Automatic Passive Tracking of an Manually Steerable Instrument Holder for MR-guided Interventions Applied in LITT

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Introduction

Since MR-guided interventions require both high image quality and short acquisition times, in clinical routine such procedures are increasingly performed within closed-bore high field MR systems which offer only limited patient access. Safe and precise localization of the instruments is a mandatory pre-requisite for any intervention. For this, active tracking techniques have been proposed that use miniaturized RF coils to obtain the instrument position within a few milli-seconds.

So far, safety hazards [1] prevent these techniques from being used in clinical practice. Recently, an automatic tracking technique has been presented, which uses a passive MR marker for needle guidance during prostate biopsies [2]. In this work, the passive tracking approach was combined with a manually steerable, highly flexible arm designed for instrument placement in closed-bore systems. The setup was tested in laser-induced interstitial thermal therapy (LITT) as an advanced minimally invasive technique.

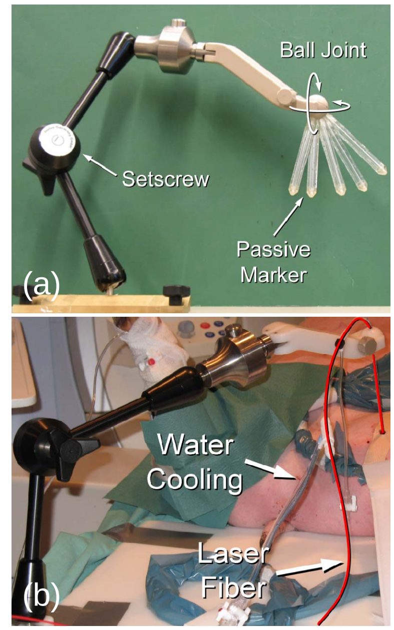

Fig. 1: (a) Flexible arm with passive marker (multiple overlaid) attached to ball joint. (b) Experimental setup for in vivo LITT intervention.

Materials and Methods

In Fig. 1a, the highly flexible arm is shown. This instrument holder (Invivo GmbH, Schwerin, Germany) was developed at Leipzig University Hospital [3] in collaboration with Invivo GmbH. The device can be directly connected to the MR patient table, allows for flexible manual steering within six degrees of freedom, and can be locked with a single setscrew. Its distal end features a plastic connector with a ball joint for instrument attachment.

The automatic tracking technique [2] uses a plastic cylinder (Invivo GmbH, Schwerin, Germany) filled with contrast agent solution (Gd-DTPA/H_2O 1:100) as a passive marker. A phase-only cross correlation algorithm determines the marker position from two tracking FLASH images in real-time. Based on the information of the marker position, a trueFISP imaging slice is automatically aligned parallel to the instrument (e.g. puncture needle) which can be inserted through the central opening of the marker. The technique (TR/TE = 4.5/3.0 ms, FOV: 256×256 mm^2, matrix: 256×256, partial Fourier: 4/8) was implemented on a 1.5 T clinical, whole body MR system (Magnetom Symphony, Siemens Medical Solutions, Erlangen, Germany).

In an *in vivo* (3-month-old, domestic pig) LITT experiment, it was investigated whether the combination of the flexible arm and the automatic tracking technique is suitable for safe and precise instrument guidance. A fiducial LITT target volume was created by injection of 1.5 ml ultrasound gel into the hind leg of the pig at a depth of 4 cm. Next, the LITT applicator (Somatex, Teltow, Germany) was placed in the target volume in several steps (Seldinger technique). At first, the passive marker was attached to the ball joint of the arm (Fig. 1a) and moved manually under real-time guidance until aligned with the target (Fig. 2a,b,c). After alignment, the setscrew was locked and the puncture needle was inserted into the target under real-time imaging. Next, the puncture needle mandrel was replaced by an MR-compatible guide wire under automatic tracking guidance.

After confirmation of the guide wire position, the passive marker and the puncture needle were removed. At fixed position of the arm, a coaxial dilator and an LITT applicator were inserted along the guide wire (the applicator (Fig. 1b) was too large for the passive marker). The final position of the LITT applicator, which provides a water-cooled light guide diffuser, was verified on T_2-weighted images prior to laser irradiation. For thermal ablation, a Nd:YAG laser (mediLas 4060 N, Dornier MedTech, Wessling, Germany) was used (λ = 1.06 µm, P = 20 W, irradiation time: 90 s). MR-thermometry (segmented EPI, 3 parallel slices, TR/TE = 144/15 ms, FOV: 280×280 mm^2, matrix: 128×128, EPI factor: 7, th = 3 mm) was based on the shift of the proton resonance frequency (PRF). The thermal dose was calculated using the approach of cumulative equivalent minutes (CEM) [4]. Post-therapy T_2-weighted images were acquired to estimate the size of the thermally induced lesion.

Results

Alignment of the passive marker and insertion of the puncture needle into the fiducial LITT target was feasible under real-time guidance in less than 5 min. The corresponding slice orientation was automatically adjusted parallel to the passive marker, and thus parallel to the needle trajectory. Fig. 2c shows the final position of the puncture needle successfully perforating the target. The subsequent needle replacement by the guide wire had no effect on the position of the passive marker. Consequently, the imaging slice orientation was not affected. This particular slice position and orientation was maintained for any further MRI investigations as the passive marker had to be withdrawn prior to insertion of the LITT applicator. In Fig. 2d, a T_2-weighted, post-laser therapy MR image is showing the thermal lesion and the final position of the LITT applicator in the target volume which is in excellent agreement with the previous needle position (Fig. 2c). During laser irradiation a maximal temperature increase ΔT of about 35 K (99%-quantile) was measured. Corresponding PRF-temperature maps and thermal dose maps are presented in Fig. 2e,f. The diameter of the thermal lesion was about 20 mm (Fig. 2d), which was consistence with temperature and dose maps.

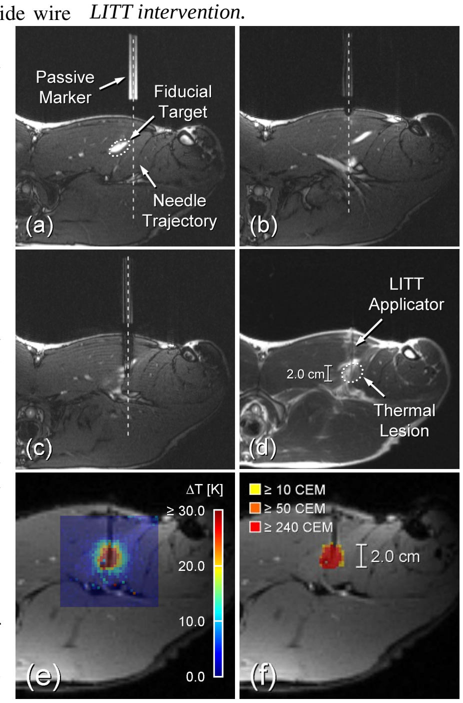

Fig. 2: (a,b) Real-time tracking images during alignment of marker prior to needle insertion. (c) Final needle position after real-time guided alignment. (d) Final applicator position and induced LITT lesion. (e) PRF temperature map. (f) Thermal dose map.

Discussion

Safe and precise instrument guidance was demonstrated with the automatic tracking sequence during insertion of puncture needle and guide wire. The flexible arm allowed for accurate placement of the guide wire and subsequently of the LITT applicator in the target volume. Accurate applicator positioning was additionally confirmed during creation of a well-defined thermal lesion in the target volume. During the entire intervention, no manual and time consuming slice repositioning was needed, and the time needed to insert needle/guide wire was less than 5 min. Even though only slow movements of the passive marker are possible, the technique might lead to shorter procedure times while preserving precise instrument monitoring and is suitable for a wide range of interventions. In a next step, the passive maker will be adapted to the geometry of the LITT applicator to perform the complete intervention under automatic real-time tracking guidance.

References

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