Retinal Image Quality Assessment for Spaceflight-Induced Vision Impairment Study

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Introduction

Long-term exposure to space microgravity poses significant risks for visual impairment.[1,2] Evidence suggests such vision changes are linked to cephalad fluid shifts, prompting a need to directly quantify microgravity-induced retinal vascular changes.[3] The quality of retinal images used for such vascular remodeling analysis, however, is dependent on imaging methodology. For our exploratory study, we hypothesized that retinal images captured using fluorescein imaging methodologies would be of higher quality in comparison to images captured without fluorescein. A semi-automated image quality assessment was developed using Vessel Generation Analysis (VESGEN) software[4,5] and MATLAB® image analysis toolboxes. An analysis of ten images found that the fluorescein imaging modality provided a 36% increase in overall image quality (two-tailed *p*=0.089) in comparison to non-fluorescein imaging techniques.

Methods

A semi-automated image quality assessment was developed using NASA's Vessel Generation Analysis (VESGEN NTR 18724) software and MATLAB® image processing toolboxes. Image quality in ophthalmological clinical images was based upon three metrics: image sharpness, image contrast, and image detail.

❶ Image Sharpness
Image sharpness was determined using the Sobel edge detection algorithm.[6] Because the algorithm relies upon abrupt changes in image intensity gradients to determine image edges, blurred images have lower edge detection rates, and sharper images have higher edge detection rates.

❷ Image Contrast
In retinal images of good contrast following image inversion, vessels are of high intensity, while the background is of low intensity. Because of this, pixel intensity histograms of retinal images exhibit a bimodal distribution. Data were fit to a two-node Gaussian Mixture Model and the bimodal separation and bimodal amplitude were determined.[7]

❸ Image Detail
Grayscale ophthalmic clinical images were converted into binary trees using Adobe Photoshop®. From the binary images, vessel density for each branching generation (G1, G2, … Gx) was determined by normalizing the branching generation area by the total vascular tree area. A higher vessel density, especially for small vessels, defined here as branching generations greater than six (G≥6), suggests a higher level of image detail.

To ascertain if there was a statistically significant difference in the four measures between the two imaging modalities, a two-tailed *t*-test was performed, using an a priori significance level of 0.05.

Acknowledgements & References

Supported by the Space Life Sciences Training Program at NASA Ames Research Center, a NASA Human Research Program Award, NIH R01 HL110170 Award, and Wyle Laboratories.

1. Recapturing a Future for Space Exploration: Life and Physical Sciences Research for a New Era. Washington, D.C.: National Academies, 2011. http://www.nap.edu/catalog.php?record_id=13048
2. Mader TH, et al. Optic Disc Edema, Globe Flattening, Choroidal Folds, and Hyperopic Shifts Observed in Astronauts after Long-duration Space Flight. Ophthalmology 118(10):2058-69. 2011.
3. NASA Human Research Roadmap: Mapping by VESGEN of Blood Vessels in the Human Retina for Improved Understanding of Visual Impairments and Increased Intracranial Pressure. NASA. http://humanresearchroadmap.nasa.gov/tasks/task.aspx?i=1634
4. Parsons-Wingerter P, et al. Oscillation of Angiogenesis with Vascular Dropout in Diabetic Retinopathy by VESsel GENeration Analysis. Investigative Ophthalmology & Visual Science. 51(1): 498–507. 2010.
5. Vickerman MB, et al. "VESGEN 2D: Automated, user-interactive software for vascular quantification and mapping of angiogenic and lymphangiogenic trees and networks," *Anatomical Record A* 292(3):321-333 (2009).
6. Maini R, et al. Study and Comparison of Various Image Edge Detection Techniques. International Journal of Image Processing 3(1).
7. Zhang C, Mapes BE, Soden BJ. Bimodality in tropical water vapour. Q.J.R. Meteorological Society 129(594):2847-66. 2003.

Preliminary Results

Five images from each group (fluorescein and no fluorescein, Figure 1) were analyzed using the VESGEN/MATLAB® image quality assessment tool. As hypothesized, the fluorescein images were of higher quality and more sensitively displayed the presence of small vessels. The fluorescein group exhibited increases of 14%, -6%, and 60% in image contrast, sharpness, and detail, respectively, in comparison to the non-fluorescein group. The overall, scaled image quality scores for the fluorescein and non-fluorescein imaging methodologies were 6.48 and 4.13. This is a 36% increase in image quality using the fluorescein imaging methodology (*p*-value = 0.089).

Figure 1. Sample fluorescein image: (A) Original image, (B) Edge trace by Sobel filtering, (C) Pixel intensity histogram, (D) VESGEN venous tree segmented for G1-G9 with pseudo-colored legend. (E) VESGEN segmented venous tree, grouped into large (G1-G3, red), medium (G4-G5, orange), and small (G≥6, yellow) vessels. Sample non-fluorescein image: (F) – (J).

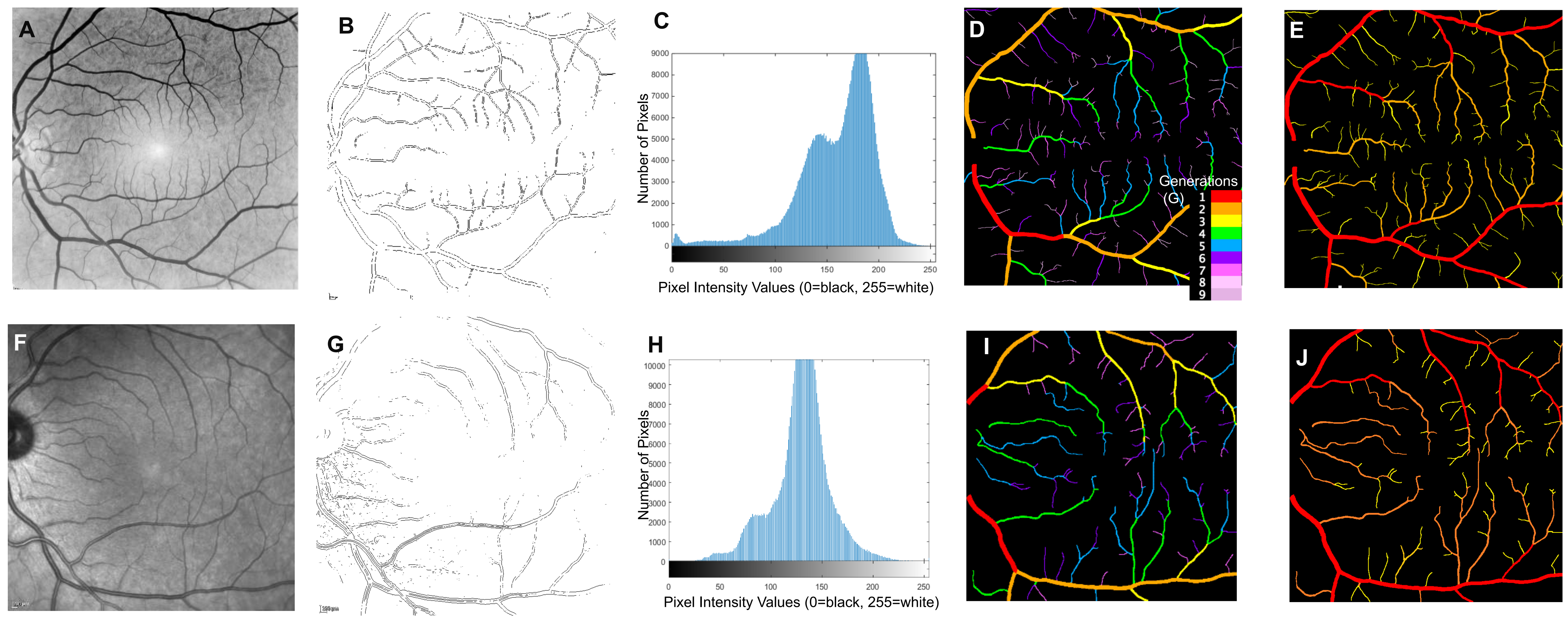

	Image Sharpness			Image Contrast			Image Detail			Image Quality Score		
	Mean	SD	*p*-value	Mean	SD	*p*-value	Mean	SD	*p*-value	Mean	SD	*p*-value
FA	0.145	0.054	0.751	1.211	0.253	0.018	1.776	0.190	0.196	6.48	1.49	0.089
Non-FA	0.153	0.024		0.496	0.543		1.524	0.351		3.92	2.30	

Conclusions

An analysis of ten images found that the fluorescein imaging modality provided a 36% increase in overall image quality, suggesting that the use of fluorescein during retinal imaging improves overall image quality, and in particular, the detection of clinically important vessels of small diameter. This result has significant implications; previous work has shown that small vessel remodeling is a key indicator of pathological progression.[4] However the difference in image quality score between the two imaging modalities was not statitistically significant (*p* = 0.089). The statistically insignificant improvement in image quality may be due to several reasons: The FA and non-FA images were drawn from two separate populations - diabetic retinopathy and astronaut studies, respectively. Physiological differences between the two populations may have affected results. In addition, the small sample size may have skewed results.

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Discussion

The VESGEN/MATLAB® image quality assessment software protocol provides an automated, quantitative method to assess retinal image quality for vascular branching analysis. With this new assessment, we hope to help guide and inform future studies on the quality of different imaging methodologies. More broadly, this work may be applied to other microgravity vision studies, clinical retina studies, and to vascular remodeling studies of other systems. Future work includes refining the current image analysis algorithms and working with larger data sets to generalize the study's results.