A quantitative evaluation of skin phantom by skin TD-OCT

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Abstract: Optical Coherence Tomography (OCT) has been practically used in ophthalmology, however, its quantitativeness is more valued for the evaluation of human skin. In this study, Time-Domain typed Optical Coherence Tomography (TD–OCT) was specialized to evaluate human skins quantitatively, and skin phantom measurements were assessed. At first, skin phantoms at different concentrations of titanium dioxide were prepared and measured according to its representation of dermis on human skin. Same increment of the extinction coefficient was obtained as the concentration increases. This OCT measurement result was compared with the result from the transmittance experiment. The difference between two results was considered as the effect of multiple scattering in the strong scattering medium. Next, the TD-OCT measurement was performed on the human skin. Extinction coefficients were evaluated with criterions of accurateness in medical field. Based on the linearity of the specialized TD-OCT, the extinction coefficient obtained by this method could accurately represent optical property of dermis and epidermis of human skin.

Keywords: Optical Coherence Tomography, Extinction coefficient, Human skin, Skin phantoms.

1. Introduction

Generally, humans have the same skin structure. However, the quality of skin varies depending on genetics and lifestyle. Furthermore, the character of the skin changes day by day with age, environment, and hormone’s work. In recent years, as the concern for the skin shifted from diseases to skincare and beauty, the demand for skin examination devices is increasing. Current skin diagnoses are performed by specialists after a physical examination, a patch test or a microscopic observation that are targeted only for the skin surface [1]. Thus, the deviation occurs when it comes to the evaluation of the actual optical properties of the skin. A quantitative evaluation of the optical characteristics of human skin is probable, due to the existing Optical Coherence Tomography (OCT) used in ophthalmology.

OCT is a non-invasive ophthalmologic diagnostic technique that renders in vivo cross-sectional view of the retina. OCT utilizes a concept known as interferometry to create a cross-sectional map of the retina with the accuracy of 10 -15µm. OCT was first introduced in 1991 [2] and has found many uses outside of ophthalmology, where it has been used to image certain non-transparent tissues. Acquisition of the OCT signal is based on splitting the incident low coherent light beam into two paths: (1) a sample beam and (2) a reference beam, which follow two different paths but with the same length. When the reflected light beams (derived from each of these two paths) simultaneously reach the detector, they induce an interference signal. The amplitude of this interference signal is measured and used to acquire the image.

Swept-Source OCT (SS-OCT) and Frequency-Domain OCT (FD-OCT) are the current standard of OCT techniques. In recent years, as technology advances, the OCT also developed in fields other than ophthalmology, i.e. skin diagnosis. Although, the FD-OCT and SS-OCT have been popular with their high resolution and high acquisition speed [3-6], it is difficult to accurately judge the optical characteristics of the skin due to the nonlinearity of the backscattered light signals derived from indirect signal processing. On the other hand, TD-OCT can measure the human tissue with high linearity because of simple magnification of return intensity. Therefore, TD-OCT is the efficient way to measure and evaluate the human skin quantitatively.
In this study, for quantitative evaluation of the human skin, skin phantoms made with titanium dioxides were utilized and their extinction coefficients were evaluated by the specialized TD-OCT. These results were then compared with other results from transmittance measurement. Then, actual human skin in section of the forearm and the upper arms were measured and evaluated with the same procedure that in the medical field. This method is expected to increase the accuracy of skin measurement values in diagnosis and contribute to early detection and prediction of skin diseases [7-9]. Furthermore, it could also be expected to provide guidelines for the formulation of cosmetic products.

2. Experimental setup and Method

The schematic diagram of the skin OCT used in this research is shown in Figure 1. The basic configuration is the Michelson interferometer. Super Luminescent Diode (SLD) is used as a light source for this TD-OCT. The SLD is in the near-infrared light with a central wavelength of 1.31μm, and since the measurement depth is less than 1.0 mm, the absorption was neglected [10-11]. In the present apparatus, a variable optical path mechanism is used as a reference optical path. This variable optical path consists of a rotating corner reflector and a fixed mirror to create an approximately linear motion. In this setup, the rotation angle was ±20° and the deviation of the linear motion was about 1%. Therefore, measurement with good reproducibility was possible, and a stable scanning can be performed. Skin phantoms (model paint with titanium dioxide) with volume 5%, 10%, 20%, 30% and 50%, were measured. Figure 2 shows the result of plotting the skin phantoms placed on a light box. It can be seen that the transmitted light intensity decreases with the increase of concentration from (5%) to (50%). The skin phantoms were made by an applicator, and the thickness of the phantom were fixed as 200μm. In addition to the titanium dioxide(TiO₂), the phantom was also included with dispersion resin and other solutions.

Figure 1. Basic schematics of the experiment setup. Figure 2. Appearance of the phantom (a) Measured spots (b) Appearance on the light box.

3. Result and discussion

Figure 3 shows the measurement results. Here, the time difference caused by rotation of the reflector was converted to the media depth (L). The graph is indicated in log scale and the slope represents the extinction coefficient (σ) that was derived from the equation (1):

$$\log \frac{I}{I_0} = (-2\sigma L)$$

Where, I and I₀ are incident and reflected light intensities. Back scattered light from the depth of 1 mm was obtained. The smoothly declined linear trend of the slope indicates the homogeneous characteristics of the material of the phantom.
Figure 4 shows the derived extinction coefficients, it can be observed that, as the increment of the concentration, the extinction coefficient of the backscattered light decreases slowly. Furthermore, it can also be inferred that even if the concentration doubles, the change in the extinction coefficient remains almost constant.

Figure 5 indicates the transmittance measurement result. The extinction coefficient gradually increases as the media concentrations increases. The increment of the extinction coefficient was smooth as the growth of concentrations. However, the trend of the increment was different with that of the OCT result.

Figure 6 presents the adjusted and corrected results of OCT measurement showed in Figure 4. The maximum optical path length (1 mm) was the consequence of original thickness that based on the fixed standard of 200 µm of the provided phantom. The original thickness of the phantom was fixed to the 200 µm when it was made. However, the derived optical thickness of the phantom was turned out to be 1 mm according to the OCT measurement result. The actual thickness of the phantom measured as 16.8 µm, 14.1 µm, 29.4 µm, 23.0 µm and 50.0 µm for 5%, 10%, 20%, 30%, and 50%, respectively by confocal microscopy. The difference of phantom thickness was dependent on the particle amount and vapor process of dispersion resin. Therefore, the thickness was normalized to 50 µm based on 50% concentration and other phantoms were also normalized the same way. Due to the different thickness of the phantom, as the concentration increases, digits of the extinction coefficient changes. Therefore, the correction was carried on the extinction coefficient according to the different thickness of the phantom. As a result, the increment tendency of modified results showed the same trend with the result from transmittance measurement.

The adjusted and corrected OCT results in Figure 6 have a large fluctuation when it is compared with result from the transmittance measurement. This variation was considered as follows: as for the OCT measurement, the material texture and density evenness will be strongly influenced due to small spots that carried on by the microscopic measurement. For the transmittance measurement, however, the observation size was large 6 mm. Therefore, the result appears as a smooth increment.
4. Summary

In this paper, our work was mainly conducted by following two subjects: at first, due to the complexity of the human skin, we purposed to prepare, measure and evaluate 5 phantoms with different concentrations 5%, 10%, 20%, 30% and 50%. Optical property of these titanium dioxide phantoms was resemblance to the human skin. Next, we implemented same OCT measurements for human skins applying the demonstrated evaluation method. To achieve the objective of this paper, we applied the TD-OCT system to obtain the extinction coefficient from both phantom and human skin. Thickness of the phantoms was measured by confocal microscopy to confirm the actual thickness of the phantom. Transmittance measurement was also applied to compare the extinction coefficient with that of TD-OCT measurement results. As a result, attenuation tendency of backscattered light was obtained from the phantoms in different concentration. Almost constant extinction coefficients were observed as the increment of concentrations. And the difference between OCT and transmittance measurement results were considered as effects of (1) consideration of actual thickness of phantoms and (2) variation of the extinction coefficient as the change of concentration that was led by the distinction of the measurement size of objectied area. At last, the extinction coefficients of the human skin were measured and evaluated as 7.3 for forearm and 7.0 for upper arm, which are reasonable on the medical criterion.

Since the OCT measurement can be considered as a type of microscopic analysis, it can be applied for the quantitative determination of micro structures (such as skin roughness) and larger structures (such as wrinkles) on skin diseases. We also quantified the internally reflected light from the human skin. This study measured the optical characteristics (such as extinction coefficient) in human skin for dermis and epidermis. For a cosmetic product to achieve a brilliance effect, the determination of backscattered light is important. These measurements and results provide guidelines for formulation of cosmetic products.

5. References