
TECHNICAL NOTE

Alternate Biplanar MR Navigation for Microwave Ablation of Liver Tumors

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(Received December 14, 2004; Accepted July 6, 2005)

Real-time MR (magnetic resonance) images in two perpendicular planes, both of which included the path of the needle, were utilized for MR-guided microwave ablation of liver tumors. The two image planes were automatically and alternately switched by new MR scanner control software installed on an external PC. This technique is possible only with MRI (magnetic resonance imaging) units with multiplanar and multisection capabilities. Reformatted images in the corresponding two planes were also constructed from preoperative three-dimensional volume data. These four images (two real-time and two reformatted) were continuously visible to the surgeons. These images enabled the needle position in the three-dimensional space to be accurately and clearly recognized, in contrast to the difficulty encountered with two-dimensional MR images in a single image plane. This technique was also applied to MR temperature mapping during microwave ablation, as it allowed monitoring of the spread of the heat in a three-dimensional space. This type of computer-integrated image navigation was demonstrated to be feasible for MR-guided microwave ablation of liver tumors.

Keywords: MR image navigation, computer-integrated surgery, microwave ablation, MR temperature map

Introduction

MR (magnetic resonance) images provide many advantages for navigation in interventional procedures, including good soft tissue image contrast, absence of ionizing radiation, and applicability to bone or air space. In addition, the multi-planar capability of MR images is a unique feature not available with other imaging modalities. MR image-guided minimally invasive interventional procedures, therefore, have been developed in response to the increased use of open-configuration MR systems.1–4 With regard to one type of feasible MR-guided interstitial thermal therapy, we have already reported on MR-guided microwave ablation of liver tumors.5,6 In this procedure, insertion of the electrode into the tumors was guided by real-time MR images. Because two-dimensional tomographic MR images are used for navigation, the image planes must include both the exact path of the needle and the target. For this reason, an interactive optical tracking system is integrated into the MR scanner.7 As a result, surgeons using a handpiece with a needle guide can control the planes of the real-time MR images.

In the effort to achieve high temporal resolution, real-time MR images have usually been acquired under T1-weighted conditions with a gradient echo sequence for two to three seconds. The targets, however, are not necessarily clearly visualized under this condition. Furthermore, because of the limited acquisition time, the signal-to-noise-ratio of real-time MR images was not always satisfactory. To measure such problems, we utilized “3D Slicer” navigation software developed by the Artificial Intelligence Laboratory of the Massachusetts Institute of Technology and by Brigham & Women’s Hospital, a teaching affiliate of Harvard Medical School.8,9 One real-time image and two reformatted images (of the same plane and a plane perpendicular to the real-time image) from high-
resolution 3D volume data obtained just before the procedure were displayed together. Computer-integrated image navigation was found to be helpful. The information, however, was transferred in only one direction, from the MR scanner to the external PC. Observation in just one image plane is not sufficient for accurate recognition of the location in the three-dimensional space. To ensure more accurate and reliable MR image navigation, we have developed new MR scanner-control software for an external PC. This software can automatically and alternately switch image planes. The present study examines the feasibility of using this software for alternate biplanar image navigation.

Materials and Methods

The ethics committee of the Shiga University of Medical Science approved this study. Forty-five cases with microwave ablation of liver tumors were included in our research. The procedure and any possible complications related to this type of therapy were explained to each patient, and signed informed consent was obtained from the subjects. All MR data were collected with a superconducting 0.5T Sigma SP/i system (GE Medical Systems, Milwaukee, WI, USA) into which a FlashPoint Model 5000 optical tracking system (Image Guided Technologies Inc., Boulder, CO, USA) was integrated. The surgeons controlled the planes of the real-time MR images with a three-point handpiece provided with a needle guide at the center and three light-emitting diodes (LEDs) on its three pedicles. One of the two perpendicular planes (inplane 0 and inplane 90) that included the needle path was usually selected (Fig. 1). A Microtaze microwave coagulator (Model OT-110M, Azwell, Osaka, Japan), which operates at 2.45 GHz, was used as the heating device. Liver tumors were percutaneously punctured with a 15-cm 14G MR-compatible puncture needle (Daum, Schwerin, Germany). A custom-made MR-compatible needle-type electrode (Azwell) measuring 1.6 mm in diameter was inserted through the outer sheath of the needle. A notch filter with attenuation profiles of 40 dB at 21.25 MHz (1H frequency at 0.5T) and 0.3 dB at 2.45 GHz was inserted in the output line to eliminate noise in MR images during ablation. Real-time MR images for needle tracking were acquired with a spoiled gradient echo (SPGR) sequence with a 14-ms TR, 3.4-ms TE, and 256×128 matrices. MR temperature data during microwave ablation were collected with an SPGR with a 33-ms TR, 13-ms TE, and 256×128 matrices with respiratory triggering under controlled ventilation. Temperature changes during ablation were calculated with the proton resonance frequency method.

Newly developed software installed on an external PC was applied to all 45 cases routinely. After the patient position was determined for the procedure, high-resolution three-dimensional MR volume data were acquired and transferred to the PC. T1- or T2-weighted images, dynamic studies, or any type of MR image could be used for this volume data. The acquisition conditions were changed according to the visibility of the target. Basically, MR volume data were acquired with a 3D-SPGR with a 17-ms TR, 2.7-ms TE, 30° flip angle, 300×300 mm² field of view, 5-mm slice thickness, 0-mm gap, 256×160 matrices, and 28 slices. A server program loaded in the MR system continuously sent real-time MR images and information regarding handpiece position to the PC through a network cable. Two reformatted images were directly constructed from the volume data with three-point linear interpolation based on the position of the handpiece. One real-time image and two reformatted images from the 3D volume data (one on the same plane and one on a plane perpen-
Fig. 2. Picture with biplanar acquisition mode during the puncture of a liver tumor for microwave ablation. The upper two images are real-time MR images and the lower two are reformatted images from the preoperative 3D data in the corresponding two perpendicular planes, inplane 0 (left) and inplane 90 (right). The vascular structure is well visualized in the reformatted images.

Results

Figure 2 shows a picture with biplanar acquisition mode during the puncture of a liver tumor for microwave ablation. Four images—two real-time and two reformatted in the corresponding two perpendicular planes—were displayed together. The image planes in the real-time MR image and the corresponding reformatted images were apparently identical, but the reformatted images were directly constructed according to information on the handpiece position. The update time of the reformatted images was 0.5 s, which was much faster than that of the 2-s data acquisition time of the real-time images. The inplane 90 reformatted images (lower right) were somewhat blurred compared with inplane 0 images (lower left) because the reformatted images were constructed from a data set of axial images. The resolution in the slice direction was lower than those in the read and phase directions, but the location of the tumor in this direction was clearly shown. The combination of two real-time and two reformatted images was useful for MR image navigation. Liver tumors and the surrounding vascular structures were usually clearly visualized in the reformatted images and a safe puncture route could be selected. The puncture needle could be observed in both of the real-time MR images in two perpendicular planes,
**Fig. 3.** Picture with biplanar acquisition mode during the puncture of a liver tumor for microwave ablation
The upper two are real-time MR images and the lower two are reformatted images from the preoperative 3D data in the corresponding two perpendicular planes. The needle is bending within inplane 0 and out of inplane 90.

**Fig. 4.** Biplanar temperature maps during the microwave ablation of a liver tumor
The upper two are MR temperature maps and the lower two are reformatted images in the corresponding two perpendicular planes. The color-coded scale on the right, overlaying the magnitude images, indicates the temperature increase.
which made it easy to recognize the accurate needle position in the three-dimensional space. The needle could bend during the puncture because of either the tissue structure or the respiratory movement of the liver. As shown in Fig. 3, biplanar observation did not result in loss of the needle tip position even when the needle exited one of the two planes.

The biplanar mode was also utilized for MR temperature maps. Temperature changes in the liver during microwave ablation could be monitored in the two perpendicular planes (Fig. 4). The process of changing parameters from real-time image navigation to temperature monitoring also became much easier. Baseline images for temperature calculation could be set automatically by clicking one button without specifying the image number.

Discussion

The combination of real-time images and reformatted images was helpful for navigation. The reformatted images in the two perpendicular planes were useful for recognition of the location in the three-dimensional space. In the reformatted images, the resolution in the superior-inferior direction was relatively low because of the data set in the axial planes. To increase the resolution, more images obtained with thinner slices could be applied. For image acquisition of the liver, respiratory suspension is generally required. In the present condition (28 images with 5-mm slice thickness), the total acquisition time for one data set was 1 min, 40 s. As described above, the location of the tumor in this direction could be shown clearly. The acquisition parameters for the volume data are considered reasonable.

The actual position of the puncture needle must be observed in the real-time images. To confirm the needle position in the three-dimensional space, observations of MR images in two planes are necessary. The operator in the control room had to change the image plane as requested by the surgeon in the magnet room, which resulted in some time delay. In the biplanar mode, image plane control was automatically accomplished through the external PC. The needle position could be monitored in the two perpendicular planes. Displacement of the needle within the image plane was readily apparent, but out-of-plane displacement was not. This has the potential to provide seriously misleading results. The 14G puncture needle was visualized as a signal void 8 mm in diameter and the slice thickness of the real-time MR images was 7 mm. Therefore, an 8-mm out-of-plane displacement could, in theory, result in loss of visibility of the needle tip. If the needle tip were displaced by 8 mm from both planes, the needle tip would not appear in either image. Even in such a case, the basal part of the needle would appear in both images, and the direction of displacement would be easily determined. Observation of the needle in the two perpendicular planes combined with the two corresponding reformatted images enabled both safe and accurate image guidance. One disadvantage of the biplanar mode was the halving of the temporal resolution in each plane. However, whenever high temporal resolution in one plane was required, we could easily revert to single-plane mode while running the MR image acquisitions.

Microwave thermocoagulation therapy is feasible under MR guidance because it does not interfere with MR imaging even during ablation. At present, however, MR temperature monitoring is not applied to all ablations during a procedure. The results of the temperature calculation are susceptible to patient movement and the surrounding environment, including the surgeon. The introduction of respiratory triggering is one solution to these problems. Another difficulty is the time-consuming process of changing acquisition parameters for the MR temperature map and specifying the baseline data for the temperature calculation. This software significantly shortened the preparation time and simplified the process of MR temperature monitoring. Such a practical improvement is an important step in increasing the applicability of MR temperature monitoring in clinical cases. In addition, biplanar navigation could be applied for temperature monitoring. Although complete three-dimensional information was not included, temperature data in two perpendicular planes could predict the heat spreading in the three-dimensional space as a result of the microwave ablation.

In conclusion, alternate biplanar MR imaging, which effectively utilizes the multi-planar capability of MR, enabled feasible real-time image navigation and MR temperature monitoring in the MR-guided microwave ablation of liver tumors.

References