Improved Workflow for Freehand MR-Guided Percutaneous Needle Interventions: Methods and Validation

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Introduction: Long thought to be an ideal modality for guiding percutaneous needle interventions [1] such as biopsies, sclerotherapies, targeted drug deliveries, and thermal ablations, MR guided procedures are still mainly performed at tertiary care centers. A primary barrier to more widespread adoption is the complexity of the current interventional MRI workflow. Although stereotactic guidance systems exist, MR-guided percutaneous needle interventions are usually performed using the freehand approach [2-6]. The three key workflow steps of freehand needle interventions are *trajectory planning*, *skin entry point localization* and *slice alignment* for continuous needle visualization during placement. Each step presents significant challenges to the physician and the technician. This study presents software-based methods designed to simplify the workflow steps.

Methods:

Trajectory Planning: A rapid trajectory planning tool (Fig. 1) was developed capable of displaying MRI datasets using multiplanar reformatting (MPR), maximum intensity projection (MIP) and volume rendering. Multiple trajectories can be defined in any arbitrary orientation by selecting appropriate entry and target points in any MPR plane. Moreover, a strategy was developed to automatically align MPR planes such that two are along the trajectory orthogonal to each other and the third is orthogonal to the trajectory at the target point. This configuration is favorable for reviewing the trajectory path to ensure vital structures are not harmed during device insertion.

Skin entry point localization: Typically, the skin entry point is found using a fingertip or water-filled syringe under continuous real-time imaging [2-6]. A more precise and intuitive method was developed that uses the built-in landmark laser of the MR scanner to identify the prescribed entry point on the subject's skin. Superior-inferior localization is performed by moving the MR scanner table such that the laser delineates the slice in which the prescribed entry point lies. Lateral localization is determined by measuring the L-R offset of the planned entry point from the laser cross hairs by using an MR-compatible measuring tape. Both the required table movement and L-R offset are calculated by the planning software based on the 3D coordinate of the planned entry point, the current table position, and the distance between the isocenter of the magnet and the laser light.

Slice alignment: Manual slice alignment, even with an experienced team, can be time-consuming and difficult, particularly when attempting double-oblique trajectories. A method for slice alignment was developed wherein three imaging planes – two along and one orthogonal to the planned trajectory – are automatically positioned during interactive, real-time, multi-planar imaging (2-5 fps) [7]. This intelligent alignment strategy defines the imaging planes such that they are oriented preferentially to the principal patient axes. Further, aliasing artifacts are minimized by optimally choosing the center of the imaging planes determined with respect to the planning dataset. This slice layout (Fig. 2) is advantageous for real-time needle placement as 1) the slices are oriented as closely as possible to the standard anatomical cuts and 2) the user can simply follow the slice saturation bands and knows the target is reached once a cross-sectional needle artifact appears at the target in the third plane.

Implementation and Validation: Methods were fully integrated into the Interactive Front End [8], a real-time MR scanner control interface. Phantom (96 punctures in a gelatin phantom with embedded O-seal ring targets) and in-vivo pig (11 paraspinal and 16 kidney punctures) validation studies were performed to assess targeting accuracy and procedure time. Punctures were performed by two interventional radiologists (phantom and in-vivo) and two non-radiologists (phantom only) on a 1.5T scanner (Siemens MAGNETOM Espree). Initial clinical applicability was further shown in needle placements for sclerotherapy in the abdomen, spinal infiltrations and abdominal biopsies in over fifteen patients.

Results: Mean targeting error was 1.8mm ± 1.5 in all directions for phantom studies. Two-way ANOVA showed no significant difference in targeting accuracy with respect to level of experience or trajectory obliquity. In-vivo targeting accuracy was 3.0mm ± 1.8 in all directions with no significant difference based on trajectory obliquity or organ type. The average time from trajectory planning to verification of accurate needle placement in-vivo was six minutes. Average time from planning to verification for the sclerotherapy case using these methods was 4 minutes per abdominal needle placement (Figs. 1-3). These times are much shorter than reported in literature [2-6].

Conclusion: New methods have been presented which simplify the key workflow steps of MR-guided percutaneous interventions through rapid trajectory planning for multiple needle placements, intuitive identification of skin entry site using only existing MR system hardware, and automatic slice plane alignment with preference to the principal patient axes. By reducing procedure time, improving targeting accuracy and simplifying the overall workflow, these methods hold promise for facilitating the adoption of MR-guided percutaneous interventions into the community at large.

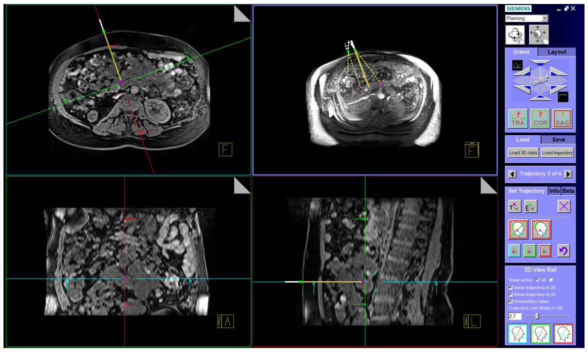

Fig. 1. Planning of needle placement for sclerotherapy of a complex intra-peritoneal venous malformation involving the mesentery (3D T1w GRE dataset). The MIP (upper right) shows the orientation of the planned trajectories in space. All four needle trajectories were planned in one session.

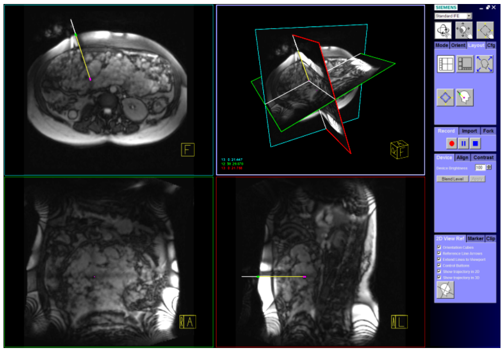

Fig. 2. Needle placement under real-time MRI following automatic slice alignment. The slice orientations are visible in the 3D view (upper right) and by the orientation cubes (yellow boxes).

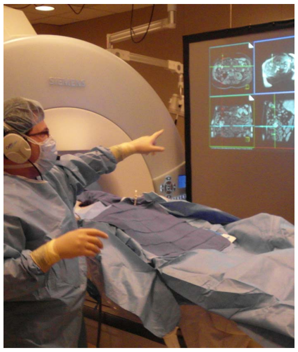

Fig. 3. Display of the prototype on a projection screen tableside with the needle entry site sterilely draped.

References: [1] Mueller et al., Radiology, vol. 161, pp. 605–609, 1986. [2] Fritz et al., Am J Roentgenol, vol. 193, pp. W161-W167, 2009. [3] Ricke et al., Eur Radiol, vol. 20, pp. 1985-1993, 2010. [4] Fischbach et al., Cardiovasc Intervent Radiol, vol. 34, pp. 188–192. [5] Stattaus et al., Eur Radiol, vol. 18, pp. 2865–2873, 2008. [6] Hoffmann et al. Eur Radiol, Sep 2011, Epub ahead of print. [7] Pan et al., Proc. ISMRM, p. 195, 2011. [8] Lorenz et al., Proc. ISMRM, p. 2170, 2005.