3D polarization-sensitive OCT imaging of collagen organization within organ systems

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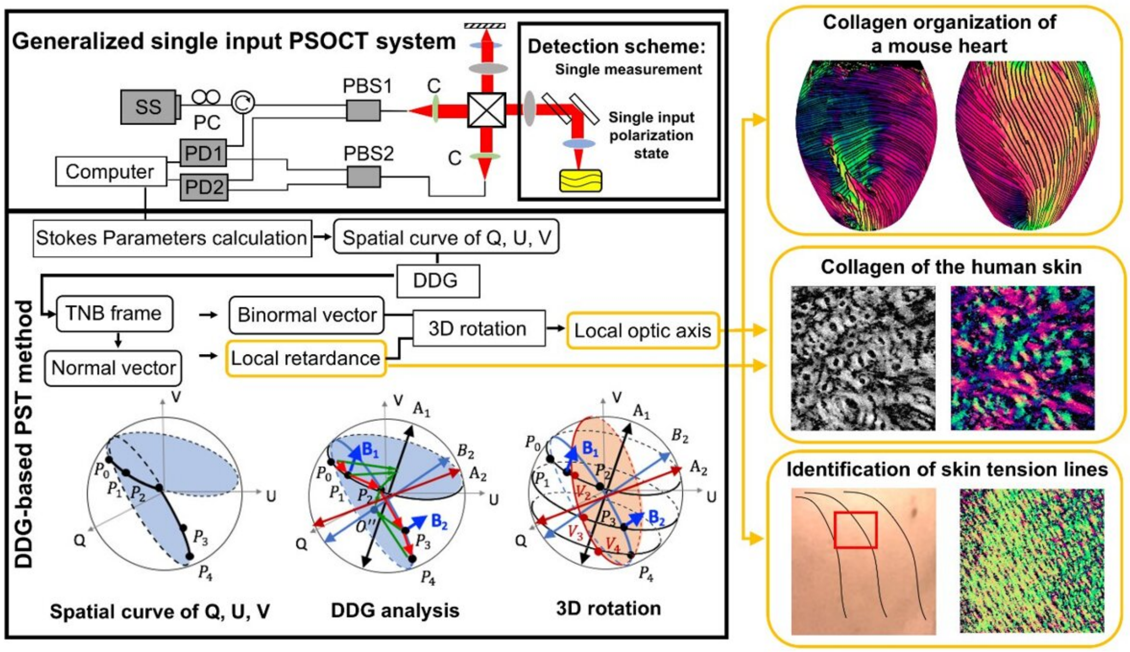

Schematic diagram of the generalized PSOCT system and the flow chart of the DDG-based PST method and its applications in biological tissues. The system used in this study is a generalized PSOCT system with a single input polarization state. The single input detection scheme allows a neat, cost-effective and flexible PSOCT system configuration. The flow chart below the system illustrates the strategies of the DDG-based PST method to derive local phase retardation and local optic axis from the PSOCT measurements. The output polarization states represented by Q, U and V are reconstructed by the Stokes parameters calculation. The trajectory of the output polarization states at the Poincare sphere is considered as a spatial curve. Then DDG is applied to this curve to provide the TNB vectors of this curve. By using a 3D rotation operation, the local phase retardations and local axis orientation can be obtained and utilized to visualize the collagen organization in the biological tissue. The images in the right show the applications of this method: collagen organization of a whole mouse heart and the facial skin of a healthy adult. A typical helical-like skeleton of the myocardial fibers in the heart and the skin tension lines in the human skin are clearly visualized using the proposed method. Credit: by Peijun Tang, Mitchell A. Kirby, Nhan Le, Yuandong Li, Nicole Zeinstra, G. Nina Lu, Charles E. Murry, Ying Zheng, and Ruikang K. Wang

Knowing 3D collagen organization within organ systems is crucial both for the disease diagnosis, e.g., heart infarction, and for the surgical guidance, e.g., skin incision. Scientists from the University of Washington, Seattle, reported a novel imaging approach that utilizes polarization-sensitive optical coherence tomography to non-invasively image the depth-resolved collagen organization within heart and living human skin. The technique will open up new possibilities for more accurate clinical diagnosis and image-guided surgery.

Collagen is essential for tissue integrity and stability, and changes in its intrinsic organization are the key features in several important diseases such as scar formation, heart infarction and cancers. Knowing the organization of collagen patterns is not only important for the early and accurate clinical diagnosis, but also valuable in dermatologic surgical planning for less scarring. However, traditional imaging techniques such as the polarized microscopy and second harmonic generation (SHG) microscopy limit the collagen imaging in the laboratory studies. For example, the polarized microscopy can only provide two dimensional images and requires destructive procedure to the sample that should be avoided as much as possible in the clinic. For the SHG generation imaging technique, the field of view and imaging depth are often too limited to reconstruct macroscopic collagen organizations that reveal the functional architecture of the tissues. Moreover, high incident power of the laser is needed in the SHG imaging to provide sufficient contrast for the collagen, which could damage the targeted living tissues. All these limitations hinder the utilization of the collagen information in the clinical diagnosis.

As a mature medical imaging technology, optical coherence tomography (OCT) provides wide-field, high-resolution, three-dimensional (3D) imaging of living biological tissues without a need of contact or damage to the sample. Therefore, it is an ideal tool of choice for clinical diagnosis and imaged-guided surgery. However, traditional OCT lacks specific contrast for the collagen. Since collagen is highly birefringent, polarization sensitive optical coherence tomography (PSOCT), a functional extension of OCT was therefore developed to image the 3D birefringent material. The challenge is, however, that the traditional PSOCT only provides the accumulated measurement of birefringent information within the sample. That is, using the traditional PSOCT method, the collagen organization embedded deep within the tissue cannot be reconstructed properly.

In a new paper published in *Light Science & Application*, a team of scientists, led by Professor Ruikang K. Wang from Department of Bioengineering, University of Washington, U.S., and co-workers have developed a novel approach that utilizes PSOCT to non-invasively image the depth-resolved collagen organization within the rodent hearts and living human skin. Their method allows scientists or clinicians to "see" the 3D collagen organization within a living tissue without applying any "side-effect" to the sample. More interestingly, this method only requires a single input polarization state to reconstruct the depth-resolved collagen architecture, allowing a cost-effective, flexible and neat PSOCT system design, which is extremely attractive to clinical translation. By providing wide field 3D contrast for the specific tissue non-invasively, this reported method will open up new possibilities for more accurate clinical diagnosis and image-guided surgery, targeting to precision medicine.

This method, called polarization state tracing (PST) method, utilized the trajectory of the output polarization states at the Poincare sphere to extract the local birefringent information at each depth of the sample. By innovatively applying discrete differential geometry (DDG) analysis to the trajectory, local phase retardation and local axis orientation at each depth of the sample can be acquired using a single input polarization state. The scientists summarize the purposes of their development: "We develop the DDG-based PST method to meet the challenges of: (1) a clinical demand for a non-invasive method that can resolve the local birefringent information within a living tissue; and (2) a desire of a method and device being able to meet the requirements for clinical translation."

Because fibrous collagen shows intrinsic optical anisotropy, local axis orientation mapping can visualize collagen organization by revealing the direction of the collagen alignment. The authors successfully used this method to reconstruct the typical helical-like myocardial fiber structure of a whole mouse heart, observe the disorganization of the myocardial fibers within an infarcted rat heart and visualize the macroscopic architecture of the skin tension lines in a generalized PSOCT system with a single input polarization state. "All these findings are extremely valuable in numerous clinical applications in, for example, early detection of acute myocardial infarction, monitoring of the graft remodeling in the therapeutic treatment of heart infarction, evaluation of scar formation and the imaging-guided plastic surgery, etc. In addition, the significant simplification of the PSOCT imaging system facilitates the clinical translation of this imaging technique, which would provide a new matrix of diagnostic information" they added.

More information: Peijun Tang et al, Polarization sensitive optical

coherence tomography with single input for imaging depth-resolved collagen organizations, *Light: Science & Applications* (2021). DOI: 10.1038/s41377-021-00679-3

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