NOTE

Feasibility of Microwave Ablation for MR-Guided Interstitial Thermal Therapy: An Experimental Study Using 2T MR System

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The feasibility of microwave ablation for MR-guided interstitial thermal therapy was examined using a 2.0T MR system. The microwave ablation was operated at a frequency of 2.45 GHz for the study. An MR compatible needle-type electrode used for microwave ablation showed no apparent susceptibility effects on MR images. In MR images without special devices required in radio-frequency ablation at 500 KHz such as filters or switching circuits, microwave ablation caused little electromagnetic interference. Using the proton resonance frequency method, temperature information during ablation could be obtained from both an agar phantom and a block of beef. The coagulated area of the beef was visualized with high signal intensities in T_1-weighted images. Microwave ablation can therefore be considered as a possible method for MR guided interstitial thermal therapy.

INTRODUCTION

In MR-guided thermal therapy, MR images can be used not only for anatomical guide, but also for temperature monitoring. Therefore, the effects of interstitial thermal therapy can be evaluated immediately. Although, laser beams, which are free from radio-frequency (RF) noise, have been widely used[1),2)] as therapeutic modality, the laser beam transmission is affected by tissue color or carbonization. The control of the region with effective heating is not necessarily easy. On the other hand, RF ablation operated at a frequency of approximately 500 KHz has also been used as an energy source in MR-guided thermocoagulation therapy because of its good reliability regarding therapeutic effects[3)]. One disadvantage, however, is that the RF generator is a source of noise for MR images. Various equipments, such as filters or switching circuits, have been applied to reduce the electromagnetic interference in MR images[4)]. Some investigators have also reported on the feasibility of microwave thermocoagula-

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tion at 915 MHz under the MRI guidance[5),6)], and just started clinical studies for the prostate cancer[7)]. On the other hand, in Japan, a microwave coagulator, which is operated at 2.45 GHz, has been applied for hemostasis and tissue destruction during liver surgery for over two decades[8),9)]. Recently, it has also been used in minimal invasive thermocoagulation therapy[10),11)]. Microwave ablation of liver tumors has been established as a useful treatment of liver tumors. In the present study, the feasibility of this MR-guided microwave thermoablation therapy was examined using a 2T MR system.

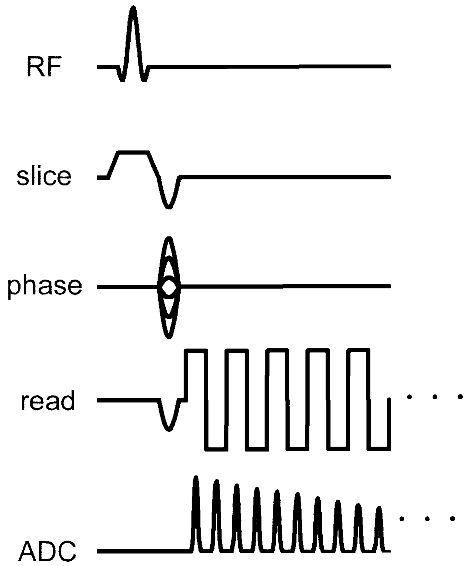

Fig. 1. Scheme of ^1H echo planar spectroscopic imaging (EPSI) for temperature increase mapping

MATERIALS AND METHODS

A 2.0T CSI Omega System (Bruker, Fremont, CA) and a bird-cage coil were used. A microwave coagulator, Microtaze® (Model HSD-20M, Azwell, Osaka, Japan), operating at 2.45 GHz, was used as a heating device. An MR-compatible needle-type electrode (250 mm long, 1.6 mm in diameter) was custom-made from brass coated with silver and gold. The electrode was set in the direction of the static magnetic field because the diameter of the magnetic bore was 15 cm. Microwave ablation was carried out on agar phantoms or beef blocks at 60 W for 90 seconds. The apparatus was set up in the control room next to the magnet room and connected to the electrode in the magnet bore using a 5 m long coaxial cable. The magnet room and control room were not specially shielded from external RF noises. For the reduction of external noise, a double shield coaxial cable, whose external layer was grounded, was used. Neither other modifications nor filters were employed. T_1-weighted MR images were acquired with gradient recalled echo sequence of 100/7/60 (TR/TE/flip angle). The temperature increase was calculated from the chemical shifts of the water ^1H signal (85.56 MHz at 2T) obtained by echo planar spectroscopic imaging (EPSI) sequence[12)]. The scheme of EPSI pulse sequence is shown in Fig. 1. In this technique, chemical shift information of each pixel in the read direction was obtained from sequential echoes. Phase encoding was also required in the other direction. EPSI data was collected with 100–120 mm^2 FOV, 4 mm slice thickness, 75 ms TR, 2k block size (64 points × 32 echoes), 32 KHz spectral width, 64 phase encoding steps and 1 acquisition. The

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total acquisition time of one data set was 5 seconds, but actual temporal resolution was approximately 15 seconds because it took considerable time to save the data in this system and to transfer it to the other computer for data processing. The odd and even echoes were separately processed by 3D Fourier transformation with zero-filling and magnitude calculation. The obtained two datasets of 64×64 spectra with 250 Hz spectral width were added. The chemical shifts of water ^{1}H signal were automatically extracted from individual spectra by fitting to a Lorenzian line shape. The constants for the temperature dependent chemical shift changes were taken from a previous report[13]. Relative changes in temperature of an agar phantom and beef block from the room temperature was calculated using 0.0103 and 0.0114 ppm/℃ as constants, respectively.

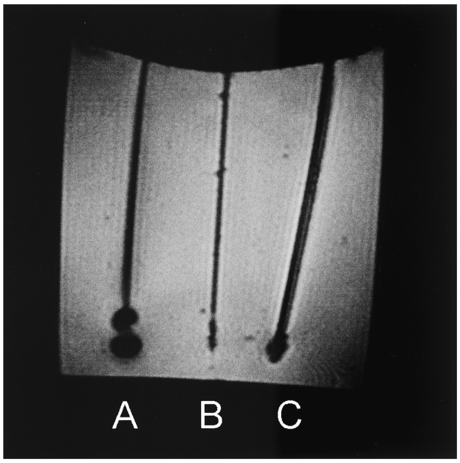

Fig. 2. T_1-weighted MR image of MR-compatible electrode and needles in an agar phantom. Needles were set in the direction of the static magnetic field. A : 18G needle (E-Z-EM), B : electrode of Microtaze® 1.6 mm in diameter, and C : 14G needle (DAUM).

RESULTS

The susceptibility effects of the custom-made needle-type electrode on MR image were negligible. As shown in Fig. 2, its artifacts on MR image were less than those of MR-compatible biopsy needles. When the electrode was connected with a coaxial cable on the outside of the magnetic bore (without connecting to the microwave coagulator), some external noises were observed on MR image (Fig. 3B). The quality of MR images, however, was maintained fairly well and was considered good enough for evaluation. Connection of the cable to the microwave coagulator or microwave irradiation did not show any apparent adverse effects (Fig. 3C, D). The signal intensities under T_1-weighted conditions slightly decreased around the electrode in images C and D by heating.

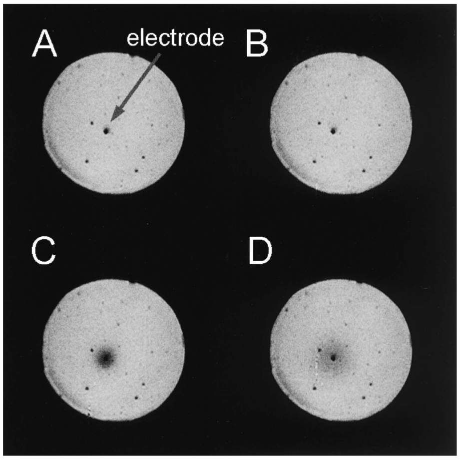

Fig. 3. T_1-weighted MR images of an agar phantom with a microwave electrode. A and B : without and with connection to a coaxial cable, respectively. C and D : during and after microwave ablation, respectively.

Temperature increase mappings before, during and after microwave ablation were con-

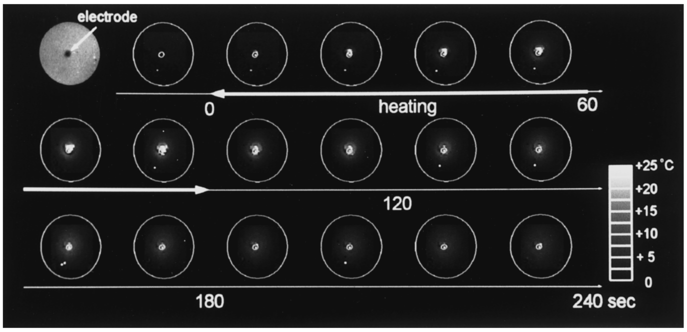

Fig. 4. Temperature increase of an agar phantom before, during and after the 90 s microwave ablation

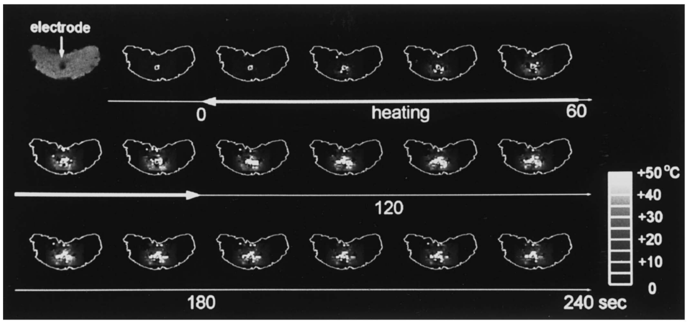

Fig. 5. Temperature increase of a beef block before, during and after the 90 s microwave ablation

structed using an agar phantom (Fig. 4) and a beef block (Fig. 5). Even during microwave ablation, the temperature could be monitored without noise interference from the microwave coagulator. In the beef block, the coagulated area was about 10 mm in diameter. Such changes could be shown with high intensities on T_1-weighted MR images at least several minutes after the ablation (Fig. 6).

DISCUSSION

No serious adverse effects were observed with microwave ablation at 2.45 GHz, in contrast with RF ablation at 500 KHz. In addition, no special devices were required to use the microwave coagulator under the MR environment. The main problem we encountered was several dot noises. Although the connection of the coaxial cable to the electrode caused some dot noises on MR image, connection to the microwave coagulator or the microwave ablation caused no apparent negative effects. Therefore, this equipment can hardly be considered as a noise source. Our magnet room is not shielded from RF noise. An appropriate RF shield would therefore reduce the noise. The frequency of ^{1}H MR signal on our 2T machine

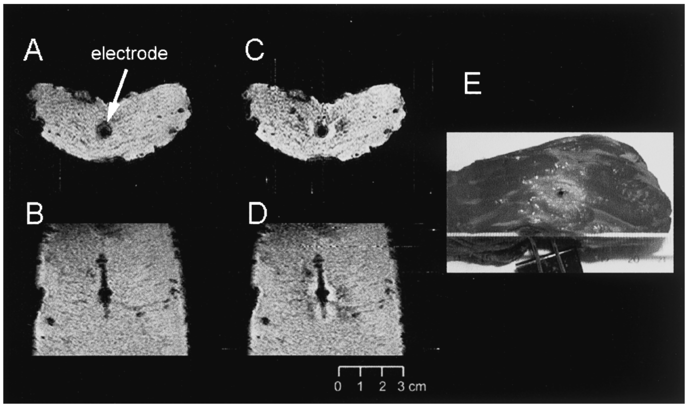

Fig. 6. Effects of the 90 s microwave ablation on a beef block. T_1-weighted MR images before (A and B) and after (C and D) the microwave ablation, and cross section of the beef (E). The coagulated area could be shown with high intensities on T_1-weighted MR images.

is 85.5 MHz and that of the microwave is 2.45 GHz. Such a large difference in frequency might prove to be beneficial. Thus, we have used this microwave coagulator with our 2T machine. The feasibility of microwave ablation for MR-guided interstitial thermal therapy can be positively anticipated. This benefit however cannot be directly applied to other MR systems. Many open MR systems for interventional use have lower magnetic field strengths and the difference in frequencies further increases.

Our temperature increase mapping technique using the proton resonance frequency method with EPSI is still in its early stages. The pulse program and acquisition parameters should be more optimized. In this study, temperature changes of agar and beef were calculated using the constants 0.0103 and 0.0114 ppm/℃, respectively[13]. In other reports, the value of 0.008 ppm/℃ was used as the constant for temperature calculation in rabbit muscle[12] and rabbit brain[6]. Although accurate calibration of temperature might be also required under our experimental conditions, both temperature rise around the electrode and the heat spreading were readily observed, not only with the phantom, but also with the beef block. Even during microwave ablation, temperature measurement by MR does not seem to be interfered with.

In addition to the temperature increase mapping, the signal intensities in the agar phantom decreased around the electrode during and immediately after microwave ablation (Fig. 3C, D). Temperature increase elongates T_1[14] and might cause signal decrease in T_1-weighted MR images. On the other hand, the coagulated area in the beef block could be shown with high intensities on T_1-weighted MR images after the temperature went back to the base line level. Such information obtained from MR images must be also useful in MR-guided microwave ablation.

In conclusion, the preliminary results of our experimental study showed that microwave ablation at 2.45 GHz can be a possible method for use in MR-guided interstitial thermal therapy.

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