Impact of an advanced patient registration on the experimental targeting accuracy of percutaneous MRI interventions guided by a clinical navigation system

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Introduction/Purpose

Many radiological and surgical interventions are guided by preoperative or intraoperative MRI data that need to be registered to the patient, a task typically accomplished by marker-based methods. This work aims (1) to present a fully automatic technique for fast and simultaneous 3D localization of a larger (>3) number of MR-visible markers and (2) to determine the impact of the marker number used for patient registration on the targeting accuracy. Experiments were performed using a clinical navigation system for percutaneous interventions in a closed-bore MRI environment.

Materials and Methods

The interventional MRI environment and related navigation technique have been described elsewhere [1]. In short, a surgical instrument is tracked by a real time optical digitizer and navigated by views that are reformatted from registered roadmap MRI data (Localite, St. Augustin, Germany). Outside the scanner (1.5-T MRI with closed, 60-cm wide bore, Magnetom Symphony, Siemens), registration is established by a reference board (Fig. 1) with special MR-visible markers (Fig. 2) [2]. These markers were imaged with a standard pulse sequence (TrueFISP, FOV: 300×300 mm^2, slice thickness: 300 mm, three orthogonal projection views, TR/TE: 6.78/2.82 ms, matrix 512×512, flip angle: 0.5°, total TA<11 s) and simultaneously localized in 3D using an existing software tool developed under IDL (ITT Visualization, Boulder, CO) [3] that matches the independently determined peak coordinates of the individual 2D views in 3D (Fig. 3). Euclidean distances between the needle-tip position set according to the navigation display (Fig. 4) and the actual target position (Gd-DOTA-filled, 1-mm wide capillary in a water bath) were measured for 10 different positions of the reference board (mean 3D distances of 76-183 mm to the isocenter) and two different marker numbers *m* (3 and 5).

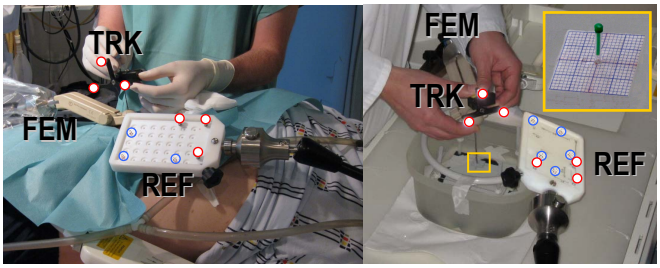

Fig. 1. left: Clinical example of a navigated kidney biopsy (68-y.o. male patient, BMI 35.4 kg/m^2) performed outside the bore of a standard 1.5-T scanner (Magnetom Symphony, Siemens). TRK: instrument tracker, FEM: front-end module for instrument guidance and fixation; REF: reference board with optical (red) and MR markers **right:** Experimental setup of accuracy measurement. A transparent board with a small central hole for the target was supported by four rods, placed in a water-filled cylinder and aligned to the x and z-axes of the scanner. Inset shows capillary (0.8 mm inner diameter) with 2-mm high column of Gd solution that was used as target.

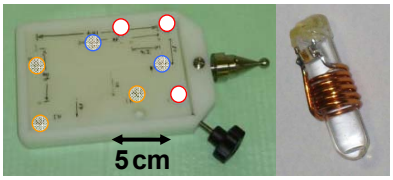

Fig. 2: left: Reference board with 3 (orange) or 5 (orange and blue) MR markers. **right:** Close-up of ICRF coil marker with tuning capacitor around water-filled glass tube (outer diameter 2.0 mm) [2].

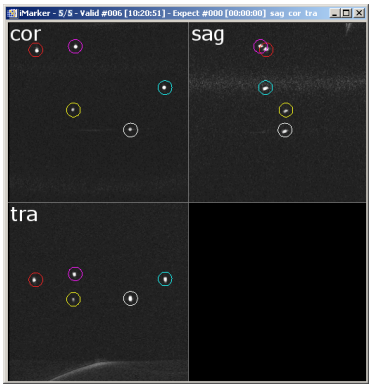

Fig. 3: Simultaneous localization of five MR-visible markers in 3D by matching of independent peak coordinates determined in three orthogonal 2D projection views (Trial #4). Displayed region was zoomed 200% for clarity.

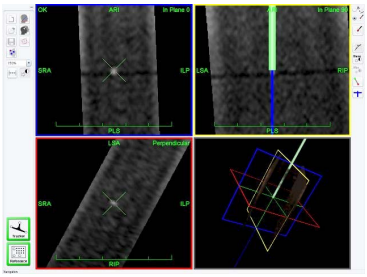

Fig. 4: Screenshot of navigation scene showing virtual needle tip (green crosses) in the target (Gd-filled capillary). Virtual instrument is overlaid in one of the views.

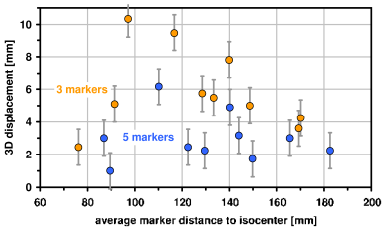

Fig. 5: 3D displacement of needle-tip position as a function of average marker distance from the isocenter for 10 trials and two different marker numbers (m=3 and m=5). The error bars reflect both tolerance of setting (1.0 mm) and reading accuracy (0.5 mm).

m =	5			3		
View / Trial	S	C	T	S	C	T
1	5	5	5	4	3	3
2	6	5	4	4	3	3
3	5	5	6	4	3	4
4	6	5	5	6	3	3
5	4	4	5	3	2	3
6	5	5	4	3	3	3
7	7	5	5	6	3	3
8	5	5	4	3	3	2
9	5	5	5	3	3	3
10	5	5	5	3	3	3

S: sagittal; C: coronal, T: transverse

Tab. 1: Breakdown of number of individual 2D peaks detected in three orthogonal views for actual number of markers *m* of 3 and 5. The predefined sets of intensity-based and shape-based criteria for discrimination of the marker signals [3] were the same for *m*=3 and *m*=5.

Results and Discussion

Sample marker images for *m*=5 are shown in Fig. 3. A screenshot of the navigation scene is given in Fig. 4. Mean needle tip displacements in 3D over all 10 trials were 5.9±2.5 mm (*m*=3) and 3.0±1.5 mm (*m*=5) (p<0.001, Fig. 5). Sensitivities (positive predictive values) for marker detection in the individual 2D views were 97.8% (89.8%) for *m*=3 and 96.0% (96.0%) for *m*=5, respectively. The breakdown of the individual number of 2D peaks detected in the three underlying orthogonal views is summarized in Table 1 for both *m*=3 and *m*=5. Despite missing true and additional false peaks in these views, the clinically relevant 3D localization was successful in 20/20 trials due to the overdetermined measurement of 2D peak coordinates and smart matching [3]. On average, image analysis of five markers took 50 ms longer (430 vs. 380 ms, +13%, p<0.001, Intel Core2 Duo CPU @ 2.66 GHz) than that of three ones. Complete patient registration (acquisition, transfer and analysis of the marker images) took less than 30 s.

Conclusion

The presented technique for simultaneous localization of MR-visible markers was generally fast, accurate and very reliable. The clinical navigation system could be adapted to a larger number of markers without additional efforts. The use of more than three markers for registration may improve the resulting targeting accuracy. A larger number of trials is required to obtain statistically more reliable estimates of success and accuracy. Despite the specific setup used here, these findings are likely to apply to other MR markers and settings as well.

References [1] H. Busse et al., MRM 2010; 64:922. [2] N. Garnov et al., Med Phys 2011; 38:6327. [3] H. Busse et al., JMRI 2007; 26:1087.