New Devices for Safety and Usability to Introduce Robot Assistance into Clinical MR Guided Microwave Ablation of Liver Tumors

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INTRODUCTION

In order to assist MR guided microwave ablation of liver tumors (1), we have developed a motorized remote-center-of-motion (RCM) constraint robot (Fig. 1). At the previous ISMRM Meeting in Seattle, we reported the compatibility with MR environments and the accuracy of RCM to the target (2). To introduce this robot into clinical procedures, we have developed a new hand-piece for the practical puncture of liver tumors in various locations and mechanical fuse on the robot arm to guarantee the safety. The feasibility of these newly developed devices has been investigated with phantom and also volunteer studies.

MATERIALS AND METHODS

An open configuration MR scanner, 0.5 T GE SIGNA SP/i, was used. The robot, consisting of a passive end effecter with 2-degree-of-freedom rotation and active XYZ-base stages with 3 ultrasonic motors for 3-degree-of-freedom, automatically chased the preset target point (2). As a new robot hand-piece, a detachable longitudinal pole was added to the standard one, which has 3 light emitting diodes (LEDs) on 3 pedicles (Fig. 2). With this detachable pole, two ways of puncture directions can be selected. A mechanical fuse, consisting of a hinge and wedge, was prepared on the vertical pole of the robot (Fig. 3). When the force to the robot arm exceeds the threshold, the joint is released and the arm goes up. The threshold force level can be controlled by adjusting the gap for the wedge. The needle positions were examined using an agar phantom and simulation studies were carried out with healthy volunteers.

RESULTS AND DISCUSSION

The 3 LEDs on the hand-piece must be visible from the detectors on the ceiling. Using this robot with the standard hand-piece, puncture from ventral position is possible, but that from lateral position is impossible, even if the range of robot motion is extended. Various puncture routes should be selected depending on the locations of liver tumors. This new hand-piece attached to the end effecter of the robot enabled punctures of the liver from the side while controlling image planes interactively. In experiments with agar phantoms, the needle tip position successfully controlled the real-time MR images planes in both vertical and horizontal directions. This new hand-piece considerably expanded the availability of the robot. The ultrasonic motors used for our robot have high torque of 0.5Nm. It can harm patients if it works unexpectedly. Guarantee of safety is the primary issue for human studies including volunteers. With this mechanical fuse, surgeons can easily lift the robot arm anytime necessary. When the robot arm is lifted, it can not touch the patient physically. Actually, the authors were the first volunteers. When the robot arm intentionally pressed the volunteer, the mechanical fuse spontaneously snapped without causing actual pain. There can be various switches, such as mechanical, electrical and optical ones, in case of emergency. We chose the mechanical switch for the robot, because it is the most primitive and reliable method. As a simulation study, 3D volume data of the liver were acquired with a volunteer and imaginary tumor area was marked on them. The robot could target the imaginary tumor by just inputting its position. In addition, real-time MR images of the volunteer including the target area at the center could be successfully acquired (Fig. 4). After accomplishment of sufficient simulation studies with volunteers for safety and accuracy, we are planning to start clinical studies.

REFERENCES

1. Morikawa S, Inubushi T, Kurumi Y, et al. J Magn Reson Imaging 16: 576-583, 2002.
2. Morikawa S, Hata N, Inubushi T, et al. ISMRM 14:1449, 2006.

Fig. 1 A motorized robot to assist MR-guided microwave ablation of liver tumors.

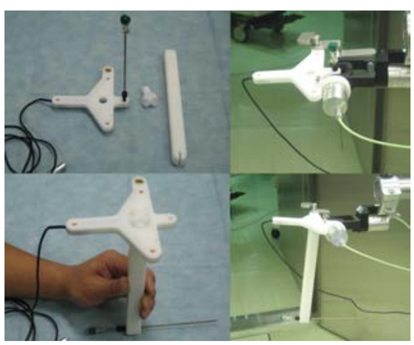

Fig. 2 A new robot hand-piece with a detachable longitudinal pole. Punctures in both vertical and horizontal directions are available.

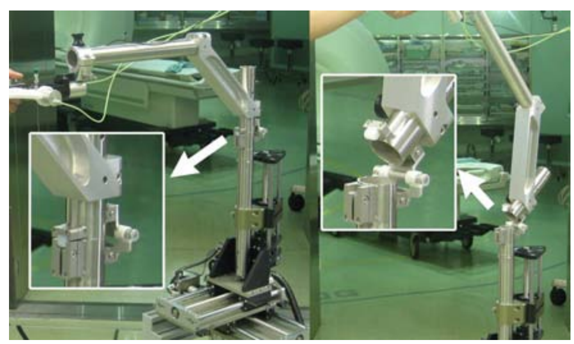

Fig. 3 A mechanical fuse on the vertical pole of the robot consisting of a hinge and wedge. The joint is released above the threshold force, which can be controlled by the gap for the wedge.

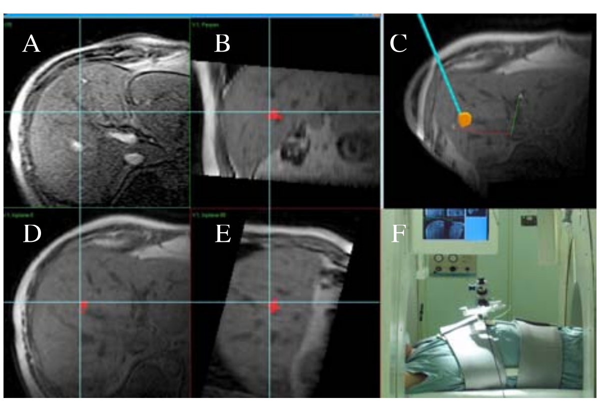

Fig. 4 A simulation study with a healthy volunteer. An imaginary tumor area was marked on the 3D volume data of the liver of the volunteer. The position of the imaginary tumor was inputted to the robot and the robot automatically targeted the tumor with its RCM function. The optical hand-piece attached to the robot's end effecter controlled real-time MR image planes. Our navigation software displayed one real-time MR image and corresponding 3 reformatted images from 3D data in orthogonal planes determined by the hand-piece.
(A) Real-time MR image. (B, D, E) Reformatted images from 3D data in orthogonal planes. (D) Inplane 0 (corresponding to the real-time image), (E) inplane 90 and (B) perpendicular plane. (C) 3D display of reformatted images with a virtual needle. (F) A volunteer and the robot in the magnet. Imaginary tumor area is displayed in red and orange.