MRI-BASED QUANTIFICATION OF OPTIC NERVE TORTUOSITY AND SUBARACHNOID SPACE 3D GEOMETRY: RELIABILITY ASSESSMENT

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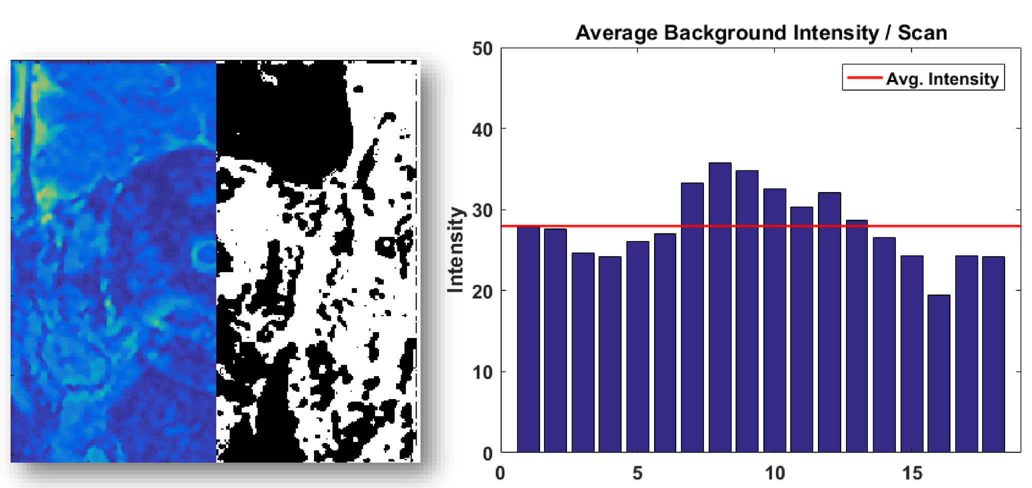
Abstract

In some astronauts, long-duration space flight results in ophthalmic structure changes such as optic nerve (ON) kinking, ON distention, and globe flattening. Assessment of the ON and ON sheath (ONS) may provide insight into the mechanisms responsible for ophthalmic structure changes seen in a subset of astronauts. Automated and manual methods were developed to quantify 3D ON/ONS geometry and ON tortuosity.

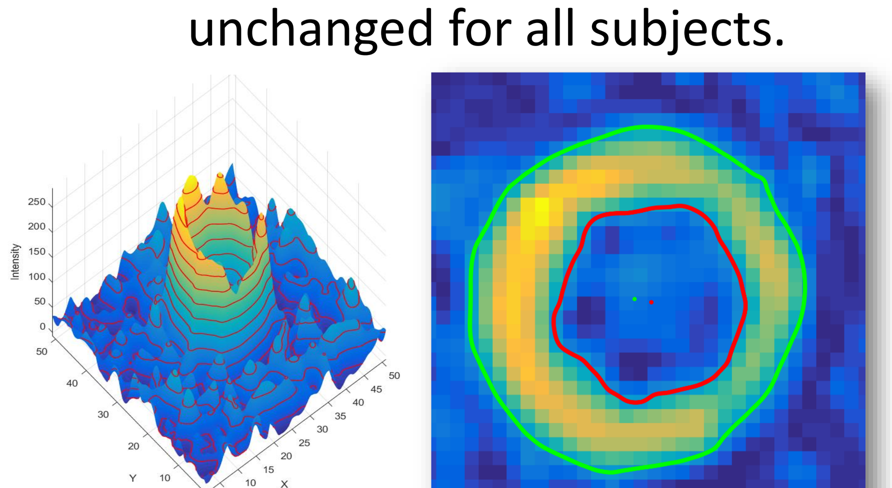
3D Assessment

Method: High-resolution T2-weighted coronal magnetic resonance (MR) images were collected. An offsetting procedure was applied to correct for variations in scan intensities. A threshold chosen by the user is used for segmentation of all slices in all scans. The result is ON and ONS contours with area, perimeter, and hydraulic diameter as parameters with respect to distance from the ON head (ONH)

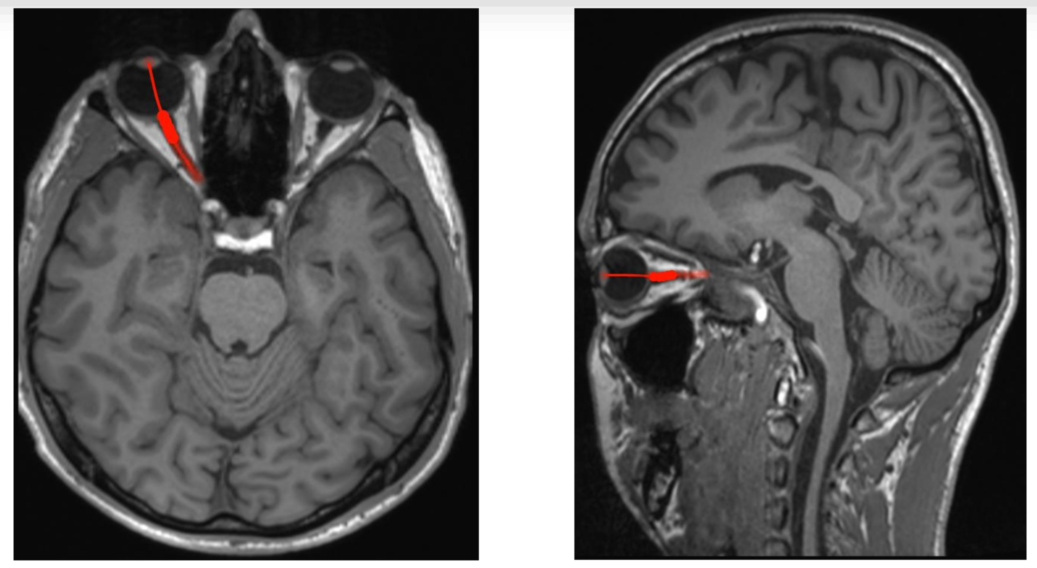


MR imaging (MRI) scan intensities were offset with the difference between average background intensity per scan.

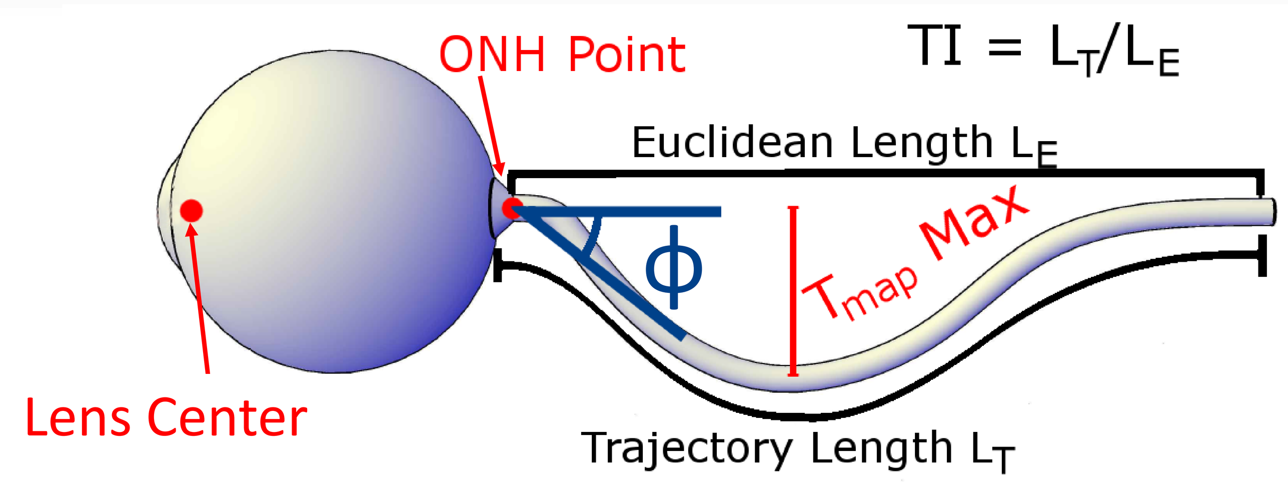
Threshold value chosen by user and left unchanged for all subjects.



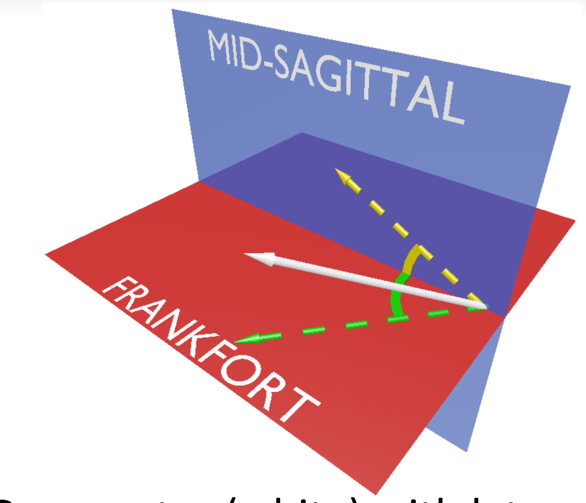
Interpolated contour generated at the specified threshold using MATLAB "Contour" and "Meshgrid" functions.



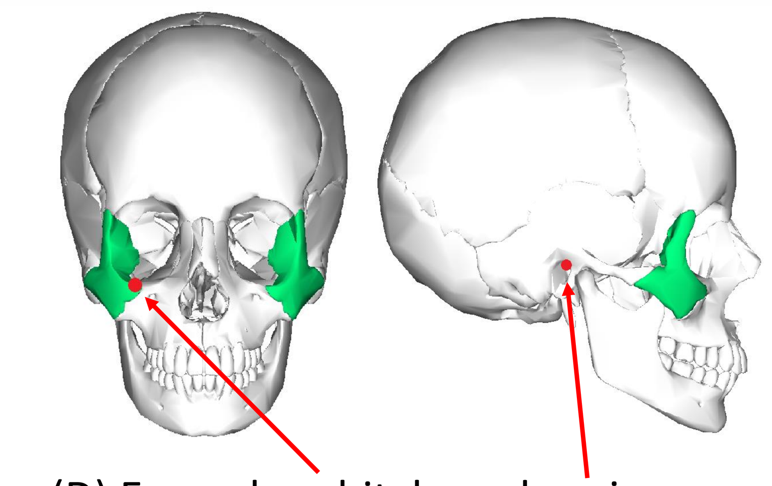
(A) Transverse and Sagittal views of example ON trajectory



(B) Optic globe and nerve with tortuosity parameters



(C) Gaze vector (white) with lateral (green) and vertical (yellow) gaze angles



(D) Example orbitale and porion locations

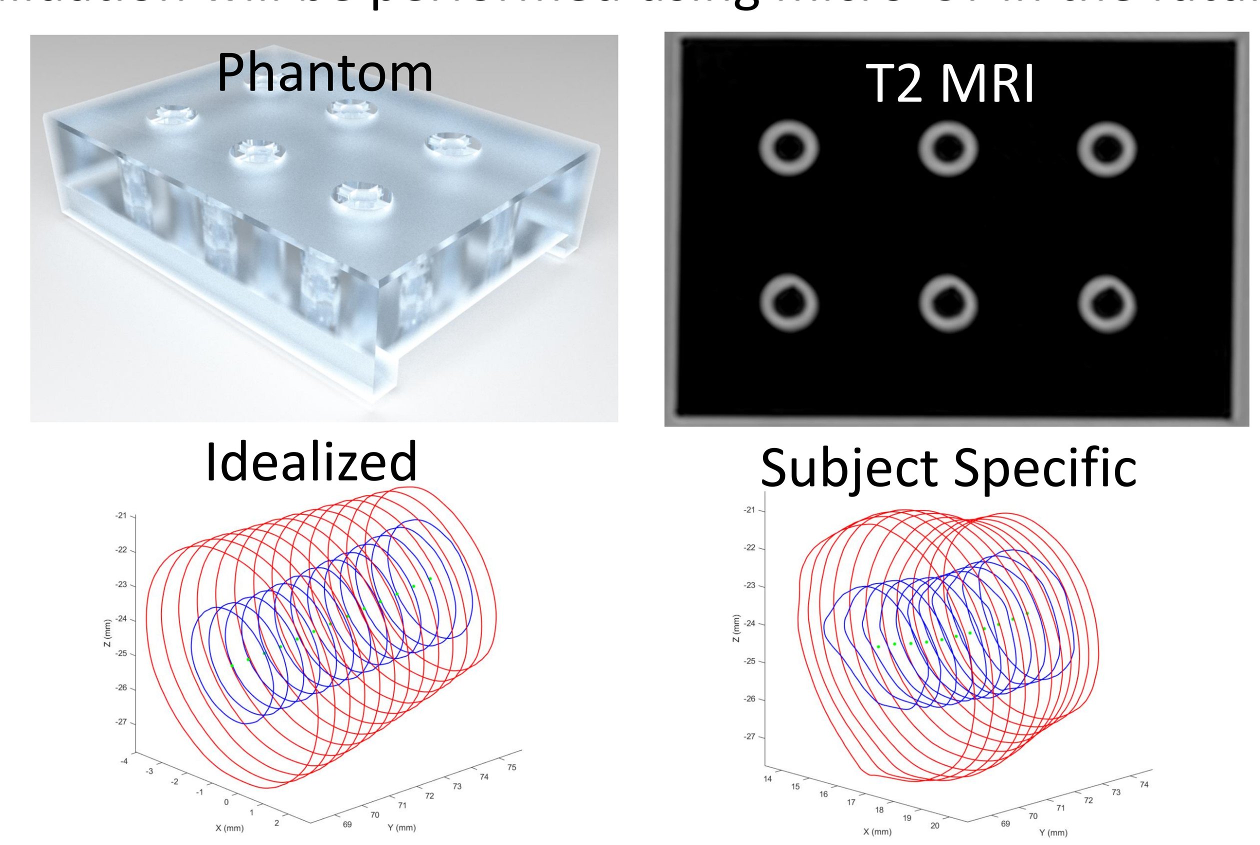
Test	Lens Center Location [µm] Ave. ± std	ONH Location [µm] Ave. ± std	Axial Length [mm] Ave. ± std	Left Porion Location [µm] Ave. ± std	Right Porion Location [µm] Ave. ± std	Orbitale Location [µm] Ave. ± std	Insertion Angle (ϕ) [°] Ave. ± std	Lateral Gaze Angle [°] Ave. ± std	Vertical Gaze Angle [°] Ave. ± std	Tortuosity Index (TI) [mm/mm] Ave. ± std	T_{map}max [mm] Ave. ± std
Intra-operator (N=1)	206 ± 94	368 ± 225	0.157 ± 0.166	452 ± 130	532 ± 298	773 ± 358	3.616 ± 2.507	0.528 ± 0.371	0.773 ± 0.576	0.002 ± 0.001	0.152 ± 0.112
Inter-operator (N=4)	266 ± 100	361 ± 202	0.167 ± 0.128	866 ± 631	1234 ± 817	1482 ± 1059	4.110 ± 3.075	0.575 ± 0.454	1.037 ± 0.757	0.003 ± 0.002	0.132 ± 0.114

Tortuosity Assessment

ON trajectories (A) were generated manually in Osirix MD software (version 8.0.1, Pixmeo, Geneva, Switzerland) using 3D multi-planar reconstruction (MPR) with high-resolution T1 weighted MRI. Lens and ONH points (B) were collected manually as the first two points of the ON trajectory. Axial length defines the Euclidean distance between these two points. Lateral and vertical gaze angles (C) were calculated using the gaze vector originating at the ONH and terminating at the lens center. Porion and orbitale points (D,E) defined the Frankfort horizontal [1] and mid-sagittal orientation planes. Lateral and vertical gaze angles were computed with respect to Frankfort and mid-sagittal planes. Insertion angle was calculated by comparing the gaze vector to a vector originating from the ONH and terminating at a point exactly 3 mm along the ON trajectory. Tortuosity Index (TI) was computed based on the ratio of 3D ON trajectory length to the Euclidean length (B). For TI calculation, the first 20 mm of ON trajectory posterior to the ONH was included. Tortuosity Map (F) is a plot of the orthogonal distances from each point along ON trajectory pathway to the respective point on the Euclidean pathway. This plot transforms the 3D trajectory into a 2D map. T_{map}max corresponds to the peak orthogonal distance from the Euclidean pathway.

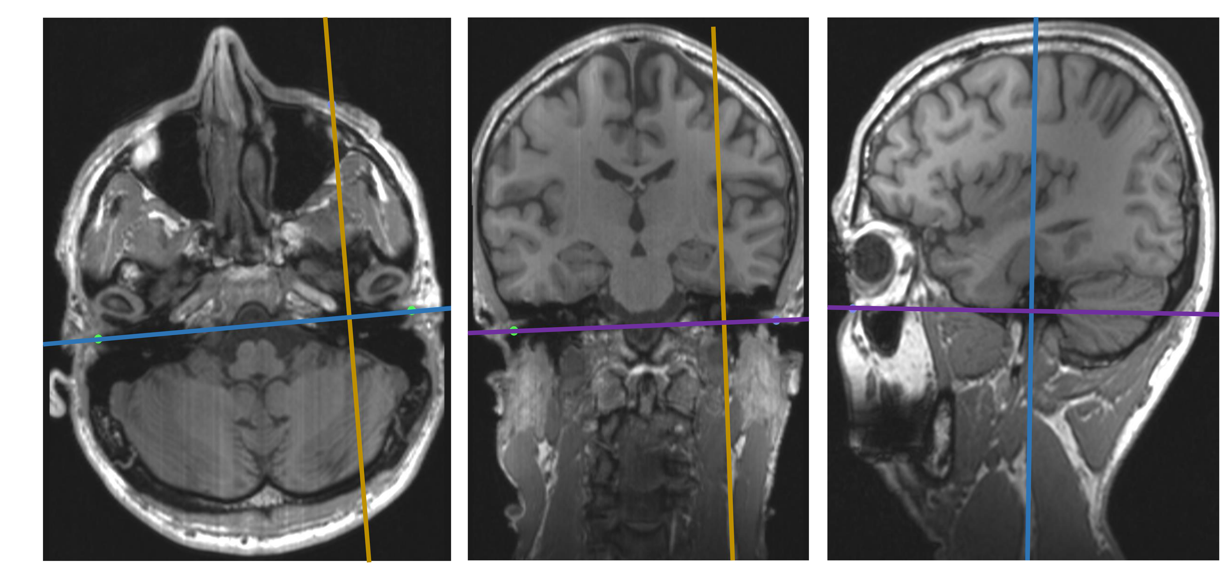
3D Verification: A 3D ON phantom model was developed with three idealized (identical) and three subject specific (identical) geometries. The model was scanned twice at one MRI center using the original study protocol with all six geometries within field of view.

Average error with one standard deviation and percent error for ON and ONS area parameters was computed with respect to the average measurement value. Validation will be performed using micro-CT in the future.

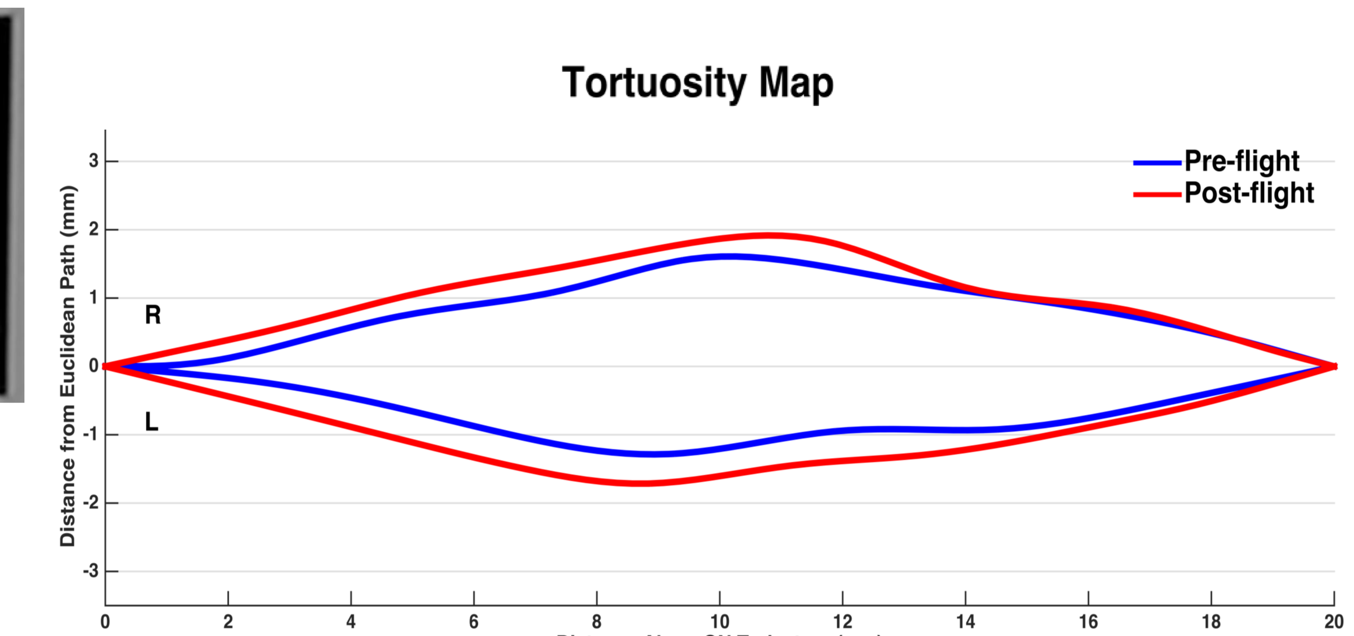


Geometry	ON Area Error [mm², %]	ONS Area Error [mm², %]
Idealized	0.361 ± 0.239 (1.69%)	0.496 ± 0.412 (0.86%)
Subject Specific	0.231 ± 0.188 (1.86%)	0.652 ± 0.727 (0.95%)

Tortuosity Verification: To assess intra-operator reliability, a single operator completed all measurements five times at intervals of at least three days. To assess inter-operator reliability, four operators completed all measurements three times at intervals of at least three days. Results were compared to find the average difference from the mean, as well as the standard deviation, for each parameter (see table). Results indicated a relatively high degree of intra- and inter-operator reliability for all parameters analyzed.



(E) Frankfort Plane highlighting porion and orbitale Points



(F) Example tortuosity map showing pre-/post-flight change in ON trajectory curvature due to space flight

Citations

[1] Daboul A, et al. (2012) *PLoS ONE* 7(10), doi: ARTNe4828110.1371/journal/pone.0048281.

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