

Evaluation of MR Image Overlay for Spinal Interventions

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Introduction:

MR guidance is being used for a host of spine injections and pain management procedures such as discography, periradicular nerve blocks, sympathetic blocks, celiac plexus blocks, sacroiliac joint injections, and facet (zygoapophysial) joint neurotomies. MR imaging provides exceptional depiction of the patho-anatomy in the vertebral column and intervertebral discs and also provides superb visualization of spinal nerves and exiting nerves structures. As a single modality, MR facilitates diagnosis and treatment of degenerative disease of the spine. Disc access is used for diagnostic (discography or aspiration for suspected infection) and therapeutic purposes. Vertebral access is important for biopsy, tumor ablation and augmentation. MR imaging is very sensitive in detecting these tumors, and it is conceivable that MR-guidance could play a major role in the focal ablative treatment of bone involvement from these entities. Imaging is used in five separate and distinct ways: planning, targeting, monitoring, controlling, and assessing treatment response [1].

In all of these cases, placing a needle at a precise location in the body as prescribed on the anatomical images is paramount. We have developed a 2D augmented reality image overlay device to guide needle insertion, thereby making diagnostic high-field magnets available for interventions without a complex engineering entourage. The device consists of an LCD screen that projects an MR image onto a semi-transparent mirror, which appears to be floating inside the patient with correct size and position. This optically stable image provides the physician with two-dimensional tomographic vision to guide needle placement procedures from any view point. We present the use of this image overlay system for spinal interventions and an independent validation of the needle placement accuracy by using electromagnetic tracking in a functionally equivalent configuration of the device in the laboratory. The validation system provides a more significant measure of accuracy than that which we can obtain from MR images taken after each insertion attempt, due to paramagnetic artifact caused by the needle and lack of distinct targets; further, cost of scanner time makes large experiments with statistically significant data infeasible.

Materials/Methods:

The MRI image overlay system is described in detail in [2]. It consists of an MR-compatible LCD screen that is housed in an acrylic shell and rigidly attached to a semi-transparent mirror and a laser line generator. This overlay unit is attached to a modular extruded fiberglass frame. The freestanding frame arches over the scanner bed as in Fig. 1(a-b) and allows for transverse images to be displayed on a patient in the correct position. The encoded couch is translated out of the bore by a known amount, so that the plane of insertion coincides with the plane of the overlay image marked by the laser. The image alignment process is performed directly on the patient by aligning the MR image with skin fiducial markers, thereby determining the in-plane transformation between the overlaid MR image and the patient.

A laboratory-equivalent configuration of the device is shown in Fig. 1(c-d); this configuration uses the same overlay unit mounted to a tabletop fiberglass frame. Electromagnetic (EM) tracking is utilized to provide the position of the tip and orientation of the shaft of an instrumented needle. All necessary components must be registered with one another in order to track the needle with respect to the preoperative plan generated on the MR images. The components of the system include: the Aurora EM Tracker (Northern Digital, Waterloo, Ontario), a tracked needle, the tracked phantom, the MR images used for pre-operative planning and the AR guidance system. Tracking data is recorded and superimposed on the treatment plan after the procedure is complete; tracker information is not shown during the procedure to avoid biased results. A human cadaver lumbar spine phantom was designed to mimic the anatomy of a patient and aid in the process of registration. Lumbar vertebrae in proper alignment with simulated intravertebral discs are embedded into layered tissue mimicking gel (Corbin SimTest, White City, OR) of two different densities emulating fat and muscle tissue. The gel phantom with lumbar spine is placed into an acrylic enclosure which was laser-cut with 24 different pivot points spread precisely over four sides for rigid-body registration. Fiducial markers (Beekley MR-Spots, Bristol, CT) were placed on the phantom in precisely positioned laser-cut slots. The markers were placed in a 'Z' shape pattern on three sides allowing for automatic registration between anatomical images and the phantom. A full set of axial MR images with a spacing of 3mm were taken with the phantom and used both for initial trials and the laboratory analysis.

Experiments and Results:

To demonstrate the workflow, four needle insertions were performed in a clinical MRI environment as in Fig. 1 (b). As expected, accuracy could not be assessed due to large artifacts as shown in Fig. 2(a). In the validation testbed, the measured needle trajectories were graphically overlaid on the plan and targeting MR image as shown in Fig. 2(b). Sixty (60) insertions were performed by an experienced radiologist as shown in Fig. 1(c) while the needle trajectory and endpoint errors in position and orientation were measured. Initial analysis revealed a positive correlation with direct validation performed using fluoroscopy described in [3]. Mean position error with the image overlay was 3.5mm with a standard deviation (SD) of 2mm in the image plane and the error normal to the image plane was 1.5mm with a SD of 1.1mm. The orientation error had a mean value of 2.1° with an SD of 1.2° .

Discussion:

Initial trials with the system support the hypothesis that the MRI image overlay can aid in needle placement. The system provides for more accurate results with fewer insertion attempts as compared with traditional freehand and other techniques as described in [3], thereby reducing the amount of time required for the procedure. Human cadaver trials are currently underway to investigate the safety and robustness of the system for spinal interventions and clinical trials are planned for the near future. Partial funding for this project was provided by NSF Engineering Research Center Grant #EEC-97-31478, Siemens Corporate Research and William R. Kenan, Jr. Fund.

References:

- [1] Jolesz FA, Silverman SG. Interventional magnetic resonance therapy. *Semin Interv Radiol* 1995; 12:20-27
- [2] Fischer GS, Deguet A, Schlattman D, Taylor RH, Fayad L, Zinreich SJ, Fichtinger G. MRI image overlay: applications to arthrography needle insertion, *Studies in health technology and informatics - Medicine Meets Virtual Reality 14: Accelerating Change in Healthcare: Next Medical Toolkit*, Vol 119, pp 150-155, 2006.
- [3] Fischer GS, Wamsley C, Zinreich SJ, and Fichtinger G, MRI Guided Needle Insertion - Comparison of Four Techniques, *Society for Interventional Radiology 31st Annual Scientific Meeting - SIR 2006*, Toronto, Canada, March 2006

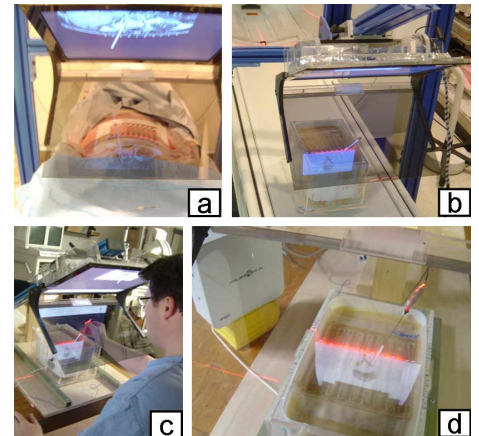


Figure 1: MRI image overlay system in cadaver trial (a) and phantom trial (b). Trials in equivalent laboratory configuration (c), and close-up of overlaid image with EM tracker and tracked needle (d).

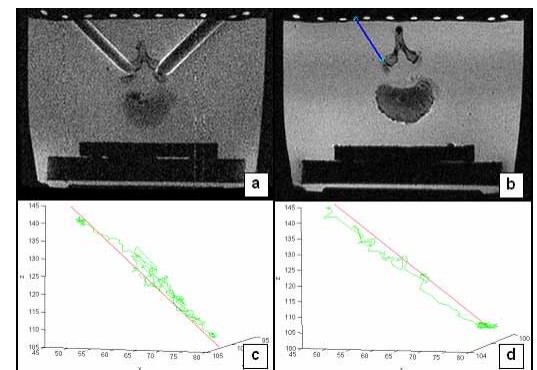


Figure 2: Typical results from an MR image (a) and a tracked path overlaid on the plan (b). Logged trajectory showing multiple corrections (c) and direct path (d).