Non-invasive temperature mapping using temperature-responsive water saturation shift referencing (T-WASSR) MRI

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Target audience: MRI researchers interested in developing MR thermometry or oncologists needing a noninvasive imaging method for monitoring cancer thermotherapy.

Purpose: To develop a new non-invasive MRI method for assessing water proton resonance frequency (PRF) shifts in response to changes in temperature that can be applied reliably in tissues with high fat content.

Methods: We adapted the previously reported Water Saturation Shift Referencing (WASSR) approach for detecting temperature induced water PRF changes. In principle, the water signal (Ms) upon the application of a weak RF saturation (strength 0.1) follows Eq [1]:

\[ M_s(t) = \frac{1}{1+((T/T_2)^\sigma)/((T/T_1)^\sigma)} \]

Where \( \sigma \) is the resonance frequency of water protons, \( M_0 \) is the water signal without saturation, and \( T_1 \) and \( T_2 \) are the spin-lattice and spin-spin relaxation times of water, respectively. Sweeping the temperature changes can be determined by comparing the water PRF (\( \sigma \)) determined for each pixel in the B0 shims map at two temperatures. The correlation coefficient (r) is defined as:

\[ r = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum (x_i - \bar{x})^2 \sum (y_i - \bar{y})^2}} \]

Results: When applied to fat-containing phantom, the T-WASSR method was able to provide steady temperature mapping of both regions containing water and regions containing both fat and water. These findings were consistent with the temperature maps obtained by a phase mapping method (Fig.1a, right) when temperature was changed from 310K to 316K.

Discussion: We have demonstrated a water direct-saturation-based approach for temperature mapping, adding additional methodology to the arsenal of non-invasive, high-resolution MRI thermometry. Our results demonstrate that the T-WASSR has an improved robustness of high-resolution temperature mapping in fat-containing tissues when compared to phase mapping. Similar to the phase mapping method, the T-WASSR was capable of mapping temperature changes at high spatial resolution. The temporal resolution can be further improved via using other fast imaging sequences.

Conclusion: The T-WASSR approach provides a suitable alternative for non-invasive temperature mapping by MRI, especially for temperature measurements in fat-containing tissues.