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Characterization of nano sensitive sub-micron scale tissue-structural multifractality and its alteration in tumor progress

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Abstract

Assessment of disease using OCT is an actively investigated problem, owing to many unresolved challenges in early disease detection, diagnosis and treatment response monitoring. The spatial scale to which the information can be obtained from the scattered light is limited by the diffraction limit (~λ/2; λ = wavelength of light is typically in the micron level) and the axial resolution of OCT systems is limited by the inverse of spectral bandwidth. Yet, onset or progression of disease /precancer is typically associated with subtle alterations in the tissue dielectric and its ultra-structural morphology. On the other hand, biological tissue is known to have ultra-structural multifractality. For both the fundamental study of biological processes and early diagnosis of pathological processes, information on the nanoscale in the tissue sub-micron structural morphology is crucial. Therefore, we have developed a novel spectroscopic and label-free 3D OCT system with nanoscale sensitivity in combination of multifractal analysis for extraction and quantification of tissue ultra-structural multifractal parameters. This present approach demonstrated its capability to measure nano-sensitive tissue ultra-structural multifractality. In an initial study, we found that nano-sensitive sub-micron structural multifractality changes in transition from healthy to tumor in pathologically characterized fresh tissue samples. This novel method for extraction of nano-sensitive tissue multifractality promises to develop a non-invasive diagnosis tool for early cancer detection.

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1 Introduction

Nano sensitive optical coherence tomography (nsOCT) is an established technique to map 3D dominant sub-micron tissue structure with nano sensitivity [1-4]. The flow chart of nsOCT study technique can be found here [4]. Multifractal detrended fluctuation analysis (MFDFA) technique is a statistical method to determine multi-scale self-similarity in physiological time series or spatial refractive fluctuations in tissue morphology [5-13]. The two-dimensional MFDFA, which is a generalization of one dimensional MFDFA has been studied and validated by Gao-Feng and Wei-Xing [14]. The trend of the surface fluctuation or surface roughness is determined by fitting it with a bivariate polynomial function and subsequent detrending calculation provides surface roughness [14]. Then, a fluctuation function calculation over the detrended surface and its scaling behavior provides multifractal parameters [14], namely Hurst exponent (**h(q=2)**) and width of singularity spectrum (**Δα**) for surface morphology characterization [14]. In this present study, we have used 2D-MFDFA to determine nano sensitive sub-micron structural roughness in each enface image of nsOCT map throughout the depth of each tissue samples.

2 Results and discussions

Figure 1(a) displaying Hurst exponent variation over 0.35 mm depth for healthy (blue line) and tumor tissue (red line). Each depth corresponding to enface nsOCT images. Results indicates a reduction of Hurst exponent (**h(q=2)**) or correlation in surface ultra-structure as tumor progress.

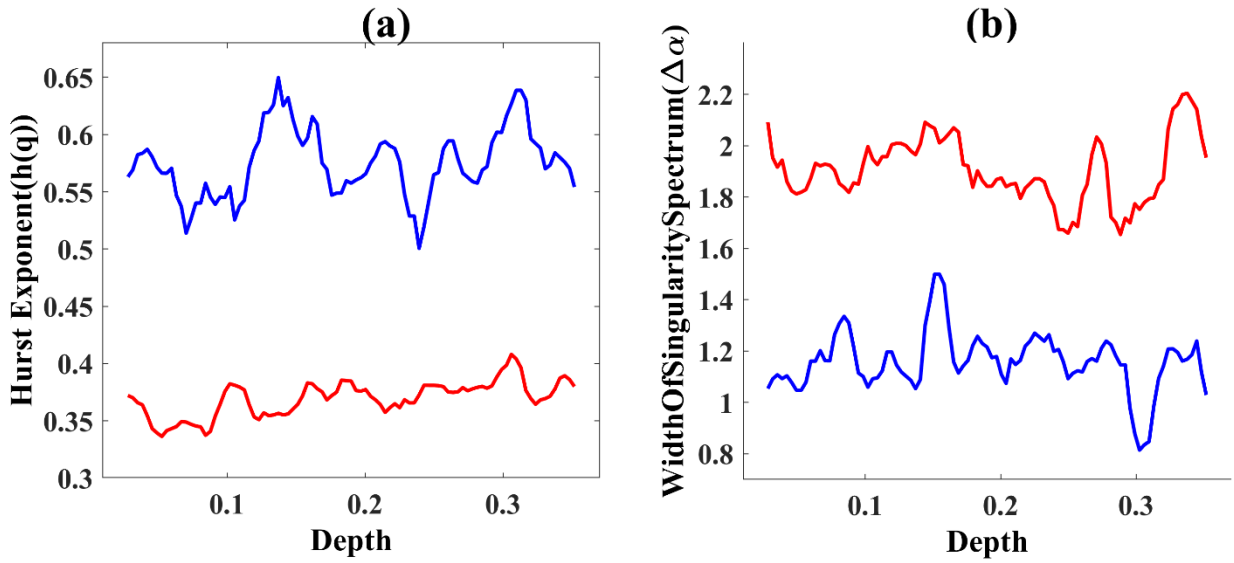

Figure1: (a) The Hurst exponent (**h(q=2)**) represents correlation of nano structures in enface images over depth. Blue line represents variation of mean **h(q=2)** in healthy tissue depth. Red line represents variation of mean (**h(q=2)** with tumor tissue depth. **(b)** The width of singularity spectrum (**Δα**) represents randomness of nano structures in enface images. Blue line represent variation of mean **Δα** in healthy tissue depth. Red line represent variation of mean **Δα** in tumor tissue depth.

Figure 1(b) displaying variation of width of singularity spectrum (Δα) over 0.35 mm depth for healthy (blue line) and tumor tissue (red line) tissue. Each depth corresponding to enface nsOCT images. Results indicates an enhancement of width of singularity spectrum (Δα) or roughness in surface ultra-structure as tumor progress.

Figure 1(b) displaying variation of width of singularity spectrum (**Δα**) over 0.35 mm depth for healthy (blue line) and tumor tissue (red line) tissue. Each depth corresponding to enface nsOCT images. Results indicates an enhancement of width of singularity spectrum (**Δα**) or roughness in surface ultra-structure as tumor progress.

3 Conclusions

We have developed nano sensitive sub-micron scale multifractal analysis technique to characterize tissue ultra-structural morphology. Reduction of the Hurst exponent (**h(q=2)**) from healthy to tumor indicates reduction of correlation / self-similarity in dominant sub-micron structures. Increase of width of singularity spectrum (**Δα**) from healthy to tumor indicates increase of multifractality or roughness in dominant nano sensitive sub-micron tissue structures. This newly developed method promises early disease detection for better treatment and treatment response monitoring of cancer patients.

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