The three-dimensional shape of the myopic eye measured with MRI

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Target audience: MRI clinicians, researchers in ocular and vision science, ophthalmologists

Purpose: There is an increased interest in methods to measure and describe the three-dimensional shape of the retina, and its relation to myopia. For example, the refractive errors of the eye can partly be explained by the length of the eye along the optical axis, the axial length, which can be measured by optical techniques. Off-axis distances, however, cannot be measured by these techniques, because refraction induces potentially significant systematic errors.[1] Since MRI is not affected by refraction, in the recent years, it has become the main tool to measure the retinal shape.[2-4] One of the important findings is that the difference between the horizontal and vertical curvature of the retina leads to different refractive errors along the horizontal and vertical meridian.[2] However, the sensitivity of MRI to eye-motion has limited these evaluations to 2D or low-resolution 3D data of the eye. In this context, we describe a method that uses the advances in high field MRI to measure the full 3D ocular shape with high-resolution and we use this method to evaluate the relationship between 3D retinal shape and the refractive error.

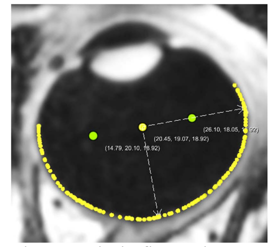

Fig. 1: Elliptic fit on high-resolution ocular MRI data

Methods: We examined 11 subjects with normal vision, |refractive error| < 0.5D, and 10 patients with mild to severe myopia (refractive error between -0.5D and -7D) with no further ocular pathologies. The examination consisted of an ocular MRI scan and auto-refraction measurement (Park 1, Oculus Inc., Arlington, WA). Four additional volunteers have been examined twice with MRI to assess the reproducibility of the method.

The ocular MRI was performed on a Philips Achieva 7 Tesla whole body magnet. The left eye was scanned with a custom-made dedicated 3-channel receive eye-coil, in combination with a volume transmit coil (Nova Medical Inc.,Wilmington, MA).[5] Eye-motion artefacts were minimized by the use of a cued-blinking protocol and the MR images were acquired using a 3D inversion recovery turbo gradient echo technique. The total MRI examination takes less than 15 minutes. The resulting MR-images were processed using an automatic segmentation algorithm, which detects the retinal contour with sub-pixel accuracy.[4]

The shape of the retina was quantified by fitting an ellipsoid to the detected contours and we used the obtained parameters as shape descriptors. In order to determine the number of contour points to be included in the ellipse fitting, a 2D fitting algorithm was applied and the accuracy and reproducibility of each fit was recorded for a range of percentages of included points. Subsequently, using this optimal percentage, 3D ellipsoid fitting was performed using the Sequential Least Squares Programming algorithm from the SciPy library. The fits were performed with the axes of the ellipsoid fixed to the optical axis, and the Left-Right and Feet-Head directions. An additional fitting procedure was programmed which allowed the ellipsoid to be rotated around the optical axis.

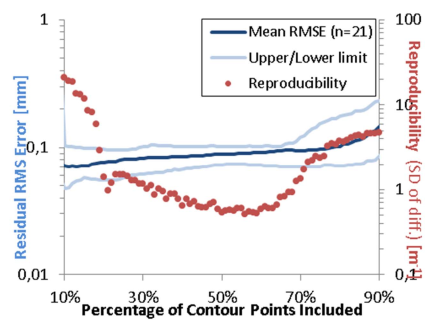

Fig 2. Goodness of fit and reproducibility as a function of amount of contour points included.

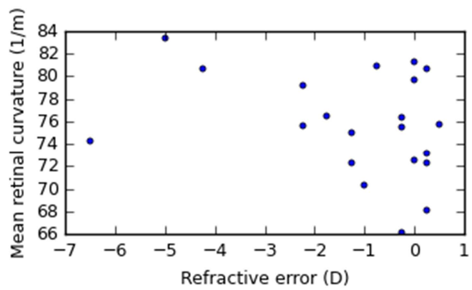

Fig 3. 3D fit results (A) The average retinal vertex curvature vs. myopia

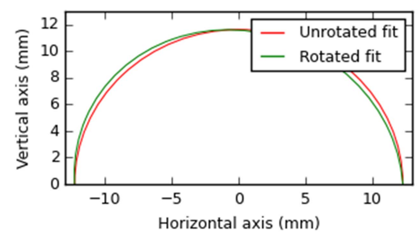

Fig. 4. 3D MRI data of eye allows for a better description of the retinal shape, since rotations around the optical axis can be taken into account. For this volunteer the maximal difference between an unrotated and rotated fit was 0.4mm.

Results: Fig. 1 gives an example of the 2D ellipse fit to the retina. The 2D fitting algorithms converged to ellipsoids with similar errors over a wide range of number of points used, fig 2, showing the retinal shape is well described by an ellipsoid. Only when more than 70% of the contour is used, the results start to deviate as the retinal shape starts to deviate from an ellipsoid near the crystalline lens and cilliary body. The reproducibility of the 2D ellipse fit was also stable for a wide range of number of included points (fig. 2). Therefore, for subsequent analysis 60% of the retinal contour was used as an input for the fit.

When the retinal shape is fitted in 3D with the axes of the ellipsoid fixed to the LR and FH directions, the previously described difference in horizontal and vertical vertex curvatures are reproduced ($73.8m^{-1}$ vs $77.5m^{-1}$ respectively).[2] When however the orientation of these two principle axes was left free as a fitting variable, for most (17/21) of the subjects a better fit is achieved by rotating the ellipsoid, fig 4 (mean maximal difference 0.2mm, range [0.0, 0.4]mm).

Discussion: The data supports the previously described increase of retinal curvature in emmetropia compared to myopia, fig. 3, ($74.8m^{-1}$ vs $77.0m^{-1}$).[2]

The main advantage of having full three-dimensional data is that it allows for a better description of the retinal shape that accounts for its potentially oblique orientation. Although this angle will average out over a large population, the improvements in descripting individual eyes are significant. This can be compared to astigmatism, the cylindrical component of spectacle glasses, whose angle also differs on the subject level. The 3D description of the retinal shape will be used in subject-specific ray-tracing eye models, enabling the evaluation of the refraction on the complete retina.

Conclusion: Ocular MRI is able to accurately measure and describe the retinal shape. Our results extend the previous 2D measures of the ocular shape to 3D. Furthermore, the high reproducibility of the method makes it a powerful tool to study the hypothesized change of eye shape the development of myopia.[6,7]

References: 1. Atchison et al. Opt. Vis. Sci. 88: E601 (2011); 2. Atchison et al. IOVS 46: 2698 (2005); 3. Verkicharla et al. Ophth Phys Opt 32: 184 (2012)
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