Retinal Image Quality Assessment for Spaceflight-induced Vision Impairment

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INTRODUCTION

Visual and ocular impairments that may be associated with increased intracranial pressure (VIIP) were reported in 2011 as a recently discovered, high-priority risk for astronauts.[1] The incidence of VIIP is greater than 60% following long-duration missions to the International Space Station (ISS). Serious, sometimes persistent symptoms of VIIP include hyperopic vision shifts (farsightedness), optic disc edema, globe flattening, choroidal folds, and cotton wool spots. NASA is seeking to understand the causes of VIIP, and to develop effective countermeasures prior to future long-duration missions such as to Mars. The etiology of VIIP remains poorly defined. We are investigating the potential role of blood vessels within the retina in the development of VIIP by analysis of a well-established analog to microgravity, head-down tilt (HDT). The response of blood vessels in the human retina to 6° HDT after 70 days of bed rest (BR) are mapped and quantified with NASA's VESsel GENeration Analysis (VESGEN) software. Developed by NASA to quantify vascular remodeling, VESGEN has been applied successfully to the human retina[2] and to a number of model organisms important to space biology research[3].

PURPOSE

For the BR study the retina was monitored by Heidelberg Spectralis® infrared (IR) imaging, in which image quality is limited by the resolution of small vessels. However, small vessels remodel actively in response to physiological stress. The aim of this study is therefore to develop an Image Quality Assessment tool to quantify and compare the capture and resolution of small vessels by various imaging modalities. For images acquired by Spectralis® fluorescein angiography (FA), a fluorescent dye is injected into the bloodstream to increase resolution of small blood vessels. For the Image Quality Assessment, non-FA images from (healthy) BR subjects are therefore compared with FA images from normal subjects participating in a clinical study on diabetic retinopathy. **We hypothesize that the FA Spectralis images are of higher quality than the non-FA Spectralis® IR images.** The hypothesis was tested by the Retinal Image Quality Assessment that examines Image Sharpness, Vessel Likeliness, Contrast, and Detail using VESGEN and other software programs.

METHODS

A semi-automatic Image Quality Assessment[4] is being developed for VESGEN applications with MATLAB® software (Mathworks). The plugin evaluates the quality (suitability) of a grayscale ophthalmic image for VESGEN analysis. For the current study, FA and non-FA Heidelberg Spectralis® images of human retinal blood vessels were evaluated and compared (n=5). The Image Quality Assessment was calculated by weighted analysis from four metrics as described below. Statistical testing of differences in the four metrics was performed with Student's t-test using unequal variances and an a priori two-sided significance level of 0.05.

1) Image Sharpness:

The Image Sharpness was determined by the Laplacian algorithm for edge detection. The algorithm estimates the edges of features such as blood vessels by calculating the second derivatives of intensity gradients defining the features. Blurred images are characterized by lower intensity gradients, and sharper images by higher gradients.

2) Image Vessel Likeliness:

The Image Vessel Likeliness is estimated using Frangi's filter[5] to predetermine which vessels are readily identifiable in the image. The algorithm utilizes dissimilarity and second order structure within an image to estimate the likelihood of tubular structures resembling vessels. The structures are displayed in a Vessel Likeliness intensity image.

3) Image Contrast:

The Image Contrast identifies vessels as high intensity pixels and background as low intensity pixels. A histogram of pixel intensity within the vascular image results in a bimodal distribution. The histogram data are fit into a Gaussian Mixture Model to compute the bimodal amplitude and separation for the Image Contrast score.

4) Image Detail:

The Image Detail is assessed from the ratio of the area of smaller branching generations of blood vessels to the total vascular area. Grayscale ophthalmic clinical images are first converted into binary images of branching arterial and venous trees with Adobe Photoshop®. Vascular areas per branching generation are quantified by VESGEN according to physiological branching rules. A larger vascular area, especially for small vessels, defined here as branching generations (G_x)greater than six ($G_{>6}$), indicates increased level of detail (resolution) within the image.

PRELIMINARY RESULTS

Images from the non-FA and FA groups were analyzed using the VESGEN/MATLAB® Image Quality Assessment tool (Figure 1). Image Sharpness yielded 4.2% higher resolution in FA images compared to non-FA images. By Vessel Likeliness, FA images scored 3.4% higher for tubular structure than non-FA images. By Image Contrast, quality of the FA images was 31.7% higher than of non-FA images, despite non-uniform contrast resolution of the FA images. The FA images also scored 11.3% higher for Image Detail than non-FA images, due to a larger number of small vessels. Overall, the Image Quality Assessment score was as 5.6% higher for the FA images than for the non-FA images.

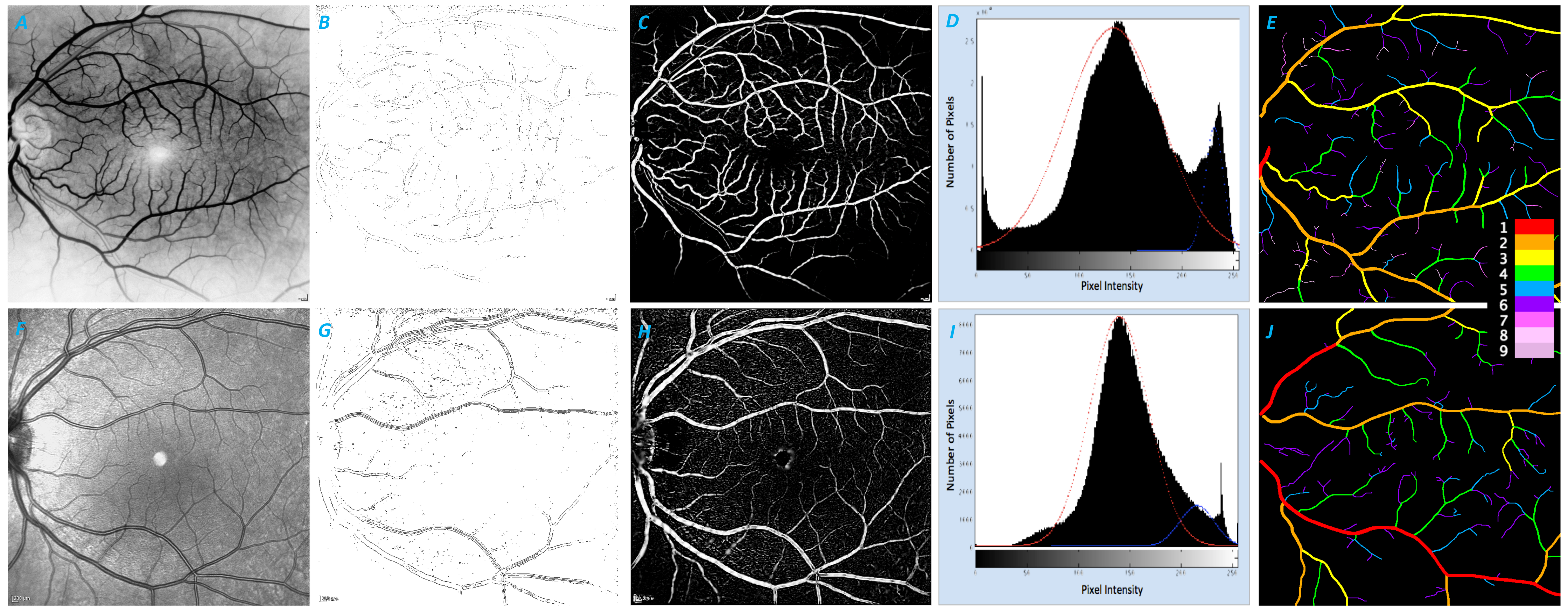

Figure 1. Image Quality Assessment calculated from four metrics. (A, F) Clinical FA and non-FA images; (B, G) Image Sharpness by Sobel edge detection; (C, H) Vessel Likeliness for tubular structures; (D, I) Image Contrast from histogram of pixel intensity (E, J), and venous trees segmented by VESGEN into G_1–G_9 (with colored legend).

	Image Sharpness Score			*Vessel Likeliness Structure Score*			*Image Contrast Score*			*Image Detail Score*			*Image Quality Score*		
	Mean	Std. Dev.	p-value	Mean	Std. Dev.	p-value	Mean	Std. Dev.	p-value	Mean	Std. Dev.	p-value	Mean	Std. Dev.	p-value
FA	12.70	10.40	0.467	0.72	0.06	0.21	0.40	0.20	0.15	1.59	0.30	0.18	3.85	2.64	0.42
Non-FA	12.17	10.39		0.69	0.02		0.28	1.82		1.41	0.28		3.64	2.61	
% Difference	4.2			3.4			31.7			11.3			5.6		

DISCUSSION

The VESGEN/MATLAB® software protocol for Image Quality Assessment is currently a semi-automated, quantitative method for calculating image quality and capture of important vessel detail. With this new method, we seek to guide and inform future studies on the quality of various vascular imaging methodologies. To further advance the technology, we will automate more fully the extraction of vascular structure, in part by adaptive thresholding (Figure 2). Other goals include refining the current image analysis algorithms and working with larger data sets to improve statistical power. In the future, the Image Quality Assessment may be applied to astronaut and terrestrial retinal health, and to vascular remodeling in other tissues.

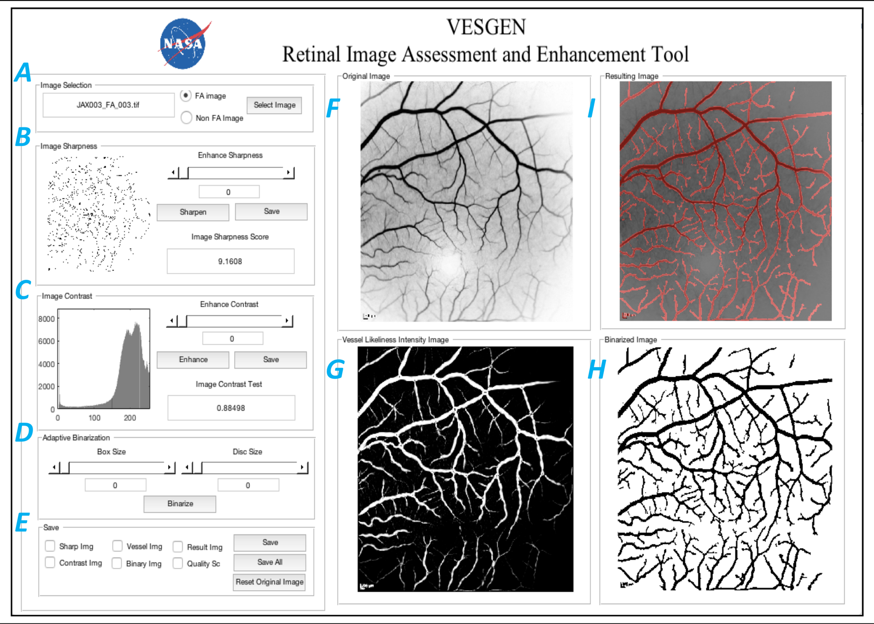

Figure 2. Interface for Retinal Image Assessment and Enhancement Tool with following adjustable parameters:
(A) Image Selection
(B) Image Sharpness
(C) Image Contrast
(D) Adaptive Thresholding
(E) Save Results
(F-I) Images for Clinical Input Image (F), Vessel Likeliness (G), Binary (H), and Result (I).

CONCLUSION

From preliminary results, the FA images achieved 4.2%, 3.4%, 31.7% and 11.3% better resolution across the four metrics in the Image Quality Assessment. The overall Image Quality score was 5.6% greater for FA images than for non-FA images.

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