Laser-assisted MRI-guided needle insertion and comparison of techniques

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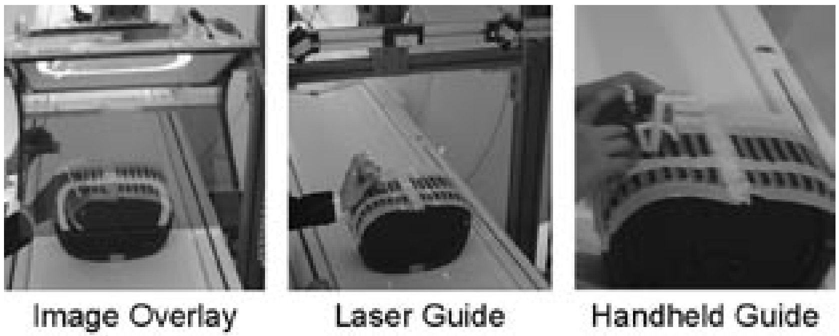
Introduction: Magnetic Resonance Imaging (MRI) offers unmatched potential for guiding interventional procedures [1]. However, in order for needle placement assistance mechanisms for these procedures to take hold, their setup and use must be straightforward and avoid lengthening the procedure. We propose a biplane laser guide that uses the intersection of calibrated laser planes to mark the intended needle trajectory. A comparison of this system to three other needle insertion techniques (including conventional freehand as a control) is performed.

Methods: The proposed biplane laser guide consists of three main components: 1) a freestanding frame which arches over the patient couch and provides a track for translation of the lasers in the left-right direction, 2) a laser line generator that provides a laser plane parallel to the transverse imaging plane of the scanner, and 3) a second laser line generator attached to a manual rotation stage that generates a laser plane at a given angle off the vertical sagittal imaging plane. The intersection between the transverse and parasagittal laser planes defines the needle's trajectory. Bilateral needle insertions are often required; therefore, two such parasagittal lasers with angle guides are attached to the horizontal rail. Conceptually similar systems for use with CT imaging have been presented previously [2, 3] and found to be superior to the unassisted freehand technique, but laser guidance has not been investigated in the context of MRI.

The workflow is as follows: A fiducial consisting of a set of parallel contrast-filled columns (Invivo TargoGrid) is first placed on the skin in the region of interest such that the columns are oriented along the axis of the scanner. A set of transverse MR images are acquired, and a single slice is selected as the insertion plane. The clinician selects the insertion and target points on the scanner console, and the needle depth and off-vertical angle are calculated. The patient is translated out of the bore so that the insertion plane lies in the laser guide's transverse laser plane. The adjustable angle guide is set to the specified angle and translated along the rail until the crosshair generated at the intersection of the two lasers is coincident with the percutaneous entry point. The physician places the needle tip at the entry point and aligns the shaft such that a crosshair generated by the intersection of the lasers is present on the head of the needle. Finally, the physician inserts the needle to the specified depth while maintaining alignment under the laser crosshair.

Four manual needle insertion techniques were compared: 1) image overlay that projects an MR image and virtual needle guide on the patient [4], 2) biplane laser as described above, 3) handheld protractor with pre-angled guide sleeve, and 4) conventional freehand needle insertion. All techniques feature translating patient out of the scanner for insertion, skin fiducials to determine puncture point, and manual needle placement in laser-marked transverse plane. All four are equivalent in controlling out-of-plane angle and depth; therefore, these aspects were not evaluated. Two series of experiments were conducted with 1.5T GE Signa scanner and 18G MR-compatible beveled needles (E-Z-EM Inc.). The first test used an abdominal phantom (CIRS Inc.) where four needle insertions were performed with each technique. In this test, the procedure was performed on the MRI scanner and MRI-based validation was used. The second test used a phantom filled with two different stiffness layers of tissue-equivalent gel and five 4mm plastic targets, and covered with neoprene skin. This test was performed based on MR images, but conducted on an equivalent configuration of the devices in a laboratory setting. A total of thirty insertions were performed for each technique; C-arm fluoroscopy was used to determine in-plane tip position error and angular error.

Results: The first test served as a proof-of-concept for all four techniques; all insertions were visually successful, but needle artifact and lack of distinct targets made quantitative measurement inconclusive. The second test served as a quantitative comparison of the four techniques. Technique made a significant difference in tip position error (p=0.015) and angle error (p=0.053). With a 75% confidence interval, biplane laser and image overlay provide for better tip placement accuracy than the other techniques. With an 80% confidence interval, biplane laser and image overlay have better angular accuracy than the other techniques. In terms of angular and positional accuracies, no significant difference was found between the laser guide and image overlay.



Comparison of three assisted needle placement techniques for use with MRI

Discussion: Enhanced needle insertion techniques appear to provide substantial benefit over conventional needle insertion. The biplane laser guide produces significantly better accuracy and repeatability that the freehand technique. In this relatively straightforward phantom experiment, the biplane laser and the more complex image overlay performed similarly. For cases where it is unnecessary to see the target anatomy, the biplane laser helps to make diagnostic high-field magnets available for interventions without involving prohibitively complex and expensive engineering entourage. However, when visualization of the target anatomy is preferred, such as when performing needle placement in the joints or other musculoskeletal targets, the image overlay may provide significant benefits over the laser guide. Funding provided by Siemens Corporate Research and NSF EEC-9731478.

References

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