A Body-Mounted MRI-Compatible Robot for Needle Interventions such as Shoulder Arthrography

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Target audience

MRI-guided procedures for percutaneous interventions are gradually increasing, as the MRI environment provides excellent soft tissue resolution with no ionizing radiation. At our pediatric hospital, we perform more MRI scans yearly than CT scans, due partially to the desire to minimize radiation exposure in the pediatric population. As part of a program to introduce MRI-guided procedures at our hospital, we are developing an MRI compatible robot for needle placement, starting with shoulder arthrography as an initial clinical application.

Arthrography is the evaluation of joint condition using imaging modalities such as fluoroscopy and MRI. Among American children ages 5-14, there is on average over one sports-related injury during this period, with a significant portion involving internal derangements of shoulders, hips, wrists, and other joints [1]. When there is concern for derangement of articular labral structures, as may be seen with these injuries or untreated congenital joint dysplasias, magnetic resonance (MR) arthrography is the modality of choice for evaluation of the labrum, articular cartilage, and other internal structures of the joint in children. Currently, this test requires two separate stages, an intra-articular contrast injection typically guided by fluoroscopy followed by an MRI.

Purpose

The current two-step workflow can result in anxiety for the patient, prolonged sedation time when sedation is needed for younger patients, radiation exposure from the fluoroscopic imaging, and may increase cost due to the use of both the fluoroscopy and MRI suite. Our goal therefore is to develop an MRI-compatible shoulder arthrography robot to enable one-stage procedures in the MRI environment. This robot will also provide a stable guide for the needle and may reduce the number of needle passes by providing a steady and precise needle holder. The latter will reduce trauma to patient and reduce the burden to the physician. Needle insertion is performed manually by the radiologist to minimize risk and ease the regulatory considerations.

Methods

A 4 degree of freedom patient mounted robot was developed using Solidworks mechanical design software and an Object 500 rapid prototyping machine. The robot can manipulate the needle in 2 transitional and 2 rotational directions. Two versions of the robot have been developed to date. The first version is shown in Figure 1 along with the degrees of freedom. The second version has just been completed and is shown in Figure 2. In this second version we aimed to reduce backlash and friction to increase the positioning accuracy of the system. In the new design, a closed plastic linear bearing with hard anodized aluminum coating (bore size: 8mm, SDP/SI corp., NY, USA) sliding on low friction Teflon rods, and Ceramic ball bearing (Boca Bearing Inc., FL, US), were used for the third and fourth links, respectively.

Results

The new version was 3D printed using Verowhite material. MRI-compatible piezo-motors, and MRI-compatible encoders were used for actuation and measurement. As shown in Fig. 2, two tube fiducials (ref. 121, Beekley Corp., CT, US) were embedded in the robot. Using these tube fiducials, we can detect two of the robot's coordinate system axes in the MRI image. The robot remote center of motion can then detected in the MRI image by finding the intersection of the two tube fiducials. Using this information, the robot/image transformation matrix would be available for targeting any area of interest in MRI image space [3]. After performing the robot to image registration, the control system will move the needle tip to the skin entry point and align the needle with the target path based on the entry and target points selected by the radiologist on the MRI image.

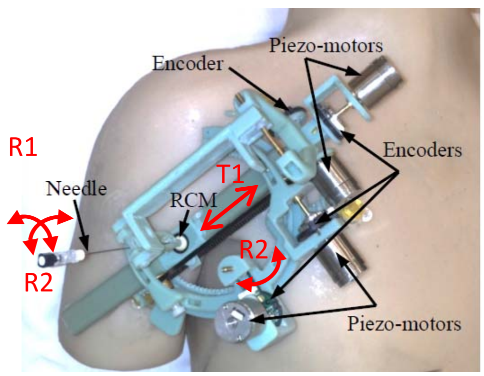

Fig. 1) MRI-compatible robot on shoulder of anthropomorphic phantom. Figure shows three rotational degrees of freedom (R1, R2, R3) and one translational degree of freedom, along with the needle guide and MRI-compatible motors [2].

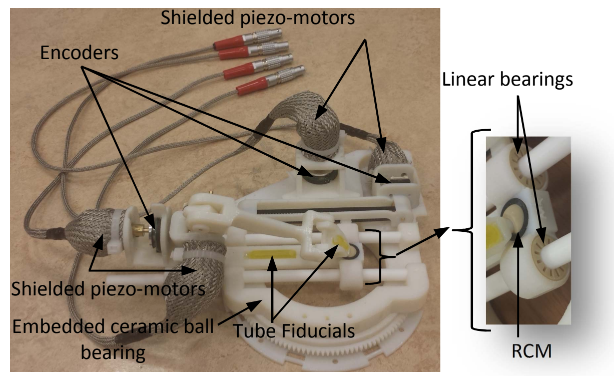

Fig. 2) New MRI-compatible robot with shielded motors and cables. Tube fiducials are embedded in the design for Robot/image registration.

Discussion and Conclusion

An MRI compatible body-mounted robot has been developed for needle manipulation in the magnet. This robot is part of a larger program in MRI-guided interventions at our pediatric hospital. Once MRI safety tests and robot accuracy tests are completed, we plan to apply for regulatory and IRB approval for a clinical trial of MRI-guided shoulder arthrography using the robot.

References

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