MR Compatible Electrode for RF Hyperthermia with Capacitive Coupling: Feasibility Demonstration

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TARGET AUDIENCE.
Scientists and clinicians interested in the techniques for MR guided RF hyperthermia treatment including MR thermometry methods.

INTRODUCTION.
The radio-frequency hyperthermia treatment with capacitive driving is now emerging as a noninvasive cancer treatment method. The tumorous tissue having higher ionic concentration have higher electric conductivity than the normal tissue. When the RF electric field is applied, the more electric current is drawn by the tumor cell resulting in the increased temperature around the tumor. This process could be carried out more safely with accuracy if we can monitor the treatment process including the temperature. We have studied the technical feasibility of developing MR compatible electrodes which can be used for RF hyperthermia in the MR systems with proper switching mechanism without affecting MR signal reception. A prototype animal 13.56 MHz capacitive RF hyperthermia system was operated with MR image acquisition capability using a 3.0-T MRI system (Achieva 3.0 T, Philips). We have designed, constructed, and tested experimentally a new RF electrode with switching resonant circuits working at 13.56 MHz without affecting the MR image acquisition at 128 MHz.

METHODS.
In this study, a capacitive RF hyperthermia method with MR guidance and temperature monitoring capability is proposed. The followings have to be considered for proper operation of the MR compatible RF hyperthermia system: 1) MR temperature imaging stability without being affected by the electrode and 2) proper RF power transmission through the tuned electrode for hyperthermia. ***MR Compatible Electrode Design***: The proposed electrode is composed of small copper sheets and tuned circuits between them. Figure 1 shows the effect of the electrode with some different switching circuits on MR images. Four different designs of electrodes were tried and gradient echo images of the uniform phantom were acquired using a Tx/Rx Q-body coil (GRE, TR/TE = 300/9 msec, 15 mm slice thickness, 80° flip angle). The heating from the electrode is shown in Figure 2, saline phantom between the two electrodes is properly heated as expected (13.56 MHz, 100 W). ***MR Thermometry with electrode***: Figure 3 shows MR temperature images of the uniform agarose gel phantom (phantom composed of agarose 20 g/L, $CuSO_4$ 1 g/L) with the proposed electrodes on top of the phantom showing the imaging capability while the electrode is working properly (PRFs methods, FFE, TR/TE = 300/15 msec, 20° flip angle, 1100W micro-wave heating and measured during cooling procedure).

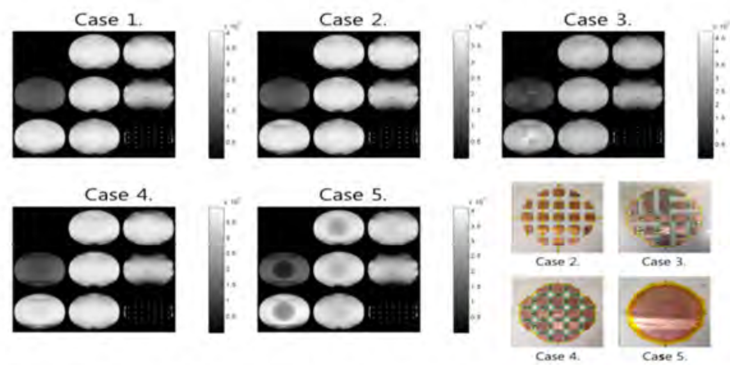

Figure 1. MR imaging results without electrode (Case 1), with copper pieces (Case 2), electrodes made of copper pieces with switching circuits A (Case3, electrode A) and B (Case 4, electrode B) and complete circular copper electrode (Case5). Case 4 with proper switching circuit (B) shows almost identical results as Case 1 or 2.

RESULTS.
The proposed electrode acts properly for RF hyperthermia while not affecting MR imaging. The temperature increase in the phantom from RF heating was more than 2 ℃/hour with RF hyperthermia system turned on (13.56 MHz, 100 W). The measured temperature change of the gel phantom is 60 ℃ as shown in Fig. 3. Electrodes were placed at the top and the bottom of the phantom and PRFs method is used to measure the temperature.

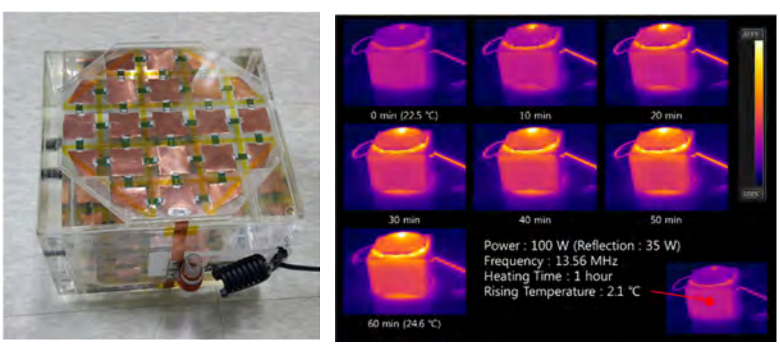

Figure 2. Electrode being used for RF hyperthermia with capacitive coupling and its thermal images during heating.

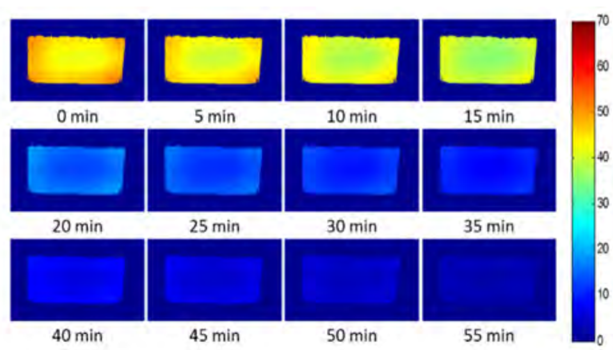

Figure 3. MR thermometry result with electrode B (using PRFs method) while cooling down (final temperature being 22 ℃).

DISCUSSIONS AND CONCLUSIONS.
MRI and hyperthermia experiments were conducted to confirm the feasibility of the MR-compatible electrode for RF Hyperthermia with capacitive coupling. Integration of the RF hyperthermia into the bore of the MRI allowed MR treatment guide as well as MR thermometry.

ACKNOWLEDGMENTS.
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