Training and Testing Environment for MR-guided Vascular Interventions

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Purpose: There is growing interest in using MRI to guide minimal invasive procedures. In particular early diagnostic evaluation of the therapeutic achievements during the intervention could enable therapeutically relevant and critical decision-making while having the patient still on the table [1]. However MRI guided interventions are challenging due to limited patient access, the need for MR safe devices and high acoustic noise levels within the scanner room. All drawbacks could be overcome by designing new procedures, devices, pulse sequences and hardware. New technologies require extensive testing prior to clinical use. A novel interventional training and testing environment was developed to entirely guide cardiovascular interventions with MRI. This provides researchers and clinicians the ability to test new procedures as well as to explore novel devices as guidewires (GW), catheters or implants in appropriate models and clinical relevant conditions. In this study, we propose resonant coils for catheter and passive markers for GW localization to demonstrate the principle.

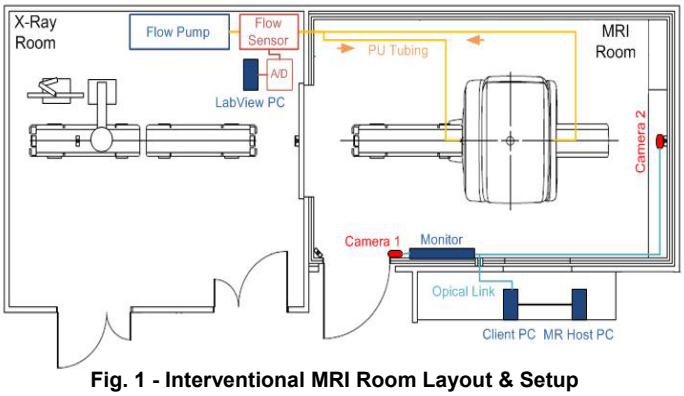

Fig. 1 - Interventional MRI Room Layout & Setup

Materials and Methods: A pulsatile flow pump (Tayside Flow Technologies), filled with MR blood mimicking fluid (water based) positioned outside the MR room was connected to a flow model placed in a clinical 1.5T MRI (Signa HDx, GE) using a 8-channel HD torso array coil. Two different models were used for experiments, an arterial vessel replica model (L-F-S-Left-003, Elastrat) and a Thiel soft embalmed human cadaver [2] with specially prepared vessel segments. The flow models were connected through the waveguides with rigid plastic tubing in order to keep the flow pattern as constant as possible over distance. The waveform was monitored with a non invasive ultrasonic flow sensor (Cynergy3), digitized (SC-2345) and displayed in Labview (National Instruments). Initial flow experiments (femoral pattern 30 mL / s, 60 bpm) to verify the pump output, MRI (FGRE) and MRA (TOF & PC) was conducted on the superficial femoral artery of a Thiel embalmed human cadavers and on the vessel replica model. Interventions as catheterizations of the left femoral artery (LFA) were conducted using customized MR compatible 0.035" GW (MRLine, Epflex) and 5F catheters (Protex, Somatex). In-house synthesized iron-platinum alloy (FePt) nanoparticles (nPs) were used on the guidewires for passive visualization and semi-active markers (tuned to 63.8 MHz) on the catheters. All interventions were displayed on a customized 40" in-room monitor (Multeos 401, NEC) enabling the interventionist almost real-time feedback. A Bluetooth mouse (WPM 8000, Microsoft) was placed in the scanner room for planning and initiating MR acquisition, interactive scan plane and parameter control within the scanner room. In-room control of the MR scanner was established on a PC running a Virtual Network Computing (VNC) client and communicating to the MR host PC running a VNC server application. The interventionist was able to remotely interact with the MR scanner host PC. All interventions could be monitored and recorded on two in-room USB webcams (C910, Logitech). Data communication was established via fibre optical cables (Opticis) through the waveguides.

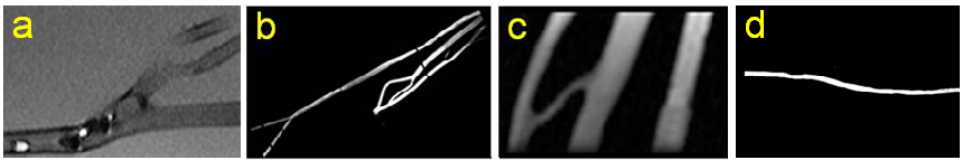

Fig. 2 – Femoral Artery a) – c) of Vessel Phantom, and d) of Thiel Embalmed Cadaver:
a) GW inserted in Catheter in Femoral Artery: FGRE TE/TR TE / TR = 2.5 / 9ms FA = 20°
b) 2D TOF TE/TR 2.7/7.7 ms FA 80°
c) 3D TOF TE/TR 4.4/31 ms FA 20°
d) 2D TOF TE/TR 2.6/7.7 ms FA 80°

Results: The sensor was first connected to the output of the pump (40 mL / s, 70 bpm) and then connected at the proximal access point of the LFA to obtain changes in the waveform pattern. The shape after the tubing was less accurate but the measured peak flow rate (38 mL / s) and the frequency (70 bpm) were similar to the sensor output while positioned at the pump output. Further flow analysis was obtained with MRA, measured with the sensor at the proximal access point of the LFA and verified using Doppler ultrasound (US) assessments (Z.one, Zonare) at the proximal access point of the vessel. 2D TOF MRA for the whole LFA showed good signal within the vessel lumen while the saturated background signals were suppressed for typical flow (34 mL / s, 70 bpm) in both flow models (Fig. 2b and d). A signal increase within the vessel lumen was obtained when changing to constant flow higher than 23 mL / s. Gaps were identifiable in discrete intervals (Fig. 2b) in the maximum intensity projection (MIP). 3D TOF (Fig. 2c) showed good MRA results for the vessel models for short segments (~10 cm). The flow pattern was set to constant (23 mL / s) for catheterizations in order to keep fluid motion of the phantom box surrounding the vessels to a minimum. Both catheter and GW were clearly visible and differentiable for the interventionist on the in-room monitor. The resonant markers (Fig 2a) exhibited high device-to-background contrast during imaging with low flip-angles (< 45°) leading to appropriate visualization of the catheter during interventions. The susceptibility artefacts from the markers on the GW exhibited good-sized signal voids (long-axis: 12-15 mm), increasing with TE. However, a decreased signal of the resonant markers was observed while the GW was passing the catheter and the passive markers of the GW were in the same location as the resonant markers. Slice repositioning from inside the room was possible in order to obtain the required markers in the current scan plane, but generally very time consuming (5 - 15 s). All MR images were inspected for RF interference in consequence of the additional installed components in the shielded room. No interference could be determined on any image. Though, a coherent noise test indicated low level RF interference.

Discussion and Conclusion: The LFA of Thiel cadavers and vessel replica models have been successfully imaged and catheterized in MRI. The results show good progress towards creating a training environment for researchers and clinicians. The flow rates provided by the pump are sufficient for 2D TOF and 2D / 3D PC imaging of the whole vessel segment or 3D TOF imaging of shorter segments. The changes in the flow pattern are still acceptable after the rather long distance between pump and flow model. Flowrates could be monitored and verified with US (poor quality as the blood mimicking fluid was not made for Doppler imaging). However, the pulsation could be visualized and corresponded with the output of the sensor. The gaps in 2D TOF images are due to the pump design. The flowrate drops to zero while the valves are switching to reverse the piston direction and the whole slice is saturated during the no flow period (~1 s). The MR images were not affected by RF interferences. However, 5 V power supplies which have been identified as source of interference need to be shielded or replaced. First initial studies correlate with the literature [1, 3] that manual slice alignments during interventions are very time consuming and influence the workflow. Automated device tracking for passive and semi-active markers, slice repositioning [4] and parameter control on the fly are highly desirable and might be applied in future. The vascular tree and organs of Thiel cadavers appear to be generally well preserved and a wide range of vascular segments may be accessed in future for training and testing. The intial results demonstrate that the training and testing environment is promising for testing of new devices and techniques for entirely guided MR interventions and can provide an anatomically-correct alternative to animal and phantom trials. This environment could also be used for multimodality guided interventions such as combined procedures of X-ray and MRI fluoroscopy.

References:
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