MR-Guided Percutaneous Interventions using a Robotic Assistance System: Initial Experiences in a Pig Model

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Introduction

MRI-guided percutaneous interventions with instruments such as needles have so far predominantly been performed in low-field strength MRI systems, where direct access to the patient is possible due to the specific construction of the magnet. Closed-bore high field MRI systems ($B_0 > 1$ T), however, offer higher gradient strengths for faster image frame rates of up to 5-10 images/s, and higher MR signal strengths that reduce the need for time-consuming signal averaging. Unfortunately, in closed-bore systems manipulation of needles, though possible, is challenging, and the precise localization and orientation of the needle can be difficult to image.

In this study an MR-compatible robotic assistance system is used to perform MR-guided needle interventions in a closed-bore MR scanner. In an initial evaluation of the assistance system, pain therapies were performed in an animal model. With the help of the systems robotic arm, a puncture needle was oriented and placed on the skin of the animal. During insertion of the needle, real-time MR images were acquired to control needle progress in the tissue.

Materials and Methods

The pneumatic robotic assistance system InnoMotion (Innomedic GmbH, Herxheim, Germany) is fully MR-compatible and consists of a robot arm which can be manipulated in 6 degrees of freedom [1,2]. The arm is mounted on an arc which is attached to the patient table of the MR system (Fig. 1). Initially, the assistance system is co-referenced with the MR scanner (1.5 T Siemens Magnetom Symphony, Erlangen, Germany) using the laser positioning system, which assures that MR scanner and robot use identical coordinate systems.

For the animal experiments four 3-month old domestic pigs were used. The anaesthetized animal was placed prone on the patient table and a loop coil was fixed around the projected needle insertion point near the animals' spine. After the acquisition of T1- and T2-weighted planning images, a needle trajectory was defined on the graphical user interface of the assistance system's control computer. The robot arm then automatically moved the needle to the insertion point and oriented the needle holder accordingly.

A 20 G MR-compatible puncture needle (DAUM, Schwerin, Germany) was then manually inserted into the animal. Therefore, the interventionalist reached into the magnet from the rear opening, where an MR-compatible in-room monitor was placed. To visualize the needle during insertion, fast trueFISP pulse sequences (TR / TE / α / TA = 4.4 ms / 2.2 ms / 70° / 0.7 s) were used. Once the needle approached the desired target structure (nerve root, plexus coeliacus), insertion was stopped and conventional spin echo images were acquired for verification. Thereafter, a test bolus of contrast agent solution (NaCl/GdDTPA : 100 / 1) was injected under real-time FLASH imaging (TR / TE / α / TA = 4.3 ms / 1.8 ms / 20° / 0.5-0.8 s) to visualize the bolus distribution volume. Finally, a therapeutic injection of 10-25 ml Mepivacainhydrochloride (Scandicain®1%, AstraZeneca, Germany) was performed, where, again, contrast agent served to control the injection.

Results and Discussion

Figure 2 shows the planning image of a plexus coeliacus injection together with selected real-time images during needle insertion and contrast agent injection. In this case, the robotic assistance system could realize the insertion point with a precision of about 1 mm in the image plane. In some cases deviations from the planned trajectory could be seen during needle advancement, which were caused by bending of the thin needle. With the help of real-time MR imaging needle bending could be corrected manually by careful rotation of the needle.

In the T1-weighted FLASH images the injection could be monitored, which helped especially in those cases, where anatomical structures such as bone obstructed the injection. The use of the robotic assistance system allowed for reliable positioning of the needle in the MR magnet. Even at positions near the iso-center, where manipulation of a needle is difficult due to the limited space in the magnet, the needle could safely be advanced close to vital structures such as the abdominal aorta.

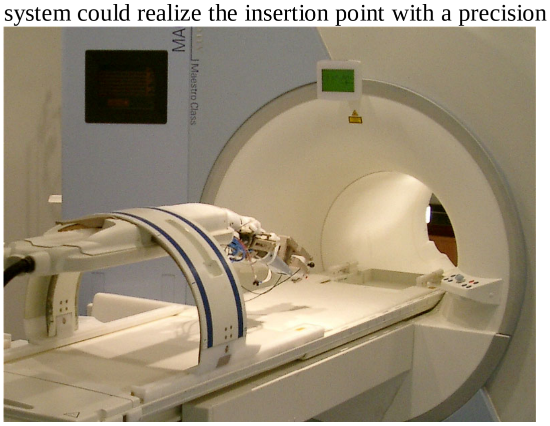

Fig. 1: Robotic assistance system on the patient table of a clinical 1.5 T whole body MR system. The robot arm slides on an arc which makes efficient use of the available space in the MR bore hole. The distal instrument holder is equipped with passive markers for localization purposes.

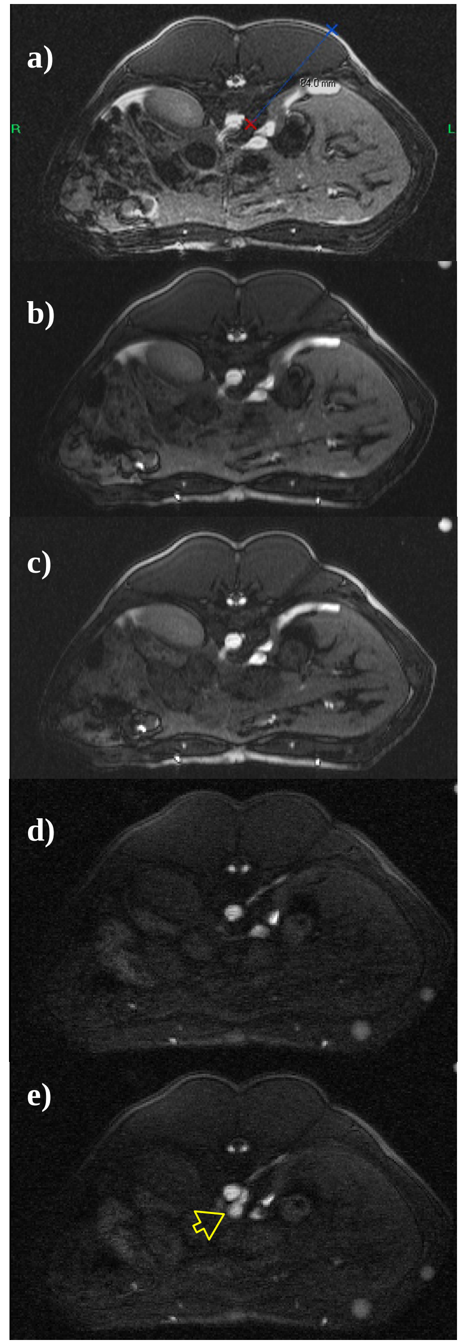

Fig 2. a) Trajectory planning image with insertion (blue cross) and target point (red cross) near the plexus coeliacus. During needle insertion (b,c) trueFISP images were acquired, while T1-weighted fast FLASH images (d,e) were used to visualize contrast agent accumulation (arrow).

References

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