and using the temperature-independent signal acquired from the oil to correct the temperature measurements. The second method "Drift of the sequence" consists in evaluating the drift progression over time right before each MRT sequence acquisition and applying a correction factor to the temperature measurements based on this assessment. The latter correction method would be useful for MRT applications in the patient or in a human size phantom where the use of probes may be difficult due to the limited size of the coils. As a further step, a phantom was developed for performing QA measurements of HT. According to European guidelines, the measure of treatment parameters such as localization of the focus, treatment field size and temperature distributions is necessary to ensure safe and correct patient treatments. These measurements can be performed with MRT provided that a phantom which is tissue equivalent for both RF HT and MR is available. Two phantoms prototypes were designed and tested. Additionally, the feasibility of introducing a MRT workflow for HT QA measurements was assessed.

Methods and materials: The MRT measurements were conducted using the Philips Ingenia Ambition 1.5T MRI system. To understand and characterize the magnetic field drift, PRF shifts were measured in both water and oil. The drift behaviour over time was analyzed under various conditions, exploring the reproducibility of different trends for different imaging acquisitions and positions along the longitudinal axis. The slopes of regression lines fitting the drift as a function of time under different conditions were compared. The "Drift of the sequence" and the "Oil reference probes" correction methods were tested by performing MRT in a heated water phantom and comparing the results to measurements obtained using a K-type thermometer, a reliable standard for temperature measurement. The Bland-Altman analysis was performed and both the bias and the limits of agreement were calculated to estimate the goodness of the temperature measurements obtained by the two methods compared to the values measured with the thermometer. The Bland-Altman analysis was also performed in order to evaluate the agreement between the temperature estimations obtained with the two drift correction methods. The two phantom prototypes for HT QA were created with materials fitting the dielectric proprieties of fat tissue in order to mimic the human body in terms of radio-wave propagation. The first prototype created to test the proof of principle consisted in a small cylindrical container made of PMMA filled with agarose. A second prototype the "wallpaper paste phantom" was created with the size of a standard human pelvis for mimicking the geometry of a patient when applying a HT treatment. This phantom was made of a mixture of deionized water, methyl powder, and sodium chloride (NaCl). The field drift trend with time was tested in the "wallpaper paste phantom". A HT treatment was calculated both with the ALBA 4D certified EasyPlan treatment planning system (TPS) and the new voxel-wise Plan2heat TPS and applied to the phantom.

Results: The measurements performed for the field drift characterization showed that the drift increases linearly with the acquisition time. However, the slope of the line changed when a new image acquisition study was acquired. On the other hand the slope did not depend on the position along the longitudinal axis up to ±5 cm from the central plane. The Bland-Altman analysis showed that the "Drift of the sequence" method and the "Oil reference probes" method presented similar results when compared to the thermometer measurements. In particular, the bias was found to be below 0.05°C for both methods. For the "Drift of the sequence" method, the limits of agreement were found to be within a range of 0.6°C, while for the "Oil reference probes" method, the limits of

agreement were within a range of 0.7°C. Further analysis through Bland-Altman revealed a bias or average difference between the two methods of 0.1°C, indicating that neither method is affected by systematic errors. Additionally, the agreement interval, representing the range where 95\% of the mean differences between the methods lie, was 0.7°C. The agarose phantom allowed the measure of appreciable phase shifts when heated. The field drift trend with time in the "wallpaper-paste phantom" was observed to be linear. This suggests that the "Drift of the sequence" method can effectively correct temperature distributions measured in the phantom, eliminating the need for oil probes. Notably, conducting five drift measurements before the hyperthermia (HT) treatment was sufficient to estimate the drift trend and correct the post-heating images. A HT treatment workflow, involving planning CT acquisition, treatment plan calculation, and treatment delivery, was successfully applied to the "wallpaper paste phantom" without encountering any issues.

Conclusion: The preliminary measurements performed for investigating the feasibility of MRT for HT QA showed that to obtain accurate temperature measurements a correction for the drift of the magnetic field with time has to be applied to the acquired images. A constant correction factor is not applicable due to the changes of the drift behavior in different image acquisition studies (sequences). Therefore, the drift assessment as well as the pre- and post-heating images have to be acquired within the same sequence. On the other hand, the same correction function can be applied along the longitudinal axis. The latter result is promising for obtaining temperature maps in 3D applying a position independent correction factor. The new method "Drift of the sequence" proposed to correct for the magnetic field drift showed high correlation and good agreement with the standard "Oil reference probes" method. The "wallpaper paste phantom" created for HT QA was suited for HT treatment simulation and MRT. Further work comprises the design of a QA program based on MRT for deep HT treatments and the validation with MRT of the 3D temperature distributions estimated with the new Plan2heat TPS.

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