An integrated system composed of magnetic hyperthermia, magnetomotive ultrasound, and ultrasound thermal strain imaging

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Background, Motivation and Objective

In the last decades, magnetic hyperthermia (MH) has been investigated as a promising technique to treat cancer. Although substantial progress has been achieved, there still exist several challenges to be overcome before this technique can be used in the clinical routine. For example, localizing the magnetic nanoparticles (MNP) within tissue and monitoring the temperature during the treatment procedure are two major concerns. Therefore, it is of great interest to integrate a MH device with an imaging system capable of localizing MNP and monitoring tissue temperature. In this study, we developed a theranostic platform where an ultrasound (US) imaging system is used for both detecting MNP and mapping the temperature variation during MH. US thermal strain imaging is used to monitor temperature and magnetomotive US (MMUS) imaging enables visualization of MNP. The system was designed so that the same coil induces the external magnetic fields for both techniques MH and MMUS.

Statement of Contribution/Methods

The two main components of the developed theranostic platform are the magnetic excitation and the US-based imaging techniques. To generate the magnetic fields, we developed an induction heating system and a current pulse generator used for MH and MMUS, respectively. In both cases, a pancake coil composed of 7 turns with 80 mm outer diameter was used. Radiofrequency (100 kHz, 8.7 kA/m) field was used in MH, while 2 ms magnetic pulses (470 kA/m) were used to induce motion to generate MMUS images. Ultrasound echo data were acquired using a linear array transducer positioned opposite the coil during magnetic excitation to generate both MMUS and thermal images. During MH, the data were collected for 100 seconds at 0.5 Hz frame rate, while for MMUS a 4 kHz frame rate was used due to the short-duration excitation pulses. The induced motion in MMUS and apparent displacement due to the temperature variation were estimated using a cross-correlation algorithm. The axial strain of the apparent displacement map was estimated to create the thermal images. The theranostic system was evaluated using a cubic gelatin phantom containing a 1 cm in diameter cylindrical inclusion filled with MNP.

Results/Discussion

A temperature rise of 7°C was measured using a fiber optic thermometer positioned inside the MNP-laden inclusion, which was in good agreement ($\rho_c = 0.98$) with the values estimated through the thermal images. These images showed the temperature rise (2°C) was confined to the inclusion for the first 28 seconds and then diffused to the background. In the background, less than 3°C temperature variation was observed during the entire experiment. A peak displacement of 50 μm was estimated 2 ms after turning the current pulse generator on. The obtained MMUS images correctly located the MNP-laden inclusion with 85% accuracy. These results show the potential of this integrated system to simultaneously visualizing MNP and monitoring the temperature during MH.