A multi-slice interactive real-time sequence integrated with the EndoScout tracking system for interventional MR guidance

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Introduction: In interventional procedures, real-time image guidance for accurate surgical device placement while avoiding damage to critical structures is important. Interactive real-time MR with the capability of rapid image acquisition, interactive scan plane control and protocol parameter update, and automatic device tracking has been demonstrated to be extremely useful in MR guided interventions [1,2]. During interventional procedures, the devices are often localized using either active or passive tracking techniques. However, active device tracking methods require consideration of coil heating, whereas passive device tracking causes signal voids from the susceptibility artifacts that disrupt visualization of the underlying anatomy. The EndoScout gradient-based tracking system (Robin Medical Inc., Baltimore, MD) serves as an alternative method for device tracking [3]. In this system, a cubic sensor with either one or two sets of orthogonal micro-coils is integrated into a surgical tool holder or catheter. By switching gradients in X, Y and Z directions, the position and orientation of the sensor can be determined [4]. The purpose of the present work was to integrate the EndoScout tracking technique into a multi-slice interactive real-time sequence (iRTTT) to assist MR guided interventions.

Methods: *Pulse sequences*: The iRTTT sequence was modified to provide the excitation gradients and trigger signal that are fed into the Endodoscout system for sensor tracking. Bipolar excitation gradients are applied in X,Y and Z directions consecutively and repeated for every phase encoding line or every slice in both TrueFISP (Fig. 1) and GRE acquisitions. The repetition interval of excitation gradients determines how fast the sensor position and orientation can be updated. Based on the sensor tracking updates and the relative position of the sensor with respective to the surgical holder and the device, the position and orientation of the surgical device (biopsy needle) are determined. The sequence can also automatically update the scan planes to acquire the images along the surgical device in real-time.
EndoScout tracking system: The X,Y and Z fields from gradient coils determined during system installation are used as reference. The EndoScout system is connected to the gradient amplifiers to detect the currents sent to the gradient coils during the gradient excitation and determine the gradient fields generated inside the magnet. The EndoScout system then measures the voltages induced in the micro-coils during gradient transition to determine the sensor position and orientation [3].
Experiment setup: Before each scan, three reference images with the planned target and surgical paths are acquired and uploaded into three image frames on the scanner user interface and also sent to EndoScout system for registration. During the scan, a graphic overlay from the EndoScout PC is superimposed on the scanner user interface to indicate the relative spatial relationship between the surgical device and the respective underlying three slices (Fig. 2).
Animal Study: An animal study was performed in a swine model in a 1.5 T system (Magnetom Espree, Siemens Healthcare, Erlangen, Germany) to test the capability of this integrated system for MR guided interventions. Needle puncture targets were selected on the shoulder joint and the cervical neuroforamina and needle insertion paths were planned from a 3D GRE (Fig. 2, left and middle) as well as a 2D T2 HASTE acquisition (Fig. 2, right). A 20cm long 20-G MR visible needle was used for puncture. The iRTTT sequence with EndoScout integration using TrueFISP acquisition was run during the needle insertion for MR guidance. A T2 HASTE sequence was repeated after the procedure to confirm whether the needle followed the planned path and hit the target.

Results: In the animal study, the EndoScout tracking updated the device position and orientation every 8.2 ms and the acquisition time for each slice was 377ms. Three slices were displayed in the inline display window in a mosaic mode, with Slice 1 always following the needle plane, and Slices 2 and 3 updated with real-time images along the planned path and final target but without slice location change (Fig. 3). One slice containing the planned surgical path was shown as intersection plane on an axial slice (Fig 2, right) and was used as the reference for the operator to align surgical device to keep it within planned path. The needle appeared as a signal void on the real-time images (Fig 3, Slice 1 and 3) and was used to monitor the needle insertion. The operator adjusted the needle orientation based on both the EndoScout tracking overlay and the needle artifacts on the real-time images. The total planning time to setup the EndoScout for insertion path and target planning was approximately 3-5 minutes. The total needle insertion time for each planned target was approximately 2-3 minutes.

Discussion and Conclusion: In this work, an interactive real-time sequence was integrated with the EndoScout tracking system for MR guidance in interventional procedures. The integrated system was capable of reliably tracking the surgical device and superimposing the real-time updated device position and orientation either on pre-acquired images or real-time images for MR guidance of the needle insertion along the planned paths to reach the targets. The multi-slice real-time images were acquired and displayed in a mosaic mode to enable both surgical device guidance and underlying organ and tissue monitoring. MR guidance using the integrated system is feasible and effective at performing the interventional procedures. Future work will include further evaluation in animal and patients.

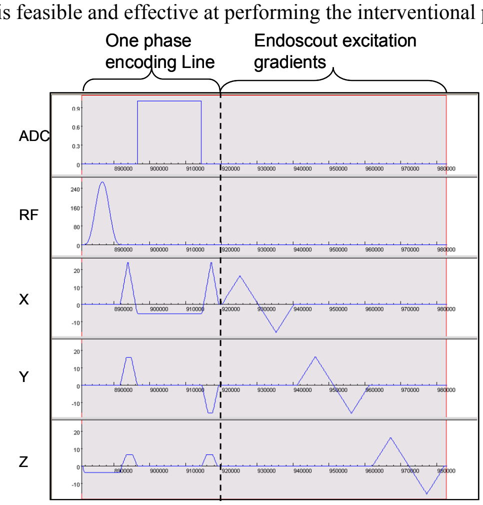

Fig 1. Sequence diagram. The EndoScout excitation gradients applied for every phase encoding line in a TrueFISP acquisition.

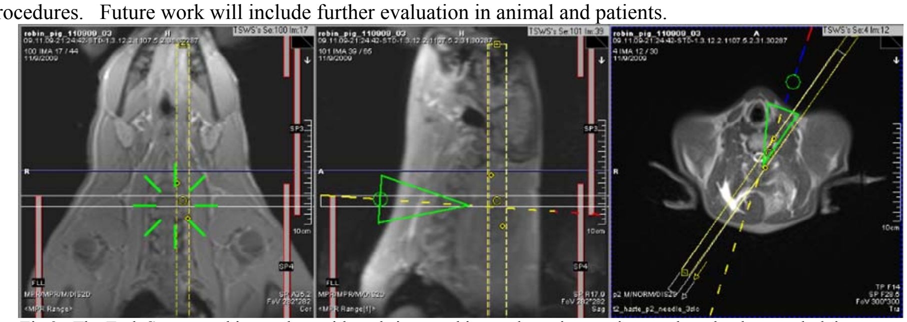

Fig 2. The EndoScout graphic overlay, with real-time tracking updates, is superimposed on the three underlying static slices on the scanner user interface with the tip of the green triangles indicating the needle tip position, and the lines going through the triangles indicating the direction of the needle (yellow: proximal; blue: in-plane and red: distal relative to the respective slices).

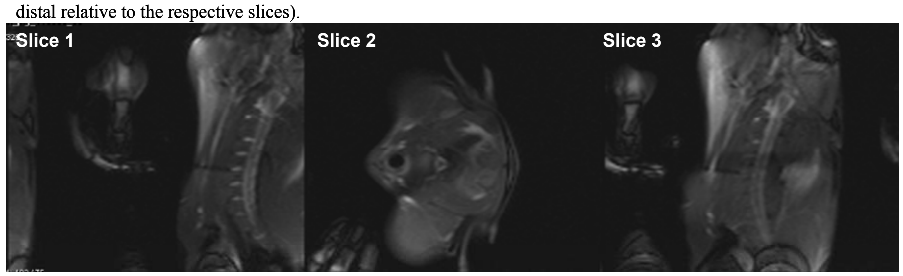

Fig 3. The three real-time acquired slices are displayed in the inline display window of the scanner user interface in a mosaic mode, with Slice 1 always following the needle path and Slices 2 and 3 updated with real-time images for reference, but without slice location change.

References:
[1] Zuehlsdorff et al., ISMRM 2006; 1403.
[2] Zuehlsdorff et al., ISMRM 2005; 2157.
[3] Nevo et al., ISMRM 2002; 0334.
[4] Van der Kouwe et al., ISMRM 2009; 4623.