Dynamic MRI of the orbit

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Introduction: In preparation to perform strabismus surgery, ocular misalignment is mainly investigated by fixation and subjective tasks. In some selected patients, static MRI or CT data are additionally evaluated for detecting mechanical disorders of the orbit [1]. In more complex cases however, there is a need for better understanding of the dynamics of the 3D eye movement resulting from contractions and relaxations of the six extraocular muscles and the surrounding orbital connective tissue. This study will provide basics for new scanning methods providing dynamic, high-resolution MRI images of the orbit combined with motion encoded images (CSPAMM [2] and CDENSE [3,4]).

Methods: For reproducible and accurate eye alignment during the experiments, subjects gazed at a horizontal sinusoidally moving target (peak velocity: 63°/sec, amplitude: ±20°), presented with a typical fMRI setup (software: "Presentation" and digital projector). A microscopy coil (47mm diameter) at 1.5T was used to acquire dynamic 3D-TFE images (15 slices, 256x256 scan-matrix) with 18 time frames at a resolution of 0.4x0.4x1.4mm^3. Conventionally, this scan took over 26min. k-t BLAST encoding [5] with k-t acceleration factors of up to 9 were evaluated to reduce the scan time to 3.3min. 2D CSPAMM images (256x151 scan-matrix, 512x512 recon.-matrix, in 6min. 21 time frames of 70ms, at a resolution of 0.3x0.3x4 mm^3 and an EPI factor of 5, tag-line distance: 2mm) and 2D CDENSE images (128x111 scan-matrix, 256x256 recon.-matrix, in 5min. 21 time frames of 70ms, 0.6x0.6x5mm^3, EPI factor: 5, encoding strength: 3,6mm/pi) were obtained using the same setup. Data were post-processed to get displacement maps.

Results: The dynamic images without using k-t BLAST were moderately blurred due to motion compared to the static images. Reducing the scan time by using k-t BLAST did not further degrade the sharpness of the slower moving muscles. Only fast moving tissue like the optic nerve and the lens of the eye, which are not of interest in this project, were further blurred. However, these images allowed a reasonably good visualization and segmentation of the extraocular eye muscles (Fig 1) with an 8-fold scantime reduction compared to equivalent static images.

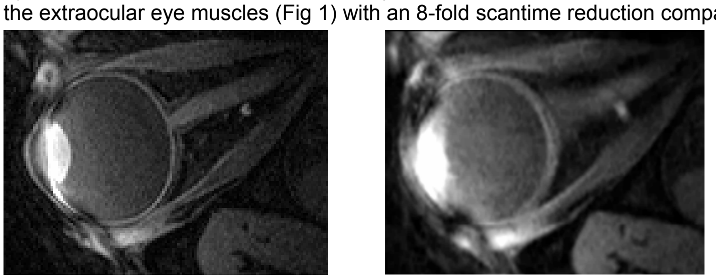
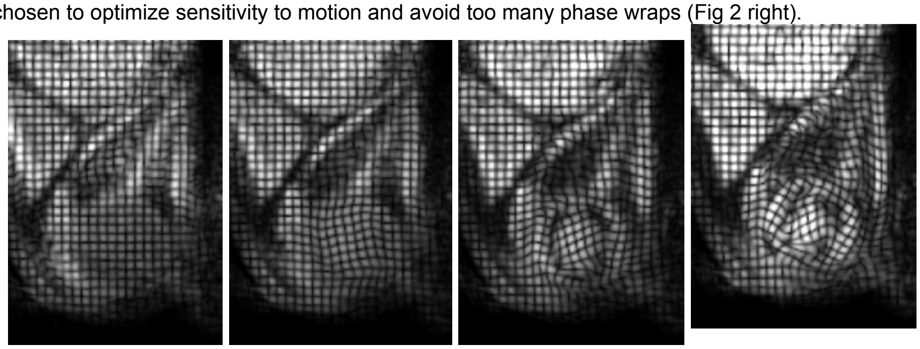


Figure 1:
(left): *Central slice of a static experiment (1 fix gaze direction at 0°, scan time 1.5 min).*
(right): *Central slice of dynamic experiment with a k-t BLAST acceleration factor of 9 (max. rotational speed of the eyeball: 63°/sec, 15 slices, 18 time frames, scan time 3.3 min, same* resolution: 0.4x0.4x1.4 mm^3*). Only fast moving tissues like the optic nerve and the eye lens, which are not of interest in this project, are strongly blurred.*

The CSPAMM motion encoded images provided information of the movement also within homogeneous regions of the orbit like the vitreous humor, the muscle, and the orbital fat (Fig 2 up). CDENSE had a higher sensitivity to motion than CSPAMM, but also to noise. An optimal motion encoding strength was chosen to optimize sensitivity to motion and avoid too many phase wraps (Fig 2 right).



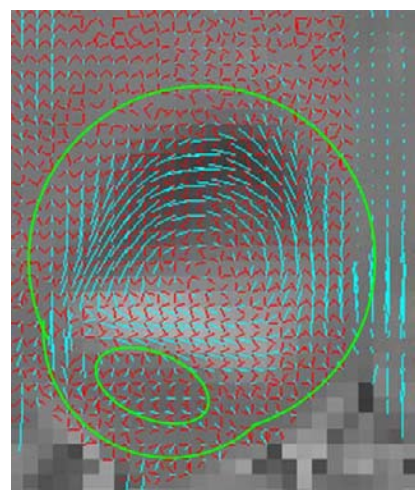


Figure 2: (up) *Four CSPAMM images of the clockwise rotating eye (first half of a sinusoidal movement). The movement of the vitreous humor was a damped oscillator due to its high viscosity. The data reveal the region of greatest contraction along the muscles. The movement of the orbital fat is also clearly depicted.* **(right)** *CDENSE image of the eye globe at the change of direction by a sinusoidal movement. The vitreous humor was still turning clockwise as the globe already began to rotate counterclockwise. The vitreous humor movement was clearly affected by the eye lens and it was not moving at the center of rotation (in green: schematic representation of the eye globe and lens, the arrows heads in red indicate the actual position of the tissue points, and the arrows bodies in blue are 4 times bigger than the real displacement).*

Conclusion: k-t BLAST offers a unique possibility for high-resolution fast dynamic 3D images of the orbit with acceptable quality, therefore enabling segmentation of all six extraocular muscles. However, it does not reveal motion inside homogenous tissues. CSPAMM allows visualization of the muscles contraction and of the vitreous humor displacement over the whole movement range. CDENSE is more sensitive to noise but allows to detect smaller movements, which could be crucial for modeling the extraocular muscles. Assignment of a displacement to the corresponding tissue point could be achieved by superposing the displacement maps to the anatomical data sets. Combination of the anatomy images with motion encoded images results in a totally new way of understanding MRI orbital imaging. For the first time, the in-vivo flow pattern of the vitreous humor was measured, enabling new insight into retinal detachment pathologies.

References:
1. Demer JL, et al. A 12-Year, prospective study of extraocular muscle imaging in complex strabismus. J AAPOS. 2002 Dec; 6(6):331-47
2. Fischer SE, et al. Improved myocardial tagging contrast. MRM 1993; 30(2):191-200.
3. Aletras AH, et al. DENSE: displacement encoding with stimulated echoes in cardiac functional MRI. JMR 1999; 137(1):247-252.
4. Gilson WD, et al. Complementary displacement-encoded MRI for contrast-enhanced infarct detection… MRM 2004; 51(4):744-752.
5. Tsao J, et al. k-t BLAST and k-t SENSE: dynamic MRI with high frame rate exploiting spatiotemporal correlations. MRM 2003 Dec; 50(5):1031-42