Characterization of Human Cardiac Tissue with Polarization-Resolved Second-Harmonic Generation Microscopy

Kamdin Mirsanaye[1], Edvardas Žurauskas[2], Jonas Venius[2], Ricardas Rotomskis[2], and Virginijus Barzda[1]

[1]Department of Physics, Department of Chemical and Physical Sciences, University of Toronto, Canada

[2]National Cancer Institute, Vilnius, Lithuania

Email: kamdin.mirsanaye@mail.utoronto.ca

KEY WORDS: Nonlinear Microscopy, Polarization-Resolved Second-Harmonic Generation, Human Cardiac Tissue, Heart Conduction System, Biomedical Imaging, Collagen, Muscle.

Polarization-resolved Second-Harmonic Generation (P-SHG) microscopy enables label-free imaging of non-centrosymmetric collagenous and muscular biological tissues. P-SHG provides detailed information regarding the structural properties of the sample, beyond the diffraction limit. The extracted structural information is in the form of ratios of the second order nonlinear susceptibility tensor elements, $\chi^{(2)}_{ijk}$. Imaging of the sample is conducted with a Yb:KGW laser at 1038nm, with 400 fs pulses. The prepared polarization states of the fundamental beam, combined with the polarization measurements of the SHG signal allows for the extraction of second order nonlinear susceptibility element ratios, such as $R = \chi^{(2)}_{zzz}/\chi^{(2)}_{zxx}$ (xz-plane is the image plane) [1]. The ratio R signifies the extent at which the polarization of the excitation beam is modified, following the interaction with the nonlinear medium. In addition to R, degree of linear polarization (DLP), as well as, in-plane and out-of-plane fiber orientations are used to further characterize the structure of the tissue constituents [2].

In this work, reduced Stokes-Mueller polarimetry is utilized in P-SHG microscopy to study the structure of collagen and muscle fibers found in different regions of the human cardiac tissue. It is shown that ratio R ranges from 0.7 to 1.9 in muscle fibers, as compared to 2.0 to 2.4 in collagen corresponding to different fiber orientations. In addition to the clear variations between collagenous and muscular tissues, the value of R draws significant distinctions between similar tissue types in different regions. These findings suggest structural differences between seemingly similar tissue types, appearing due to microscopic and/or molecular structural variations.

P-SHG microscopy allows for precise investigations of subtle structural variations in the biological tissues, with applications reaching beyond general tissue characterization. It has been shown that P-SHG can be used in histopathology [3], offering great potential for in-vivo optical biopsy investigations and biomedical diagnostics.

[1] R. Cisek, "Structural Investigation of Biological and Semiconductor Nanostructures with Nonlinear Multicontrast Microscopy," Thesis / Dissertation ETD. (2012)

[2] Tokarz, et al., "Ultrastructural features of collagen in thyroid carcinoma tissue observed by polarization second harmonic generation microscopy," *Biomed. Opt. Express* 6(9), 3475–3481 (2015)

[3] Golaraei, et al., "Changes of collagen ultrastructure in breast cancer tissue determined by second-harmonic generation double Stokes-Mueller polarimetric microscopy," *Biomedical Optics Express,* 7(10), 4054. doi:10.1364/boe.7.004054, (2016)