Time-domain optical coherence tomography and gelatin-based skin phantom as training tools for venipuncture

P F Mandia1,2*, E A Vallar1,2, T Shiina3, E P Macalalad4, and M C D Galvez1,2

1 Environment And ReMoTe Sensing Research (EARTH) Laboratory, Physics Department, De La Salle University, 2401 Taft Avenue, Malate, Manila, Philippines
2 Applied Research for Community, Health and Environment Resilience and Sustainability (ARCHERS), Center Natural Sciences and Environmental Research (CENSER), De La Salle University, 2401 Taft Avenue, Malate, Manila, Philippines
3 Graduate School of Science and Engineering, Chiba University 1-33 Yayoi-cho, Inage-ku, Chiba, Japan 263-8522
4 Department of Physics, Mapúa University 658 Muralla St., Intramuros, Manila, Philippines

* paulito_mandia@dlsu.edu.ph

Abstract. Optical coherence tomography (OCT) is a non-invasive imaging modality developed in the early 1990’s for retinal imaging. Further modifications allowed OCT’s to be used on other parts of the human body, and non-medical areas as well. Time-domain OCT (TD-OCT) basically is a Michelson interferometer with a low-coherence light source which enables non-invasive, cross-sectional visualization of the sample. In this paper, the researchers used the TD-OCT system, which uses a rotating reference mirror. Using this system in conjunction with fabricated skin phantoms, students of venipuncture can hone their skills on skin phantoms before practicing on actual persons. This helps in mitigating the potential risks inherent to the performance of invasive procedures such as venipuncture. Furthermore, the skin phantom is chiefly composed of gelatin with latex tubing used to imitate the veins. Such materials are cheap and readily available, allowing multiple phantoms to be fabricated easily. Preliminary results showed that OCT is a promising tool in imaging the tissue phantom and thus can be utilized for venipuncture training.

Keywords: OCT, venipuncture, skin phantom, non-invasive,

1. Introduction

Venipuncture is an invasive medical procedure wherein veins are accessed by piercing a needle into the skin, allowing extraction of blood or injecting medications into the bloodstream. While venipuncture is a mainstay procedure in medical diagnosis and treatment, it can lead to some complications, most notably pain and risks of infection and hematoma. In addition, skin thickness and blood vessel walls vary by anatomic location and age of the patient. Taking these into consideration, the performance of venepuncture thus require training. Beginning students usually perform venipuncture only on their fellow students, and given the inherent risks and complications of invasive procedures, this limits the amount of possible practice subjects. There has been studies about training in ultrasound-guided procedures that utilization of tissue phantoms increased the proficiency of novices [1]. As such, by adopting the use of skin phantoms in conjunction with TD-OCT, students can then first gain experience on venipuncture before moving to actual persons in order to minimize the aforementioned risks and complications.
Optical coherence tomography (OCT) is an imaging modality developed in the early 1990’s wherein the first images were that of the human retina [2]. In 1997 the group of Welzel published in vivo images of the human skin [3]. Colston et al published the first in vivo application of OCT in dental tissue [4]. Later on, OCT found applications in various fields such as industry [5] and agriculture [6].

OCT is fundamentally based on the technique called low-coherence interferometry (LCI), wherein a Michelson interferometer with a broadband light source is used. As seen on figure 1, the beam of light is split into a sample arm and a reference arm. Reflected light from both arms are combined on the detector to produce interference. What is displayed on the oscilloscope is the envelope of the interference signal.

![Schematic diagram of an OCT system.](image)

This interference pattern is processed to produce an A-scan which contains depth information about the sample at one point. When several A-scans obtained from points along a line of a sample are combined, two-dimensional, cross-sectional image of the sample can be obtained. The first OCT system was time-domain OCT (TD-OCT) which uses a galvanometer-actuated reference mirror to provide a periodically varying optical path length [7]. Using a fiber optic-based interferometer enables the whole device to be made portable. A newer mechanism utilized in this research was developed by Shiina et al which utilizes a rotating reference mirror [8].

2. Materials and Methods

2.1. TD-OCT setup

The researchers used the TD-OCT system which uses a rotating reference mirror. The light source is a 1310nm SLD with 53nm spectral halfwidth. This is the chosen wavelength because this provides the greatest skin penetration. At wavelengths within the ultraviolet and visible region, light is attenuated primarily through absorption by hemoglobin and melanin, with scattering by cell components. At wavelengths in the far infrared region and beyond, much of the light is absorbed by water [9].

2.2. Skin phantom preparation

Food-grade gelatin derived from beef was used in the experiment. 20ml of distilled water at room temperature is poured onto 5gm of gelatin and was let to stand for 2 minutes. Afterwards 30ml of distilled water heated to 80°C is then poured onto the original mixture, constantly stirring until all the gelatin powder has been dissolved. The mixtures are then poured into petri dishes and left to cool and solidify. In the researchers’ lab this has been found to be the best proportion of water and gelatin.
because it produced a firm, semisolid consistency within six hours after preparation at a room temperature of 23°C. To prevent evaporation of water from the gelatin mixture, each of the petri dishes were covered while awaiting OCT scanning. Figure 2a is the schematic diagram of the experimental setup showing the relative positions of the skin phantom, probe, and translation stage. Gelatin acts as the skin tissue while the latex tubing acts as the vein. Figure 2b is the actual experimental setup used for this paper.

![Figure 2a. Schematic diagram of the experimental setup.](image)

![Figure 2b. Actual OCT experimental setup.](image)

In the latter part of the study, the researchers will add titanium dioxide to gelatin in order to match its attenuation coefficient similar to skin, which is about 7.3. This coefficient can be obtained using the Beer-Lambert’s law given in equation (1) [10]:

$$\log \left( \frac{I}{I_0} \right) = -2 \sigma L$$  \hspace{1cm} (1)

Where I and Io are the intensities of the backscattered and incident light from the sample, respectively (in W/cm²), $\sigma$ is the attenuation coefficient of the material (in cm⁻¹), and L is the distance travelled by light from the probe to the sample (in cm).
2.3. Scanning, data processing and image generation

To minimize noise and signal distortion during the horizontal scanning process, the OCT probe was fixed while the sample is moved at regular intervals. To achieve this, the sample is placed on a motorized translation stage (Sigma Koki SGSP26-100) which is controlled by a computer using the Sigma Koki SGCommander software. The sample is then moved along a single line parallel to the horizontal plane.

The oscilloscope used was Tektronix TBS 1072B-EDU, and 128 signal averaging was used for each point on the sample. One point on the sample is equivalent to one depth scan (A-scan). At present, it takes 45 minutes to scan horizontally 99 points on the sample using the 2μm horizontal resolution of the motorized stage. Background noise was collected by scanning the probe through a blank sample. The background noise is then subtracted from the averaged A-scans. Processing of the signal is performed using an academic license version of MATLAB R2018b. To produce the cross-sectional tomographic images, the meshgrid and pcolor commands are invoked in MATLAB.

3. Results and Discussion

Figure 3 shows the depth scan of one point in gelatin sample without any underlying latex “vein”. The peak shows the interface between air and gelatin as the incident light travels from the probe, then to the air in between, and finally to the sample. The single peak indicates that only one layer of material is present in the sample. Figure 4 is the tomographic image formed for a pure gelatin sample when several depth scans of adjacent points are combined.

Figure 3. Depth scan of a single point on a pure gelatin sample.

Figure 4. Cross-sectional image of a pure gelatin sample. Horizontal scanning is done at 2μm interval.

In processing data, the horizontal axis from the depth scan was first converted into depth through a conversion factor depending on the OCT circuit and path length. This depth was used as the new vertical axis in the tomogram. The new horizontal axis was from on the horizontal movement of the translation stage, with the intervals determined by the user. Finally, the intensity (vertical axis) from the depth scan was mapped onto a color scale.

On the other hand, the depth scan in figure 5 shows two peaks owing to the presence of an underlying latex layer, and figure 6 is the corresponding tomographic image. Under the latex tubing is again gelatin but the deeper portions are no longer visible owing to the strong attenuation of the incident light.
Figure 5. Depth scan of a single point on a sample with gelatin and latex layers.

Figure 6. Cross-sectional image of a gelatin-latex sample. Horizontal scanning is done at 2μm interval.

The researchers then scanned a latex tube that was only partially submerged in gelatin. Figure 7 shows the cross-sectional view of the upper part of the latex tube. Its faint signal is due to the weak backscattering by latex. This is in contrast to the intense backscattering by the adjacent gelatin portions as seen on the brighter spots of the image. A horizontal scanning resolution of 40μm was used for 99 points on the sample thereby increasing the scanning width to 3mm. However, this produces broken lines in the image with accompanying loss of detail, as seen in figure 7.

Figure 7. Tomogram of a partially-submerged latex tube. Horizontal scanning is done at 40μm interval.
4. Conclusion
Given that OCT can detect signals from layers made of different materials and subsequently able to produce a cross-sectional image, OCT has potential to be useful in venepuncture training. This research can then be expanded to image the veins of actual patients and thus be useful especially in cases where locating suitable veins are difficult.

Further improvements for the system is currently being made. To shorten the data acquisition time, the researchers will create a program to synchronize the translation stage movement and oscilloscope data capture. In doing so, the system will become fully automated. The optics will also be readjusted so that there will be deeper sample penetration and greater image detail.

Acknowledgments
The authors acknowledge the Commission on Higher Education (CHED) of the Philippine Government for funding the project entitled “Development of a Portable Optical Coherence Tomography System for the Evaluation of Human Skin Analogues”. The authors also acknowledge De La Salle University Research Coordination Office (URCO) for the additional funds under the project number 47 F U 2TAY18-2TAY19 and the Center for Natural Science and Environmental Research (CENSE) of the De La Salle University for the administrative support to the project.

Reference
[1] Kim Y H 2016 Korea J. Pain 29 pp 73-77
[2] Huang D, et al 1991 Science 254 pp 1178-81
[3] Welzel J, Lankauen E, Birngruber R and Engelhardt 1997 J. Am. Acad. Dermatol. 37 pp 958-963
[4] Colston B W Jr, Sathym U S, DaSilva L B, Everett M J, Stroeve P and Otis L L 1998 Opt. Exp. 3 pp 230-238
[5] Mauritz J, Morrisby R, Hutton R, Legge C, Kaminski C 2010 J. Pharm. Sc. 99 pp 385-391
[6] Meglinski I, Buranachai C and Terry L 2010 Laser Phys. Lett. 7, pp 307-310
[7] Fujimoto J and Drexler W 2008 Optical Coherence Tomography: Technology and Applications (Berlin: Springer) pp 1-38
[8] Shiina T, Moritani Y, Ito M and Okamura Y 2003 Appl. Opt. 42 pp 3795-99
[9] Gajinov M, Matić M, Prćić S and Duran V 2010 Serbian J Dermatol. 2 pp 131-136
[10] Adili, D and Shiina T 2018, Proc. of the 19th Coherent Laser Radar Conf. (Okinawa), vol 18 (Colorado: Curran Associates, Inc.) pp 182-185