Vitreal Viscoelasticity Revealed by Motion-Encoded MRI

M. Piccirelli[1,2], O. Bergamin[2], K. Landau[2], P. Boesiger[1], and R. Luechinger[1]

[1]Institute for Biomedical Engineering, University and ETH Zurich, Zurich, Switzerland, [2]Department of Ophthalmology, University Hospital, Zurich, Switzerland

Introduction: Retinal detachment results in visual loss and requires surgical treatment. The shear stress induced during eye movement by the vitreous on the retina can damage the retina. The following filling of the subretinal space with liquefied vitreous induce the detachment of the retina. Changes in the vitreous viscoelasticity impact on the shear stress. Up to now, the viscoelasticity of the vitreous has been measured ex-vivo and varied in function of the sampling location inside the eyeball.[1] Further, the vitreous deformation during eye movement has been simulated as a spherical homogenous fluid rotating around a diameter.[2,3] This analytical model uses two parameters (*a* and *b,* from which the viscosity and elasticity can be derived), and makes the assumption of homogeneous viscoelastic properties throughout the vitreous. The reported viscoelasticity[1] was used to describe the vitreous deformation,[3] as shown in Fig3C for 12 concentric circle (perpendicular to the rotation axis, with radii ranging from 1-12 twelfths of the eyeball radius) during sinusoidal eye rotation (±20° amplitude, 2s period).

However, the vitreous is divided into sectors by intravitreal membranes.[4] These intravitreal membranes may separate the vitreous into regions of different viscoelasticity and may also directly impact on the vitreous rheology. Here we present a MRI method to determine the vitreous deformation and viscoelastic properties in-vivo and clarify the role played by the intravitreal membranes.

Methods: All 15 subjects (6 women, 9 men, age range:22-62y/mean:34y) gazed at a horizontal sinusoidal moving target (2s period, peak velocity 64°/s, amplitude ±20°) for 4min. A microscopy coil (47mm diameter) at 1.5T (Philips Healthcare, Best, The Netherlands) was placed on one eye to acquire 2D CSPAMM (Complementary SPAtial Modulation of Magnetization)[5] images (FOV 140x140mm^2, scantime 4min., 15 time frames of 12ms every 70ms, scan-resolution 1.2x1.2x4mm^3 , EPI factor 5, tag-line distance 3mm). The lens center and the scleral insertion of the optic nerve were embedded in the image plane. The vitreous was overlaid at the 9th time phase with a 60x36 mesh centered on the center of rotation and with its outermost polygon on the sclera (in green in Fig1B). The vitreous was tracked using peak-combination[6] HARP[7] with a dedicated mesh algorithm. The rotation angle of each concentric polygon forming the mesh was evaluated. The rotation of these concentric polygons in function of time was fitted with the analytic viscoelastic model[3] for determination of the parameters *a* and *b*.

Results: The vitreous deformation over the whole movement range was successfully tracked in 13 volunteers having a monophasic vitreous (Fig1A-C). For these subjects, the vitreous deformation (Fig3A) could be fitted by the analytical model (Fig3B). By comparing the phase shift between the innermost and outermost polygons' rotation, these 13 volunteers split in 3 groups: phase shift bigger(3), smaller(6) or around(4) *pi*. As expected, the group with phase shifts bigger than *pi* (corresponding to gel-like vitreous) was the youngest. The difference between the observed deformation of the vitreous and the one expected from ex-vivo measurements of the vitreous viscoelasticity is remarkable (Fig3B-C), and presumably due to the presence of intact intravitreal membranes. For 2 subjects, the vitreous deformation was clearly polyphasic: some sectors of the vitreous were gel-like and others liquefied (Fig2). These sectors seams separated by flexible membranes (doted line on Fig2), corresponding to reported intravitreal membrane patterns.[4]

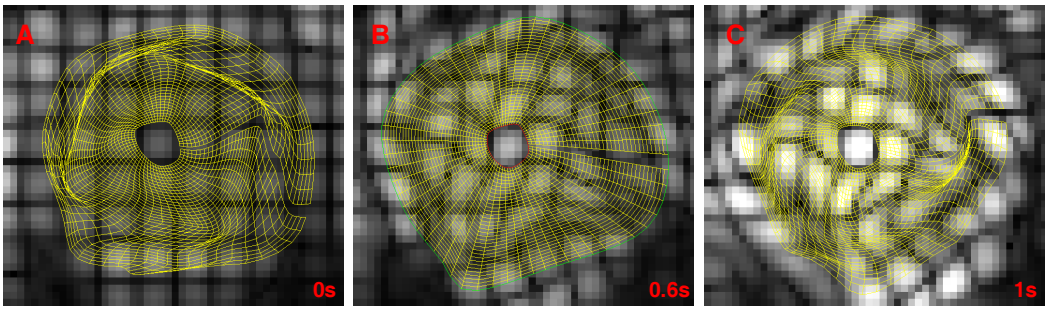

Figure 1: *CSPAMM image of the right eye at the 1st, 9th, 15th time frames. Superposed to the vitreous is the automatically tracked mesh (in yellow). The mesh was defined by radial interpolation of the red and green polygons. The rotation of each of these concentric polygons in function of time is reported in Fig3A.*

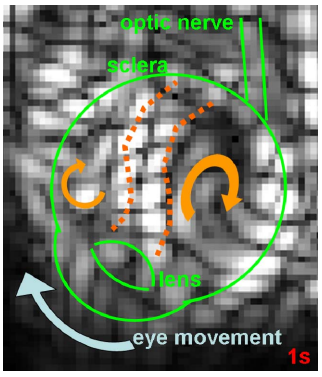

Figure 2: *The vitreous of this subject was polyphasic, i.e. divided - eventually by membranes (dotted lines) - into sectors with different viscoelastic properties. In the central sector the vitreous deforms only slightly. In the other sectors the eye movement induces the vitreous to whirl and therefore the tagging pattern to fade, making the deformation tracking impossible.*

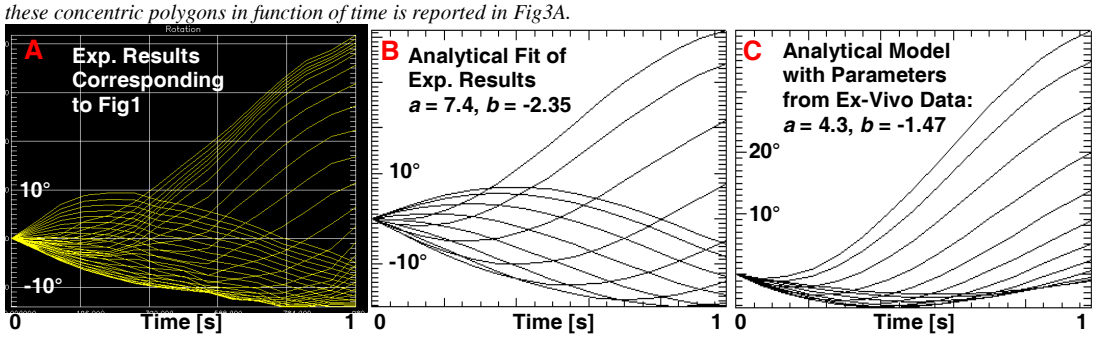

Figure 3: *(**A**) Rotation angle in function of time for each of the 36 concentric polygons of the mesh of Fig1. The outermost polygon undergoes a sinusoidal rotation with 40° amplitude, corresponding to the gaze target movement. The rotations of the other polygons differ in amplitude and phase. (**B**) Analytical model fit of the vitreous deformation depicted in Panel A, determining a and b, from which the viscoelasticity can be determined. For clarity only 1 curve out of 3 was drawn. (**C**) Deformation of the vitreous expected from the ex-vivo data.[1,3] For clarity only 1 curve out of 3 was drawn.*

Discussion: The deformation of the vitreous could be determined in-situ, so that the structure of the intravitreal membranes remained intact and their effect on the vitreous dynamic could be investigated. To check for correlation between the phase shift of polygons' rotation with age and myopia (known factor of vitreous liquefaction), the number of subjects still need to be increased. The analytical model (assuming homogeneous viscoelasticity) may not be adequate to describe the deformation of the intravitreal membranes, nevertheless "apparent" viscosity and elasticity of the subjects' vitreous could be determined (Fig3B). The use of HARP and of sequential acquisition (to shorten the time phase duration) allows the determination of the vitreous viscoelasticity, as discussed by Buchsbaum[2]. The vitreous deformation modifies the eye ball inertia and may impact on eye movement (control).[8] Finally, the determination of the vitreous viscoelasticity could help to assert the risk of retinal detachment and impact on surgery planning.

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