In vivo Double Echo MRI Stereoscopy for Real-time 3D Visualization of Blood Vessels

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Introduction

In intravascular interventions a full 3D visualization of the target region is highly desirable, for example to facilitate the introduction of a catheter into a complex vascular structure. A 3D perception can be rapidly achieved with stereoscopic imaging techniques which acquire two oblique images that are presented separately to the left and the right eye [1, 2].

This work focuses on the implementation of an accelerated stereoscopic double echo (DE) FLASH sequence [3]. To assess its usability for 3D depth perception, an inter-observer test was based on phantom measurements. The sequence was then tested in an animal experiment to visualize the vasculature with 3D perception in real-time. The results were compared to a stereoscopic interleaved (IL) FLASH sequence.

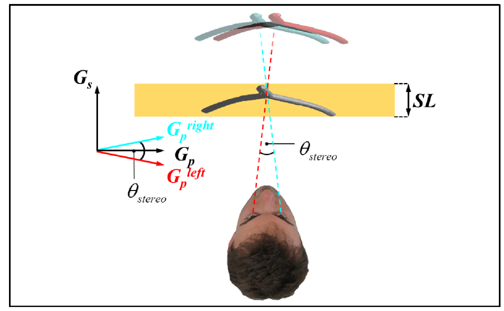

Fig. 1: Schematic of the stereo image pair acquisition. After RF excitation of a thick projection (slice thickness *SL*), the phase encoding direction (G_p) is tilted by half the stereo angle ($\theta_{stereo}/2$) resulting in G_p^{right}. A k-space line of the right view is acquired during the 1st echo. Then, G_p is tilted by $-\theta_{stereo}/2$ into G_p^{left} to acquire a k-space line of the left view during the 2nd echo.

Materials and Methods

Stereoscopic DE-FLASH sequence. A stereoscopic DE sequence with view tilting (illustrated in Fig. 1) in phase encoding direction between the first and the second echo [3] was implemented on a clinical 1.5 T MR system (Magnetom Symphony, Siemens, Erlangen, Germany). The sequence continuously acquires stereo pairs (two thick slice projections) of the target region (Fig. 1). To improve the temporal resolution, the pulse sequence was combined with view sharing of k-space lines. K-space was segmented into 3 segments (A, B, C) and the peripheral segments (A or C) were shared between subsequent images.

Real-time stereo image display. Stereo images were displayed in real time on a 3D LCD polarization monitor (ZM-M215W, Zalman, Garden Grove, CA, USA) which was connected to a separate workstation. The monitor is based on a line-by-line interleaved polarization technique and features MR-compatible polarization goggles. An in-house developed software tool was used for pre-contrast image subtraction, horizontal alignment, windowing, and online stereo image display.

Phantom experiments. An aorta phantom (Fig. 2) was connected to a peristaltic pump providing a water flow of about 12.5 ml/s. DE-FLASH stereo image pairs ($TR/TE_1/TE_2$ = 5.4/1.4/2.7 ms; α = 25°; FOV = 225×300 mm²; matrix = 204×256; slice thickness = 40 mm; BW = 890 Hz/px; θ_{stereo} = 10°, partial Fourier factor = 6/8; GRAPPA-factor = 2 with 35 reference lines; 75% asymmetric echo; 2/3 line sharing; TA = 460 ms for one stereo image pair) of the phantom were acquired continuously during injection of a 5 ml-bolus of contrast agent solution (Gd-DTPA:H_2O = 1:10). The stereoscopic DE-FLASH images acquired during peak enhancement were presented to 7 volunteers. The volunteers were asked to describe whether 3 vascular structures (L, M, and R, cf. Fig. 2A) pointed predominantly into or out of the monitor plane.

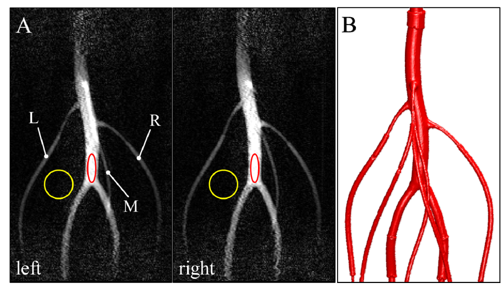

Fig. 2: A) Peak enhancement stereo image pair during contrast agent injection in an aorta phantom. The images were used for the depth perception test. B) Surface rendered image of the aorta phantom.

Animal experiment. The stereoscopic DE-FLASH sequence was assessed in a 5-month-old domestic pig. The sedated animal was intubated and mechanically ventilated. A 7.3 F angiographic catheter (Torcon Blue, Cook, Bjaeverskov, Denmark) was inserted into the aorta through an MR-compatible 9-French introducer sheath in the left carotid artery. DE-FLASH stereo image pairs ($TR/TE_1/TE_2$ = 4.2/1.3/2.6 ms; α = 20°; FOV = 263×350 mm²; matrix = 154×256; slice thickness = 40 mm; BW = 815 Hz/px; θ_{stereo} = 10°, partial Fourier factor = 6/8; 75% asymmetric echo; 2/3 line sharing; TA = 435 ms) were continuously acquired during the injection of a 10 ml bolus of contrast agent solution (volume ratio Gd-DTPA:NaCl = 1:2) at a flow rate of 5 ml/s. For comparison, stereoscopic IL-FLASH images were recorded with nearly the same parameters (TR/TE = 2.9/1.3 ms; α = 15°; TA = 588 ms per stereo pair). The peak enhancement stereo images of the DE/IL series (Fig. 3) were presented to two experienced radiologists on the stereo monitor. The radiologists assessed the visibility of 9 arteries on a three-point scale. SNR values were measured in the same images.

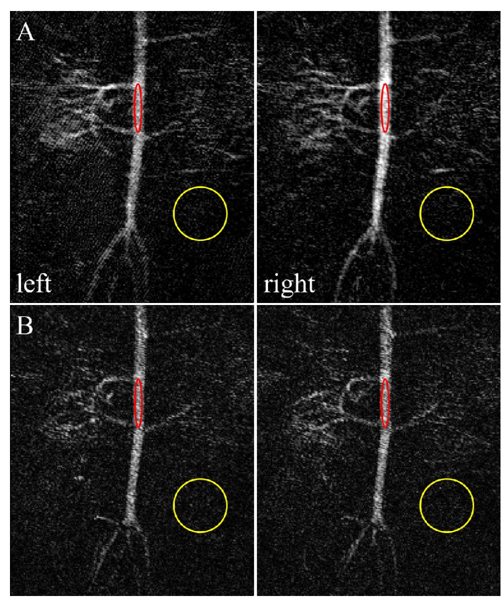

Fig. 3: Peak enhancement stereo image pair during contrast agent injection in an animal experiment: A) DE-FLASH sequence; B) IL-FLASH sequence. The ROIs for SNR evaluation are illustrated: signal = red ellipses; noise = yellow circles.

Results and Discussion

View sharing improves the image update rate of the stereoscopic DE-FLASH sequence by a factor of 1.5, which can be further increased using additional acceleration techniques such as tSENSE [4].

In the phantom measurements, an SNR of the left/right image of 31/29 (after pre-contrast image subtraction) was found (Fig. 2A). However, these minor variations did not influence the depth perception of the stereo images as all volunteers were able to recognize the orientation of the three vascular structures correctly.

In the animal experiment, the DE/IL sequence achieved a mean SNR of 10/7 (after pre-contrast image subtraction) at a stereo image update rate of 2.3/1.7 Hz (Fig. 3). In the subsequent evaluation by two radiologists 8 out of 9 vessels could be clearly identified in both DE and IL acquisitions. Motion artifacts due to the mechanical ventilation of the animal were not seen due to the high frame rates.

The stereo display provided an excellent 3D perception as long as the images were seen from a view angle range of 12° vertically/90° horizontally to the screen. For future application in the MR system's Farady cage, the monitor needs to be modified to reduce RF emission near the Larmor frequency.

In conclusion, we successfully demonstrated the *in vivo* application of a view sharing stereoscopic DE-FLASH sequence. With the sequence, fast 3D visualization of blood vessels becomes possible in real-time on a polarization based stereoscopic 3D LCD monitor during MR-guided interventions.

Acknowledgement

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References

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