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Significant Difference in Loss of Self-Similarity Between OCT Angiography of Eyes With and Without Nonproliferative Diabetic Retinopathy

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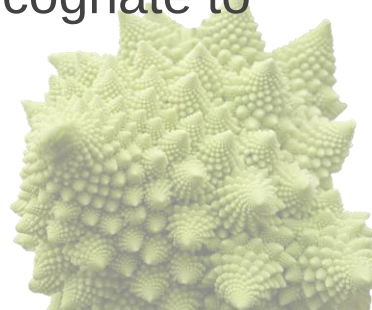
Financial Disclosure For All Authors: None

Background

OCTA technology provides quantitative information about the retinal vasculature. However, quantitative analysis has lagged behind. Surface area vascular density measurements are inherently non-physiologic and our group has shown fractal dimension to be a statistically significant parameter to distinguish NPDR from normal retinas. In this study, we introduce First Local Peak (FLP) analysis as a mathematical cognate to microvascular dropout.



What Are Fractals?

Fractals are patterns found in geographical and biological systems that demonstrate the same level of complexity and general pattern regardless of the scale on which they are measured. This property is called “Self-Similarity”

Fractal geometric analysis is a non-Euclidian mathematical framework used to assess the fractal nature of biological structures.

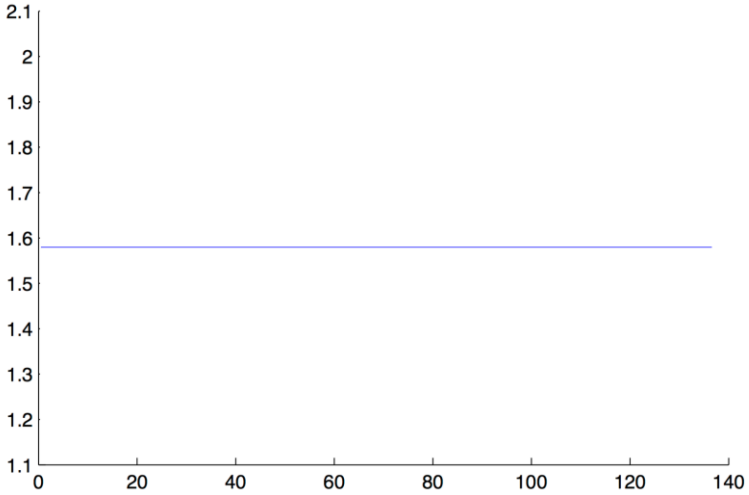
The degree of complexity of such a shape is described by the parameter‘‘fractal dimension’’ (FD) whose value is less than the spatial dimension subtended by the pattern.

Images By Author

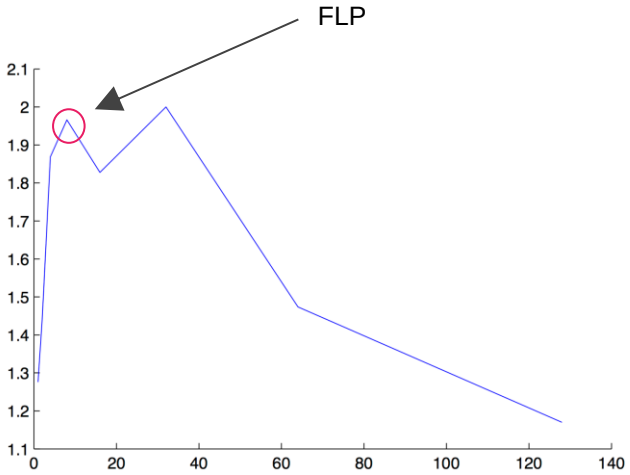
The romanesque broccoli is a great example of a fractal object found in nature. Viewed at a large scale a pattern can be discerned.

As we zoom in to smaller and smaller scales, it is clear that the pattern is repetitive. Put in other words, the pattern defined by the broccoli is scale independent or ***self-similar.***

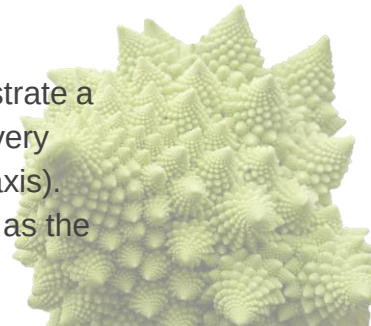
First Local Peak



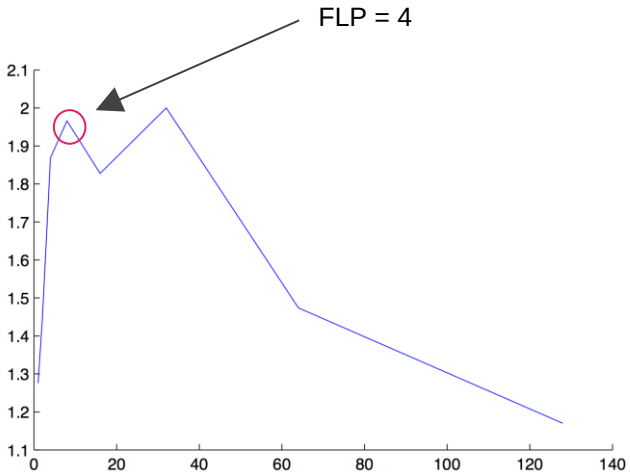
The ideal fractal pattern would demonstrate the same level of complexity (y-axis) as defined by fractal dimension (FD) over all scales (x-axis).



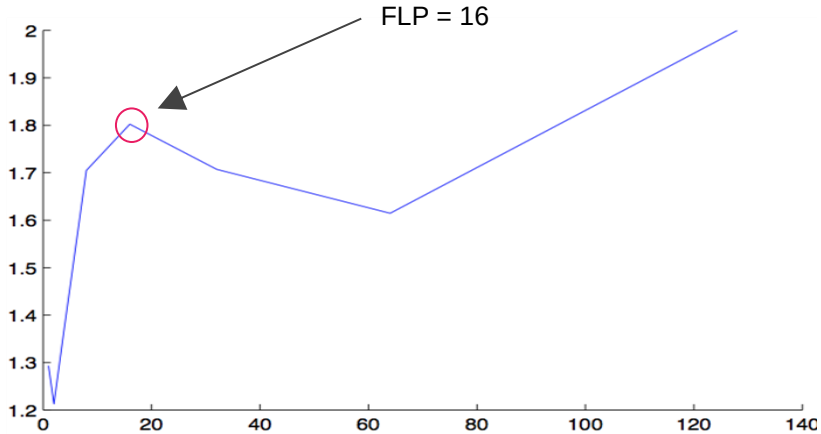
Real retinal vascular patterns demonstrate a precipitous loss of complexity on the very smallest scales (low values on the x-axis). We define the highest initial FD value as the First Local Peak (FLP).



First Local Peak - Histopathologic Relevance



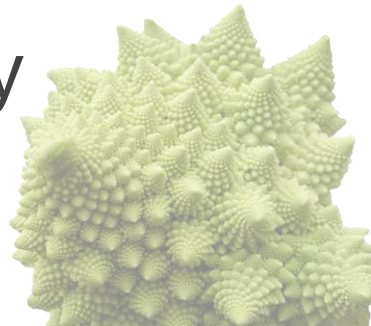
Larger FLP values indicate loss of complexity at larger scales. That means that smaller scales are less complex.



With OCTA, larger FLPs mean that the microvasculature has less complex branching than larger vessels. Clinically, this means that there is microvascular dropout.

Purpose

We used first local peak fractal dimensional analysis to determine whether differences exist between normal and nonproliferative diabetic retinal vascular disease burden with spectral-domain optical coherence tomography angiography (OCTA).



Methods

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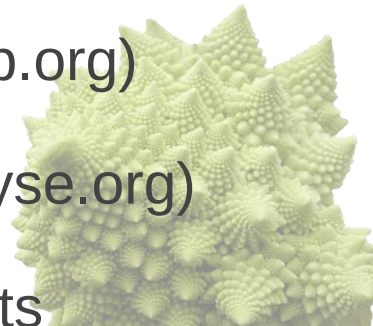
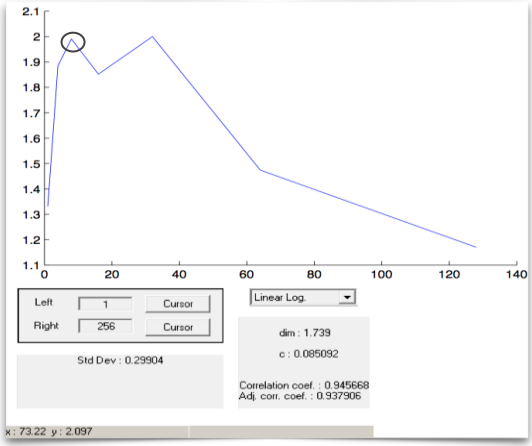
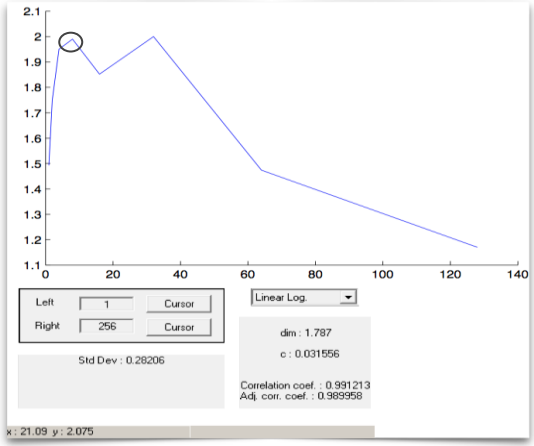
- 10 eyes with different stages of NPDR
- 58 normal eyes
- OCTA images were taken of the superficial and deep retinal capillary plexuses
- Images were converted to grayscale using GIMP (gimp.org)
- Fractal dimensional analysis using Fractalyse (Fractalyse.org)
- Unpaired T-test in excel was used to analyze the results



First Local Peaks (Normals)



Superficial

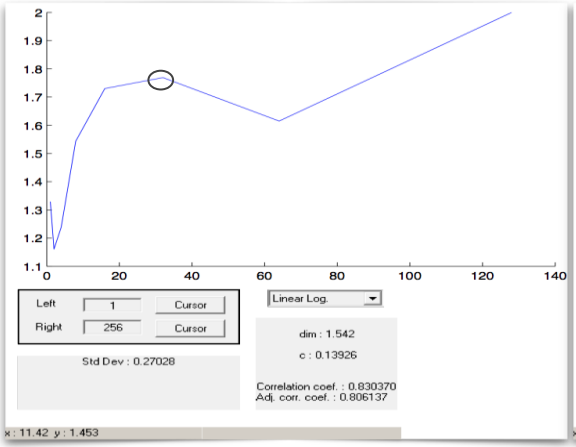


Deep

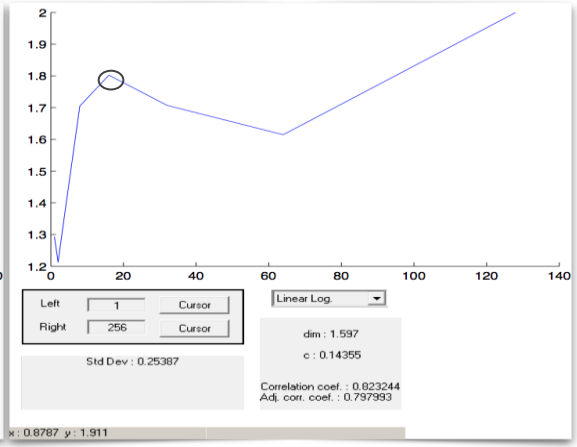
All of the First Local Peak (FLP) values for 104 normal images were at 8 pixels. The FLP is the circled point on both of the images. The FLP on all of the graphs is the point at which the retinal vasculature loses self-similarity.

Images By Author

First Local Peaks (NPDR)

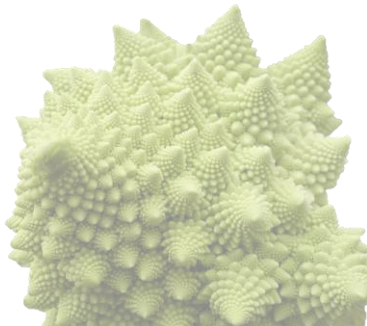


Superficial



Deep

The First Local Peak (FLP) for all 20 NPDR images was at either 16 or 32 pixels. The FLP is the circled point on both of the images.



Images By Author

Results

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Normal eyes stopped being self-similar at scales of 8^2 pixels

NPDR eyes stopped being self similar on average at 20.8^2 pixels

NPDR retinas demonstrated statistically significant increases in FLP compared to normals in the superficial plexus ($p = 5.36 \times 10^{-4}$)

NPDR retinas demonstrated statistically significant increases in FLP compared to normals in the superficial plexus ($p = 2.02 \times 10^{-4}$)

Discussion

FLP analysis is a novel method of assessing loss of microvasculature and is independent of overall vascular density. To the best of our knowledge, this is the first use of loss of self-similarity as a clinical indicator and provides not only a measure that can distinguish microvascular disease in nonproliferative diabetic retinopathy, but also one that illustrates the scale of the vessels lost in nonproliferative diabetic retinopathy. FLP analysis may hold value in other vascular retinal diseases in defining the scale of the vessels involved and may be of value in studying glaucoma as well.