Postprocessing Tool for 3D Strain Quantification from 3D Tagging Data

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Introduction: 2D Tagging acquisition of the orbit during eye movement have proven to give new inside into the mechanical properties of orbital tissues,[1] and to be a valuable tool for investigating diseases etiologies.[2] 3D tagging acquisition have been shown to be feasible in a scantime short enough to enable motion reproducibility.[3] Nevertheless, the missing of an appropriate postprocessing tool impeached the extraction of quantitative information from 3D tagging data of the orbit. To obtain quantitative information out of tagging data, tissue landmarks have to be tracked over the acquired time frames. Image noise and movement artifacts can disrupt the stability of the tracking procedure. Up to now only model-based multi-2D postprocessing methods allowed to obtain 3D quantitative information.[4,5] The model used may not apply in pathological cases. We present here a model-free method enabling to quantify out of 3D tagging data the inhomogeneous deformation along extraocular muscles.

Methods: **Post-processing:** For data evaluation tissue landmarks used for tracking were imbedded into a 3D-mesh structure.(Figure 1) The distance between the landmarks being smaller than the image resolution after HARP filtering, the local geometry of the tracked 3D-mesh is expected to remain stable over the time frames. The mesh is defined by the four outermost polylines. The desired number of landmarks is equidistantly interpolated along and between these four polylines. After tracking each landmark independently in 3D space using peak-combination [6] and HARP [7], the local consistency of the mesh is checked and corrected. The landmark relative displacement (i.e. the local strain) is calculated on a scale bigger than the resolution but averaged on the resolution scale by a sliding window filter, giving independent results for each muscle segment. 3D-mesh were defined on five extraocular muscles: medial (MRM), lateral (LRM), superior (SRM) and inferior (IRM) rectus muscle, the superior oblique muscle (SOM) and the optic nerve (ON) (Figure 2,3).

Tagging data: A fMRI setup as described in [8] has been used for a reproducible and accurate eye movement during image acquisition (horizontal sinusoidal moving target, 2s period, peak velocity 64°/s, amplitude ±20°). A microscopy coil (47mm diameter) at 1.5T was placed on one orbit to acquire 3D CSPAMM (Complementary SPAtial Modulation of Magnetization [6,9]) TFEPI-images (40x18x18 scan-matrix, FOV=51x51x51mm^3, scantime 8min., 15 time phases of 70ms, rec.-resolution: 0.4x0.4x2.8 mm^3, EPI factor: 3, TFE factor: 3, tag-line distance: 3mm). Three datasets which were each motion encoded in one spatial dimension were acquired. A reduced field-of-view method with a localized tagging preparation was applied in order to keep acquisition time short. In order to prevent tag fading, an optimized ramped flip angle approach was applied (final flip angle=47°) [9,10].

Results: 3D-Mesh postprocessing allowed to quantify the inhomogeneous deformation along the extraocular muscles (Figure 2). The local contraction and relaxation of the horizontal rectus muscles, and the non-contracting optic nerve were similar to those observed with 2D tagging.[2] The IRM, SRM, SOM could also be tracked (Figure 2).

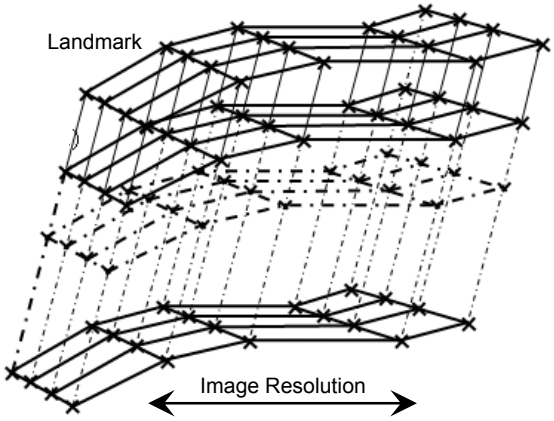

Figure 1: *3D Mesh of tissue landmark. The cells of the mesh are smaller than the image resolution. The geometrical consistency of the mesh permits to correct tracking instability due to noise or artifacts.*

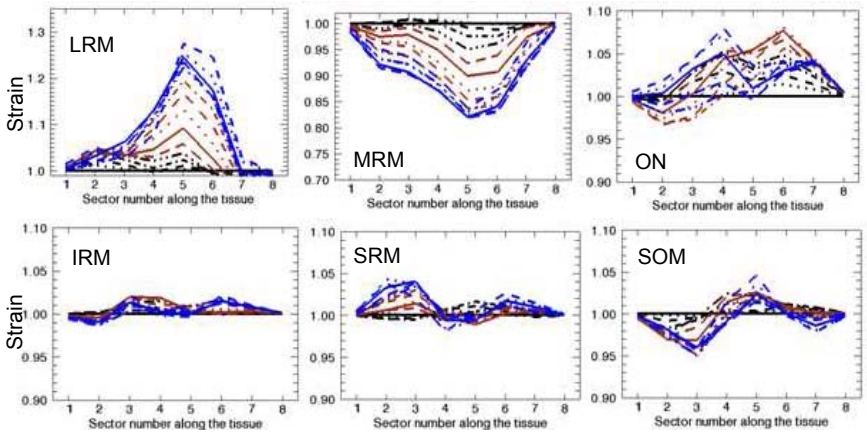

Figure 2: *Strain of segments along the relaxing LRM, contracting MRM, non-contracting ON, IRM, SOM, and SRM for right-to-left eye movement. The first five time frames were drawn in black, the middle five in brown, and the last five in blue. X-axis: the muscles are partitioned longitudinally into 8 segments. Segment 1 is on the sclera, Segment 8 at the orbital apex. Y-axis: each profile corresponds to one of the fifteen time frames. The line type has a period of 6 time frames.*

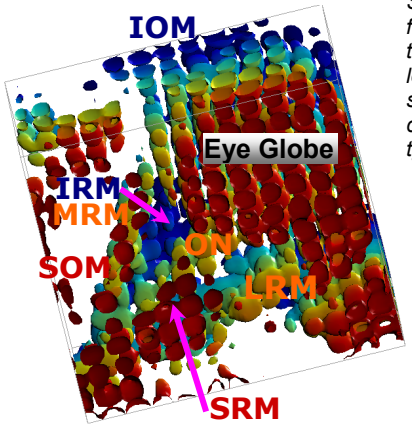

Figure 3: *3D isosurfaces representation of the tagging dataset representing the eyeball, the optic nerve and the six extraocular muscles. Color encoding correspond to the cranio-caudal coordinate so, that the orange level is approximately the slice of Figure 1, with the MRM, ON and LRM in orange; in red are the lower part of the superior rectus (SRM) and the superior oblique muscles (SOM) (the top is cut for visualization); in blue: the inferior rectus and the inferior oblique muscles.*

Conclusion: 3D-mesh allowed to quantify local muscle strain without using a deformation model. 3D-mesh is adaptable to other tissues.

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