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MRI Image Overlay: Applications to Arthrography Needle Insertion

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Abstract.
Magnetic Resonance Imaging (MRI) has unmatched potential for planning, guiding, monitoring and controlling interventions. MR arthrography (MRA) is the imaging gold standard to assess small ligament and fibrocartilage injury in joints. In contemporary practice, MRA consists of two consecutive sessions: 1) an interventional session where a needle is driven to the joint space and gadolinium contrast is injected under fluoroscopy or CT guidance. 2) A diagnostic MRI imaging session to visualize the distribution of contrast inside the joint space and evaluate the condition of the joint. Our approach to MRA is to eliminate the separate radiologically guided needle insertion and contrast injection procedure by performing those tasks on conventional high-field closed MRI scanners. We propose a 2D augmented reality image overlay device to guide needle insertion procedures. This approach makes diagnostic high-field magnets available for interventions without a complex and expensive engineering entourage.

Keywords. MRI, Image Overlay, Augmented Reality, Arthrography, Percutaneous Therapy

1. Introduction

Magnetic Resonance Imaging (MRI) is superior to all other imaging modalities in detecting diseases and pathologic tissue in the human body. Thus MRI has an unmatched potential for guiding, monitoring and controlling therapy [1]. In needle biopsies, the high sensitivity of MRI in detecting lesions allows good visualization of the pathology, and its superior soft tissue contrast helps to avoid sensitive structures in the puncture route [2]. Advances in magnet design and magnetic resonance (MR) system technology have contributed to increased interest in interventional MRI; minimally invasive diagnostic and therapeutic image-based interventions can now be performed under near real-time MRI guidance [3].

At the same time, MRI presents challenges; perhaps the most daunting problem is access to the patient inside the magnet. Open magnets offer good access, but they are built with a decrease in field strength and homogeneity, thereby offering a lesser image quality. Short magnets may provide access in certain procedures, but performing an intervention inside the bore remains inconvenient. Specially designed robots can work in the bore of closed [4] and open [5] magnets, but are unlikely to be practical in the foreseeable future.

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We propose a 2D augmented reality image overlay device similar to those in [6,8] to guide needle insertion procedures. This approach can make diagnostic high-field magnets available for interventions without involving prohibitively complex and expensive engineering entourage. The prime objective of our research is providing clinically sufficient accuracy while limiting faulty needle insertion attempts.

While routine noncontrast MRI has a high sensitivity and specificity for most ligamentous and tendon injuries, MR arthrography (MRA) is the imaging gold standard to assess small ligament and fibrocartilage injury in joints, particularly if there has been prior surgery, in the assessment of re-injuries to these intra-articular structures. Direct MRA (DMRA), where contrast is directly injected into the joint, is excellently tolerated and in efficacy is comparable to joint arthroscopy, the absolute gold standard in the evaluation of joints [9]. In contemporary practice, DMRA consists of two consecutive sessions. First a needle is driven to the joint space and gadolinium contrast is injected into the joint. This session is usually performed with radiological image guidance, typically under fluoroscopy or sometimes under CT guidance [10]; attempts at using a functionally equivalent CT Image Overlay device for arthrography needle guidance have been successful [6], and are shown in Fig. 1. Following contrast injection, a diagnostic MRI session is scheduled to visualize the distribution of contrast inside the joint space and evaluate the condition of the joint. Thus current direct MRA comprises two distinct procedures: a needle injection intervention and a diagnostic MRI session before the contrast washes out. Such a tightly sequenced double-procedure makes contemporary DMRA exceedingly expensive, resource intensive, and difficult to schedule, which together make this procedure unavailable in many non-specialized centers. To address this problem, [11] reports the use of an open MRI scanner configuration where needle insertion and contrast injection are performed directly inside scanner.

Our approach to direct MRA is to eliminate the separate radiologically guided needle insertion and contrast injection procedure from the procedure by performing those tasks right on conventional high-field closed MRI scanner with the MR Image Overlay technique. This promises to reduce the inconvenience for the patient and logistical difficulties associated with current direct MRA of large joints, in a manner that is practical and affordable for average care facilities that own conventional MRI scanners.

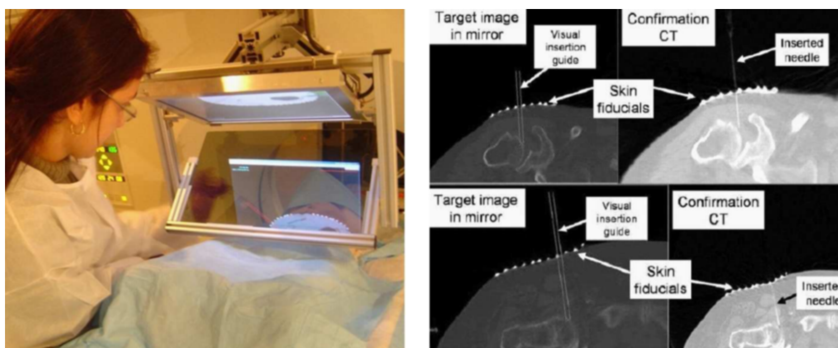

Figure 1. Functionally equivalent 2D image overlay device for CT scanners in a porcine trial (left) and preliminary joint arthrography results in human cadaver under CT Image Overlay guidance (right)

2. System Concept

The basic concept of the 2D image overlay is shown in Fig. 2 (left). The image overlay system shows axial MRI images on an LCD display, which are reflected back to the user from a semi-transparent mirror. Looking though the mirror, the anatomical image appears to be floating in the appropriate location in the body. Users from all viewpoints can share the same scene without any auxiliary tracking. The intersection of the mirror and display planes are marked with a laser plane parallel to the axial imaging plane. The laser is used for constraining the needle to the plane of the overlaid image while a virtual needle guide is displayed on the overlaid MR image controls in-plane rotation and depth.

The system creates the impression as if the image was inside the body in the correct pose and magnification, giving the physician a planar “tomographic vision.” This technique can also be characterized as an in situ visualization tool, where the medical image is rendered right in the context of the procedure, spatially registered with the physical body. Perhaps the most promising aspect of image overlay is that the physician can execute the procedure without turning his/her attention away from the patient, and execute the same series of motions and actions as in conventional freehand procedures.

In most needle placement procedures, after the entry point is selected, three degrees-of-freedom (DOF) motion of the needle needs to be controlled. In this case, the physician uses the overlay image to control the in-plane insertion angle (first DOF), while holding the needle in the axial plane marked by the overlay device’s laser light (second DOF). The insertion depth (third DOF) is controlled with a virtual depth gauge drawn on the overlay image. The advantages of 2D image overlay are numerous in comparison to other virtual reality or display augmentation methods reviewed earlier. Most significantly, 2D image overlay provides optically stable image without auxiliary tracking instrumentation and it requires only a simple alignment that does not need to be repeated for each patient. Although real-time imaging can not be used in the current design since the patient must be translated out of the bore for insertion, the overlay system assists the physician in detecting target motion and allows for gating the insertion with the use of skin fiducials.

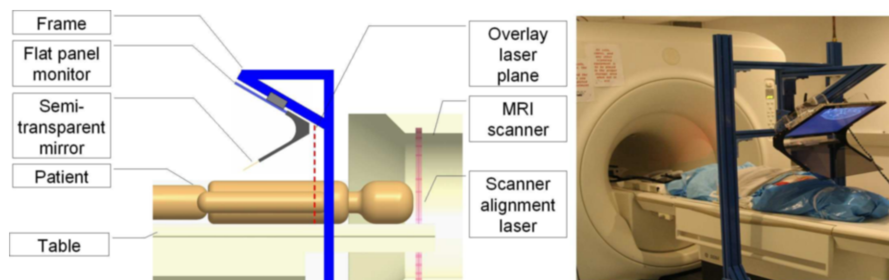

Figure 2. System concept of 2D image overlay device (left) and MRI image overlay device layout (right)

3. Materials and Methods

The MR overlay system is realized by mounting an MR-compatible LCD screen that is housed in an acrylic shell with an attached semi-transparent mirror to a modular extruded fiberglass frame as in Fig. 2 (right). The freestanding frame arches over the scanner bed and allows for images to be displayed on a patient when the encoded couch is translated out of the bore by a known amount. To maintain the goal of a very practical and low cost system, an off-the-shelf 19" LCD display was retrofitted to be MRI safe and RF shielded.

3.1. Calibration

Calibration is similar to that of the CT Image Overlay described in [6]. Calibration is accomplished in two steps: 1) make the overlay image coincide with the plane of the overlay's outer laser plane, and 2) determine the in-plane transformation between the overlaid MR image and the view of the physical object in the mirror. We fabricated a calibration phantom of perpendicular polycarbonate fiducial board with an embedded asymmetric set of 7mm diameter and 15mm long tubes of MR contrasts agent (Beekley MR-Spots, Beekley Corp., Bristol, CT). The calibration phantom also consists of a gel-filled box with targets embedded for validation as shown in Fig. 3(a).

The initial step of calibration is performed in the manufacture of the device to guarantee that the angle between the laser plane and the mirror and the mirror and the LCD are the same (60°). The laser is adjusted such that it passes though the intersection of the LCD and mirror planes while maintaining the correct angle. In the scanner room during an experiment, to ensure parallelism of the image plane, the calibration phantom is manually adjusted on the MR table until the scanner's axial laser plane sweeps the front face of the fiducial board and the overlay's laser does the same when the bed is translated out. The phantom is then translated into the scanner to take a single axial slice though the fiducial pattern; this image is then rendered on the overlay.

The first step of the in-plane registration process is image scaling. The overlay image must appear in correct size in the mirror, but there is variable linear scaling between the MR image and displayed image. The pixel size of the display is constant and it is either known from the manufacturer's specification or its measurement is trivial. The pixel size of the MR image is calculated as the ratio between the field of view (in millimeters) and image size (in pixel). The second step of in-plane registration is to determine a 3-DOF rigid body transformation. An MR image of the fiducial board and rendered on the overlay display, as seen in Fig. 3(a). The in-plane rotation and translation of the phantom's image is adjusted until each fiducial peg coincides with its mark in the image.

3.2. Workflow

Fiducials are first placed on the skin (Beekley MR-Spots) in the region of interest and are aligned with the axial direction. The subject is positioned and a small stack of MRI axial slices with a slice thickness appropriate for the given clinical application is acquired. A single MR slice is selected as the insertion plane, the patient is translated so that the appropriate slice lies in the scanner's alignment laser, and the appropriate entry point is marked on the skin with hollow IZI multi-modality markers (IZI Corp., Baltimore, MD). A single MRI image of this slice is then reacquired with the entry point fiducial in place. The image is transferred directly in DICOM format to the planning and control software implemented on a stand-alone PC. The computer is used to mark the target and entry points, draw a visual guide along the trajectory of insertion and mark the depth of insertion. This image is rendered on the Image Overlay device as shown in Fig. 3(b) and the patient is translated out so that the entry point fiducial lies in the laser plane of the overlay. The physician holds the needle at the entry point behind the mirror and adjusts the angle to the virtual needle guide while holding the needle in the plane of the laser (Fig. 3(c)). The Beekley MR-Spots and IZI fiducial are visible on both the patient and in the overlaid image; coincidence between the corresponding marks indicate correct

calibration and entry point alignment respectively. This feature is particularly important for quality assurance, especially in applications when the target anatomy is prone to motion due to respiration or mechanical forces. The skin fiducials can be used to gate or synchronize the needle insertion to the respiratory cycle. After the needle is inserted, a confirmation image is acquired (Fig. 3(d)).

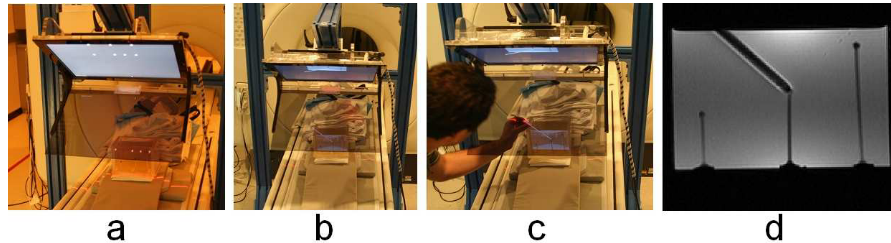

Figure 3. Workflow demonstrated in a phantom experiment: calibration(a), overlaid guide(b), needle insertion(c) and confirmation(d).

4. Results

The MR overlay system as shown in Fig. 2 (right) has been successfully tested in 1.5T and 3T scanners for compatibility. Experiments with a functionally equivalent CT guided version of the device as shown in Fig. 1 (left), a precursor to the current innovation [6,7], have very promising results. In the target application of joint arthrography, four trials were performed under CT overlay guidance. In all trials, the joint space was accessed successfully on the first insertion attempt as shown in Fig. 1 (right).

With the MRI Image Overlay, preliminary experiments in a 1.5T GE Signa Excite MRI scanner have so far been promising. The image overlay being applied to MRI-guided shoulder arthrography in a post-euthenasia porcine trial is shown in Fig. 4. In this experiment, an 18 gauge by 10cm MR-compatible diamond-tip needle (EZ-EM, Inc., Lake Success, NY) was successfully inserted into the joint space of the right shoulder. Contrast was injected, but distribution was not uniform due to the stiff tissue in the porcine cadaver. Statistical analysis of the insertion accuracy will be performed after more trials have been completed.

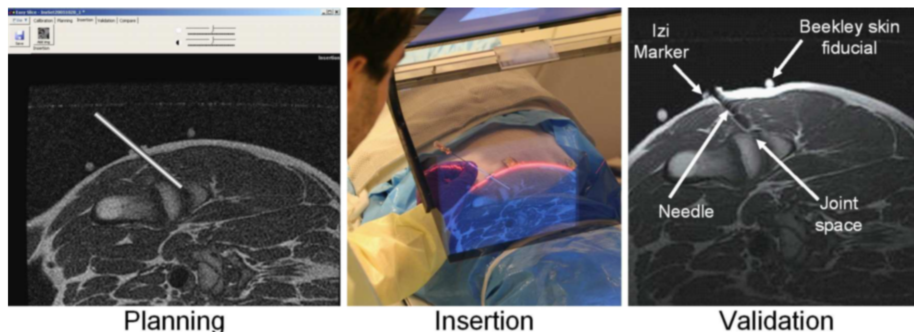

Figure 4. MRI Overlay guided direct MR arthrography in porcine trials. Targeting image with overlaid guide (left) insertion under overlay guidance (center) and confirmation image using an external imaging coil (right)

5. Conclusion

Experiments with the MRI Image Overlay device are underway and have so far shown great promise. Detailed, statistically significant accuracy trials have not yet been performed. However, since an equivalent test of the CT overlay has been successful in cadaver and ventilated porcine trials in [6] and [7], it is expected that similarly excellent results will be achieved in forthcoming MRA trials with the MRI overlay device. Animal and cadaver studies currently in progress are expected to prove the hypothesis that MR overlay will allow for accurate needle placement while significantly simplifying and speeding up the MRA procedure by eliminating the need for a separate, traditional radiographically (fluoroscopy or CT) guided contrast injection. The next generation of the device will be a smaller version that can be set up in a short bore magnet where the patient will not be shuttled in and out and we will enjoy near real-time imaging update.

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References

[1] Jolesz FA. : Interventional and intraoperative MRI: A general overview of the field, *J Magn Reson Imaging* **8(1)** (1998), 3–7.

[2] Lenchik L, Dovgan DJ and Kier R : CT of the iliopsoas compartment: value in differentiating tumor, abscess, and hematoma, *Am J Roentgenol* **162** (1994) 83–86.

[3] Lewin JS, Nour SG and Duerk JL : Magnetic resonance image-guided biopsy and aspiration. *Top Magn Reson Imaging* **11(3)** (2000) 173–183.

[4] Krieger A, Susil RC, Menard C, Coleman JA, Fichtinger G, Atalar E and Whitcomb LL : Design of A Novel MRI Compatible Manipulator for Image Guided Prostate Intervention, *IEEE Trans. Biomed. Eng.* **52(2)** (2005) 306–313.

[5] DiMaio SP, Pieper S, Chinzei K, Fichtinger G and Kikinis R : Robot assisted percutaneous intervention in open-MRI, *5th Interventional MRI Symposium* (2004) 155.

[6] Fichtinger G, Deguet A, Masamune K, Fischer G, Balogh E, Mathieu H, Taylor RH, SJ Zinreich and Fayad LM : Image Overlay Guidance for Needle Insertions in CT Scanner, *IEEE Transactions on Biomedical Engineering* **52** (2005), 1415–1424.

[7] Fichtinger G, Deguet A, Fischer G, Balogh E, Masamune K, Taylor RH, Fayad LM and SJ Zinreich : CT Image Overlay for Percutaneous Needle Insertions, *Journal of Computer Assisted Surgery* **1(4)** (2005).

[8] Stetten GD, Chib VS.: Overlaying ultrasonographic images on direct vision, *J Ultrasound Med.* **20** (2001), 235–240.

[9] Schulte-Altedorneburg G, Gebhard M, Wohlgemuth WA, Fischer W, Zentner J, Wegener R, Balzer T, Bohndorf K. : MR arthrography: pharmacology, efficacy and safety in clinical trials, *Skeletal Radiology* **32** (2003), 1–12.

[10] Binkert CA, Verdun FR, Zanetti M, Pfirrmann CW and Hodler J. : CT arthrography of the glenohumeral joint: CT fluoroscopy versus conventional CT and fluoroscopy–comparison of image-guidance techniques, *Radiology* **229(1)** (2003) 153–158.

[11] Hilfiker PR, Weishaupt D, Schmid M, Dubno B, Hodler J and Debatin JF : Real-time MR-guided joint puncture and arthrography, *Eur Radiol.* **9(2)** (1999) 201–204.