Qualitative Morphological Features of the Muscle and Cartilage Using Non-Invasive Imaging Technique

C. G. Song, Y. K. Oh, H. K. Baik , J. H. Seo, and J. Kang

Abstract— We have demonstrated a polarization sensitive cartilage and muscle imaging based on common path optical coherence tomography (CP-OCT) using near infrared source. The axial and lateral resolutions of our PS-OCT system are 9μm and 6μm, respectively. The internal structural information has been extracted by the real-time signal analysis (Fourier Transform) from the modulated spectral intensity depending on the beam and tissue birefringence. Preliminary results using fresh beef and *in vivo* rat show that we can visualize the birefringence effect of the tissue collagen fibers in the samples for better image contrast and sensitivity for detection of hidden dermal structures. Compared to conventional CP-OCT, our proposed PS-OCT could provide depth-resolved images, which reflect tissue birefringence.

Index Terms: fourier domain-common path OCT, subcutaneous, imaging, infrared, birefringence

I. Introduction

Qualitative assessment of dermal tissue recovery is invaluable in a non-invasive clinical imaging technique while monitoring the progress of wound healing in the cutaneous and the diagnosis of cancerous lesions or skin diseases as well [1, 2]. However, conventional morphological cross-sectional imaging modalities such as computed tomography (CT), ultrasound and magnetic resonance imaging (MRI) have limited depth resolution to evaluate the fine tissue variations.

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Optical coherence tomography has been used to provide finer micro scale resolution within a few mm range in depth that meets the special need in the above applications [3]. Particularly, polarization sensitive (PS) optical coherence tomography (OCT) is a non-invasive and high-resolution imaging modality that can visualize the cross-sectional view of subcutaneous and muscle images depending on the birefringence of tissues with parallel-aligned collagenous structures for diagnosis [4-6] as well as evaluating the epidermal thickness around the junction between dermis and epidermis (DEJ) [7, 8]. Especially, common path (CP) OCT technique has been attracted because of its simple configuration and less sensitive to vibration and temperature [9, 10]. Such features have advantages for clinical and biomedical applications where the diagnostic and surgical probe can be replaceable with an arbitrary length and disposable with high stability as well [11]. In this pre-clinical work, we have presented qualitative morphological features of the muscle and subcutaneous shapes *in vivo* by using a Fourier-domain (FD) common path OCT (CPOCT) configuration with polarization controls that can be used for diagnosing depth-resolved form birefringence in skin diseases by denatured collagen fibers.

II. Materials and Methods

The schematic view of the experimental setup based on Fourier-domain common path OCT is shown in Fig. 1. We used a broadband low-coherence near infrared source (super luminescence diode, SLD) at 0.8μm with 9μm coherence distance [12]. To control the polarization, fiber type circular retardation plates have been introduced and inserted between the bare fiber probe and the directional fiber coupler for manipulating the birefringence of the sample. The returned beam from the specimen is analysed by fast Fourier transform for extracting the depth information from the modulated spectrometer data. The reference plane was simply achieved by the distal end of the fiber optic probe (fiber diameter: 125μm, protective polymer jacket diameter: 240μm) without employing additional reference arm. Computer and electronics systems control the 2D scanning (translational stage or galvanometer) and data acquisition and analysis which are described in the next section (*Computer and electronics systems*). We used a piece of fresh beef and an anesthetized rat as specimens in the experiment.

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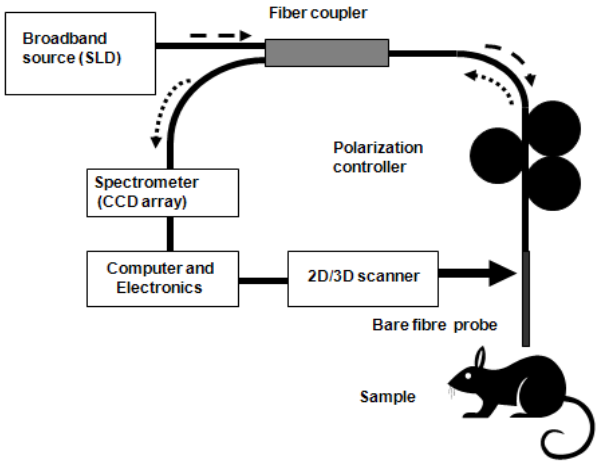

Fig. 1 Experimental setup for Fourier-domain common-path polarization sensitive optical coherence tomography with single micro-bare fiber probe

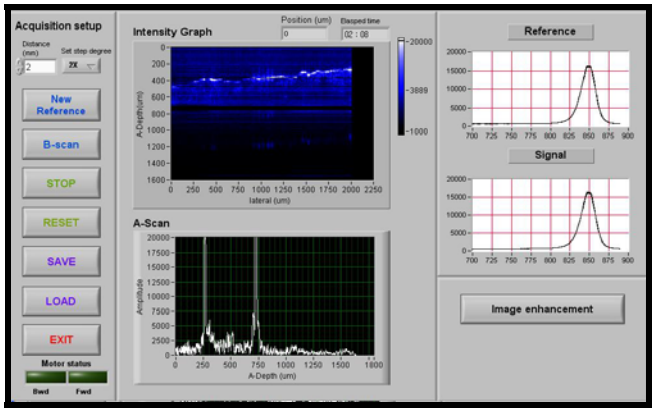

Fig. 2 Computer user interface panel of OCT control and setting system

Fiber-based PS-OCT system and Software algorithm

The software graphical user interface (GUI) for the OCT system was built using a LabView virtual instrument (VI) as in Fig. 2. It was used to develop the interface for the equipment, and the signal and image processing for our system. The LabView module was also programmed to control the scanning stage in which the user gets feedback from the motion controlled axes position and can specify both the width of the scan and the integration time. The program saves all the data automatically to a tab delimited text file and it also provides the capability of acquiring the reference light source by only pressing a button.

The software algorithm is shown in Fig. 3 in which it uses the saved spectrum of the reference signal before the scan initiates in order to remove the DC terms from the interferogram. It is started by placing the scanner arm to the initial position, and then it acquires the modulated or interferogram signal and removes the reference or non-modulated term before proceeding to the inverse Fourier transform of the signal for resolving the depth information. This itinerary process repeats with moving a regular lateral interval while the scanning arm moves continuously until the designated lateral dimension or pixels.

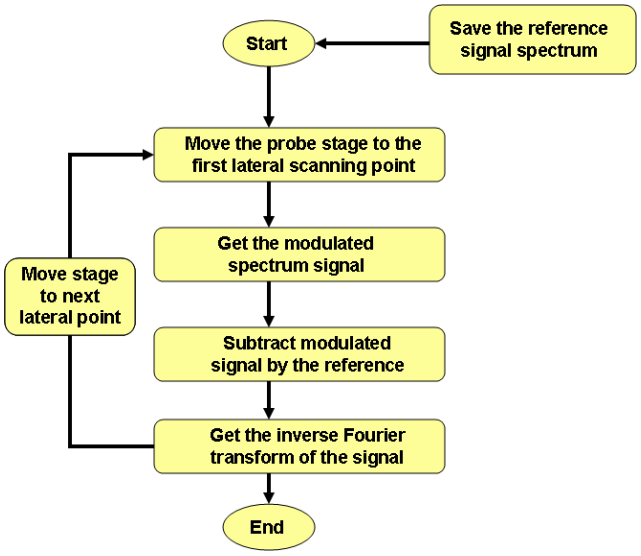

Fig. 3 Software algorithm of operation for scanning system

III. RESULTS

For the pre-clinical evaluation, we placed the micro bare fiber probe attached to the 2D scanner above the sample where the axial and lateral resolutions are basically governed by the source coherence length (9μm) and by the probing fiber core size (6μm), respectively [13].

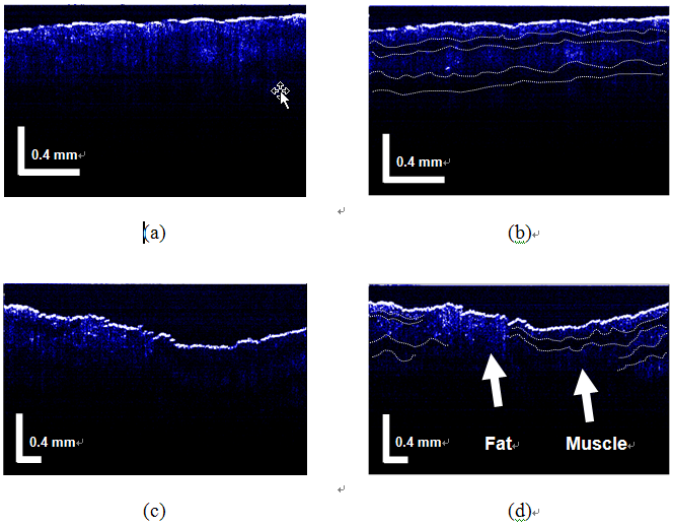

Fig. 4 polarization sensitive FD CPOCT images of beef sample: (a) without polarization control (muscle only); (b) with polarization control (muscle only); (c) without polarization control (Fat and muscle interface); (d) with polarization control (Fat and muscle interface)

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When we control the birefringence, the obtained images have different features depending on the collagen tissue characteristics so that the beam can experience various conditions for achieving the cross-section of the inner structure where different polarization resulted in different image view for the same specimen with clearer layered configuration for Fig. 4(b) with dotted lined layers than that of Fig. 4(a). In case of fat and muscle, they have different scattering features so that fat appears brighter than muscle in which birefringence-matched case shows better image contrast in Fig. 4(d) than in Fig. 4(c) which resembles the case for differentiating the cancer or tumor with higher scattering from healthy normal tissues [10]. The thin epidermal layer has a strong reflection with a brighter image due to the air-tissue interface and this high-reflectivity reduces the light penetration into the dermal layers.

The resultant scanned tomograms are shown Fig. 5 where image sizes are all 1000μm (width) x 490μm (height). In Fig. 5(a), we can clearly differentiate the characteristic layers of the articular cartilage which contains the superficial zone (or tangential layer), the middle zone (or transitional layer), and the deep zone (or radial layer) in axial direction. The middle zone image is shown brighter in OCT due to lateral distribution of collagen fibres in that layer which is more reflective and scattering than those in other two layers having longitudinal distribution.

In addition, because of the reduced index difference (Δn~0.01) between the saline solution (~1.34) and tissue surface (~1.33), we could efficiently penetrate more power into the tissue which helps to improve the total imaging depth.

Also this prevents a strong surface reflection which would have a greater index difference (Δn~0.33) between the air (1.00) and cartilage surface that reduces the overall signal to noise ratio of the OCT images. Other fundamental limiting factors of the working depth include multiple scattering and the diverging beam in the tissue.

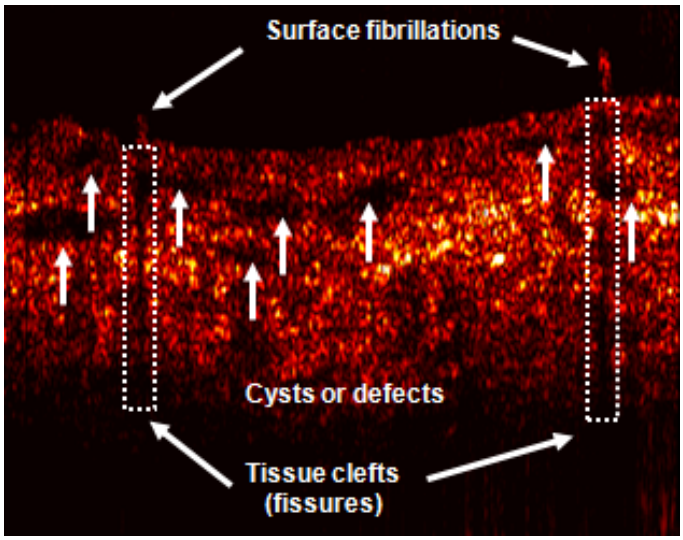

Figure 5 (a) obtained image results from chicken knee cartilage(cartilage zone layers)

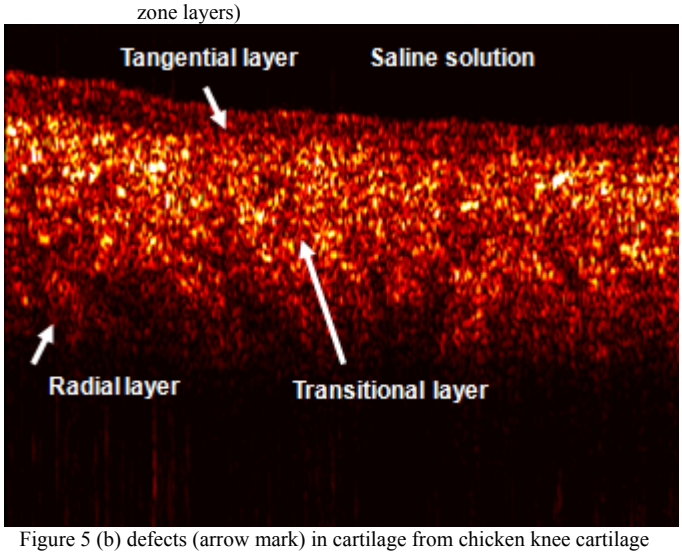

Figure 5 (b) defects (arrow mark) in cartilage from chicken knee cartilage

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