CSPAMM Tagging of the Extraocular Muscles during Eye Motion: New Insights.

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Introduction: The pattern of the lack of movement within the orbit has not been understood yet [1]. Therefore, there is a need, in complex disorders of the orbit, to better understand the dynamics of ocular movements for potentiating more effective surgery. The cerebral architecture of eye movement control can be investigated using e.g. fMRI, while the neuronal activity and pathways can be determined using electromyography or DTI. Strabologic examinations provide information on the eye movement itself; but the translation through the extraocular muscles (EOMs) of the neuronal command to the actual eye movement is still not satisfactorily elucidated. In particular, the effect of the neuronal command on the EOM contraction pattern during eye motion has not been investigated until now. Static MRI of the orbit cannot resolve the kinetics of the heterogeneous EOM deformation [2].

Motion encoded CSPAMM (Complementary SPAtial Modulation of Magnetization [3,4]) MRI permits the analysis of the EOM movements in health and disease. We studied the deformation pattern along the horizontal EOMs in seven healthy subjects and in a patient with type 1 Duane's syndrome (DST1).

Methods: All subjects gazed at a horizontal sinusoidal moving target (2s period, peak velocity 64°/s, amplitude ±20°) for four minutes [5]. One orbit of each subject was imaged with the motion encoding technique CSPAMM [2], using a microscopy coil (47mm diameter) at 1.5T, to obtain 15 time phases of 12ms every 70ms. The image plane was chosen so that the optic nerve (ON), the medial (MRM), and the lateral (LRM) were embedded in it. In order to prevent tag fading, an optimized ramped flip angle approach was applied (final flip angle=47º) [3]. For the other scan parameters see [2].
For data evaluation peak-combination HARP [6] was used. The ON, the MRM, and the LRM were tracked with an improved mesh algorithm (Figure 1). The meshes were HARP-tracked [7] and corrected for consistency between time frames. The local changes of length of the mesh along the EOMs and the ON were calculated for both gaze directions.

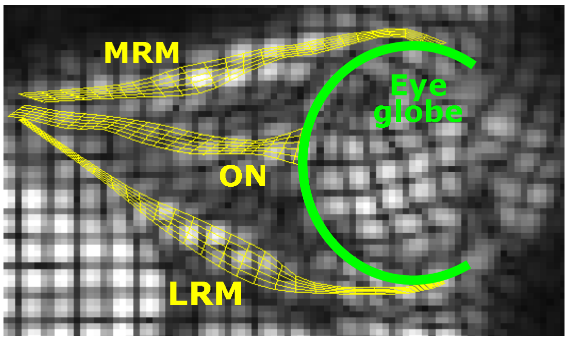

Figure 1: *CSPAMM image of the right orbit of a healthy subject at the 10th time frame (out of the 15). Superposed to the image are the semi-automatically embedded meshes (in yellow), that served to track the three tissues.* MRM: *medial rectus muscle.* ON: *optic nerve.* LRM: *lateral rectus muscle.*

Results: In the seven healthy subjects the EOM deformation patterns during left-to-right and right-to-left gaze were similar, and therefore suggest that both horizontal muscles are active during smooth pursuit. The variability among subjects was less than 10%.

The deformation along both EOMs of the DST1 patient revealed the anterior muscle segment to have different contraction and relaxation patterns than the posterior segment, compared to the control group (Figure 2).

Conclusion: Motion encoded CSPAMM MRI as used in this study resolved the dynamics of the differential contraction and relaxation of EOM segments in healthy subjects and differentiated the pathologic from the physiologic pattern. The loss of functionality was assigned to specific EOM segments, giving a new detailed insight into the pathologic innervation pattern.

References: [1] Miller JM, et al. JOV 2006; 6: 616-624. [2] Piccirelli M, et al. JOV, in press [3] Rutz A, et al. MRM, in press. [4] Fischer SE, et al., 1993, MRM 30: 191-200 [5] Piccirelli M, et al. Proc. ESMRMB 2005 #418. [6] Ryf S, et al. JMRI 2004; 20: 874-880. [7] Osman NF, et al., 1999, MRM 42(6): 1048-60.

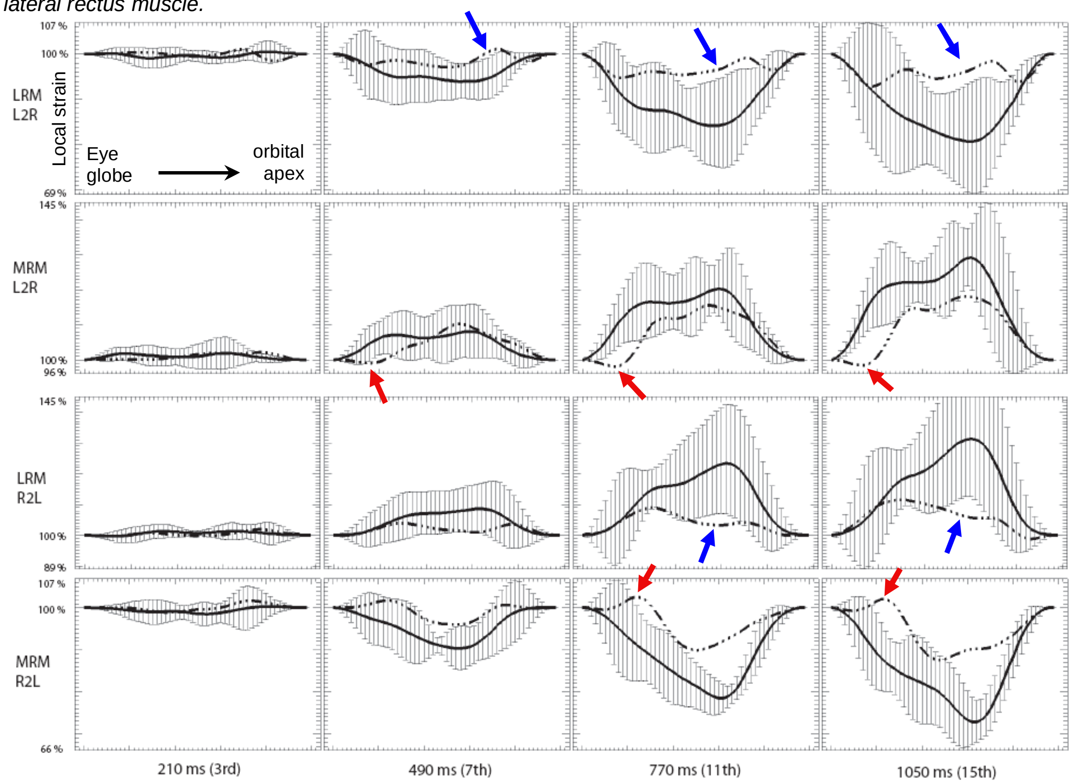

Figure 2: *Comparison of the deformation patterns along the EOMs of the DST1 patient (dotted line) with those of the healthy subjects (solid line). The deformation pattern of the posterior half of the DST1 LRM differed significantly from that of the control (blue arrows), whereas the anterior third showed a similar deformation. Conversely, for the MRM, it is the anterior third that deformed in opposite manner to the normal subjects (red arrows). The error bars are four standard deviation long, so that p<0.05. The 8 upper panels correspond to the left-to-right motion, the lower 8 to the right-to-left. The columns relate to the 3rd, 7th, 11th, and 15th time frames. For each panel the local strain along the muscle from the eye globe to the orbital apex relative to the first time frame (100%) is depicted.*