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The impact of imaging speed of MR-guided punctures and interventions in static organs—A phantom study

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ABSTRACT

Purpose: Verification of MR-guidance with image acquisitions slower than 1 image per second as it is inevitable for some interventions. Therefore, we quantified solely the effect of acquisition-time on the efficiency of MR-guided interventions in a static phantom study.
Materials and methods: We measured the duration, accuracy and error rate of simulated interventions for different acquisition-times using a simplified interventional setup. All measurements were performed in a 1.0 T open MRI scanner. Imaging was performed with a gradient-echo sequence (flipangle = 20°; TR/TE = 12/6 ms; voxelsize = 1 mm × 1 mm; slicethickness = 5 mm; FOV = 230 mm × 200 mm; acquisition-time = 1 s). Variable acquisition times were simulated with intermediate pauses of 0, 1, 2, 3, 4 and 5 s. The interventions were performed by a total of 20 volunteers including 7 experienced interventionalists.
Results: The mean duration of the intervention was 2 min. Significant differences between experienced and unexperienced volunteers were limited to the localization of the image plane and corrections made. The mean accuracy was 5.6 mm. The time to localize the image plane increased with deceleration of imaging from 24 s to 49 s. A similar increase was observed for the intervention time (55–108 s). A significant influence of the acquisition-time on durations and corrections was only found with acquisition-times greater than 4 s per image.
Conclusion: Even image rates of several seconds per image are sufficient enough for efficient interventions in static organs. Thus, the main attention has to be turned on the visibility of the needle when sequences are optimized for MR-guidance. The minimization of imaging speed is rather of secondary interest.

1. Introduction

Image-guided interventions have gained in importance over the past years. This is owed to the increasing number of minimally invasive procedures in modern medicine, which require new monitoring techniques [1–5]. The advantages of real-time fluoroscopic guidance of biopsies, punctures or tumor ablations with X-ray, computer tomography (CT) and ultrasound (US) are well described [1,2,6–11]. With the introduction of open magnetic resonance imaging (MRI) scanners and improved patient access, MR-guided interventions have become increasingly popular [12–15]. Compared to CT, MRI especially simplifies a cranio-caudal intervention approach [12,16]. Hence, MR-fluoroscopy guidance can represent a significant improvement for cross-sectional interventions.

If no additional navigation devices are used, the interventional procedure normally includes the adjustment of the image plane and the intervention itself. The image plane is fixed so that the access point of the medical device and the target of the intervention are in line with the field of view (FOV). To perform the intervention, the interventionalist has to localize the image plane and access point. The most basic way of accomplishing this is the free hand technique – also known from CT-guided interventions: the interventionalist moves the tip of his finger along the patient's skin until both finger and target are visualized on one image. To date, no specific analysis has been performed on how fast imaging should be to maximize the safety and efficiency of image guided interventions and what a minimum frame-rate should be. On this account, our study was designed to systematically measure the influence of the acquisition speed of MR-guidance on the duration and error rate of interventions solely. In an in vivo intervention, various other factors like changing tissue contrast, mechanical tissue properties, different tissue motions, patient access, the angle and distance of the puncture conduits are influencing the efficiency of the procedure. Therefore, a simplified static interventional setup in a phantom study was chosen to exclude these factors and to get a reference to the degree of impact of the imaging speed on the success of an in vivo intervention.

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Fig. 1. Experimental set-up in the Panorama open high-field MRI. Shown are the interventional seat at the curvature of the scanner and the phantom in the abdominal coil.

2. Materials and methods

The study included two procedures: (a) locating the current MR-image plane using the free hand technique and (b) the actual intervention starting with the penetration of the puncture phantom's surface and ending after a target was hit. The intervention was completed when the interventionalist was sure to have reached the target point. A total of 20 volunteers performed the interventions for each of six different acquisition times resulting in different imaging rates. Seven of the volunteers were experienced in image guided interventions (either CT or MRI).

2.1. Puncture phantom

The phantom was made of two compartments of gel filled in a 20 cm × 15 cm × 15 cm container of synthetic material (Fig. 1a). The lower compartment of the phantom consisted of a 3 cm layer of Wirogel (Bego, Bremen, Germany) and the upper compartment of 1.5% agarose gel. As a target we used a plastic hollow cone with a 3 cm diameter and 2.5 cm length. The aperture of the hollow cone was placed at the center of the horizontal plane, 3 cm from the bottom within the Wirogel and 6 cm from the surface of the agarose gel. Thus, the agarose gel could be easily renewed without changing the position of the target. To ensure a constant angle and distance of the puncture conduit, possible insertion points were restricted by a circular aperture 12.5 cm in diameter at the center of the container's cover. Thus, in-plane angulations relative to the main magnetic field resulted in maximum angulations of 28.5° with a distance of 13 cm from the target, i.e. the hollow cone. Since the phantom did not provide any anatomical land marks, visual reference points were marked around the cover aperture, similar to those on the face of a watch, to facilitate orientation for the interventionalist. These marks also simulated restrictions, which are normally provided by anatomical structures in an in vivo intervention. Controller orientation at the MR-console was achieved with corresponding MR markers attached to the bottom of the box's cover (Fig. 1b). The MR markers were two opposed cylinders (Ø = 3 cm, 0.5 cm length) filled with water and ten equally spaced vitamin E capsules in between.

2.2. Experimental set-up

All measurements were performed in a 1.0 T open Panorama HFO MRI scanner (Philips Healthcare, Best, The Netherlands) using an abdominal coil with a 40 cm aperture (vertical diameter, Fig. 2). An MR-compatible in room monitor (Philips Healthcare, Best, The Netherlands) was placed in front of the scanner's aperture to display the MR-images in the interventionalist's line of sight.

2.3. Sequence

A T1 weighted gradient echo sequence (flip angle = 20°; TR/TE = 12/6 ms; voxel size = 1 mm × 1 mm; slice thickness = 5 mm; FOV = 230 mm × 200 mm; acquisition time ta = 1 s) was used as an interventional sequence. The phase encoding direction was vertical (along columns) for all interventions. To analyze the dependence of safety and efficiency of the intervention versus the imaging speed variable acquisition times were simulated by time intervals of 0, 1, 2, 3, 4 and 5 s between each image acquisition. This resulted in acquisition times of ta = 1, 2, 3, 4, 5 and 6 s, while minimizing changes of the contrast-to-noise ratio (CNR) and SNR.

2.4. Puncture procedure

We used a 15 cm 16G titanium-based needle (Somatex, Teltow, Germany) in all interventions. The image plane was aligned with the main magnetic field at the center of the hollow cone (target) by the controller at the MR-console, while varying the degree of rotation around the symmetry axis of the hollow cone for each intervention. By varying the rotation angel, a potential influence of puncture channels from preceding interventions on the current intervention was precluded. In addition, the upper gel compartment was renewed after every 12 puncture procedures. Image plane orientation was not modified throughout the puncture process. Image plane localization began with a starting point of the fingertip at the boundary of the aperture 10 cm from the predefined image plane. To attain reproducible distances, the interventionalist was instructed by the MR controller on what "time" marker to begin with as starting point for every intervention. Thereby, the correspondence of MR-markers and visual reference points on the cover enabled an alignment of the coordinate systems of the MR-controller and the interventionalist. The interventionalist was further instructed to search for the predefined image plane in a clock-wise along the circumference of the cover aperture. The total distance of this search was constantly 6.5 cm in all experiments.

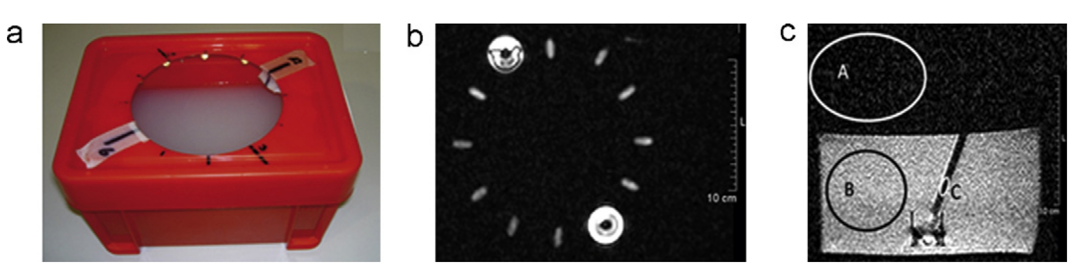

Fig. 2. (a) Phantom consisting of gel-filled synthetic box with a circular aperture and a plotted clock-face on the cover. (b) Balanced gradient echo image of the MR-marker on the back of the cover corresponding to the plotted clock-face on top (TR/TE = 4/2 ms; flip angle = 60; voxel size = 2mm × 2 mm × 8 mm). (c) Interventional gradient echo image of the phantom. The image plane was planned according to the MR-marker at (b). The regions of interest (ROI) demarked by A, B and C were used to measure SNR and CNR values at different acquisition times.