Study on the density and dimension of human sweat ducts and their frequency of resonance

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Abstract

Owing to the rapid development of electronic and photonic devices operating in terahertz (THz) frequency region, it is crucial to understand the non-thermal effects of these electromagnetic waves on human body. In the past, it was reported that human sweat duct works as a helical antenna in terahertz frequency region and it plays an important role in the interaction of THz wave with the skin. In order to further understand the effects of these waves, it is essential to know the morphological features of the sweat ducts. In this work, we analyzed the density and dimension of the ducts based on three dimensional images obtained with optical coherence tomography (OCT). We observed that the sweat ducts possess helical structure and the diameter of the ducts from different regions of the body show considerable resemblance. Based on this information, we numerically determined the resonating frequency of helical ducts which resulted in the terahertz frequency region spanning from 0.3 THz to 0.7 THz.

1. Introduction

The electromagnetic wave with the frequency extending from few hundreds of Gigahertz (GHz) to few Terahertz (THz) is known as terahertz wave and it lies in between the microwave and infrared region in the electromagnetic spectrum. Even though it lies in between these two well-developed regions, THz frequency region remains unexplored until recently due to the lack of efficient THz wave emitters and detectors. However, development of various optoelectronic technologies such as femto second lasers and semiconductor device fabrication techniques have enabled the convenient generation of THz waves. The applications of this radiation have been expanded in diverse fields such as biomedicine, security, material characterization and communication [1]. Since, the photon energy of THz wave (1 THz ≈ 4.1 meV) is small, it was regarded as non-ionizing radiation and safe to health. However, the recent experimental studies showed that high peak electric field THz waves are responsible for various non-thermal biological effects such as changes in gene expression and DNA damage [2].

Along with these effects, some other study demonstrated that the presence of helical structured sweat duct can play a significant role in mm-wave absorption [3]. Moreover, recently in the scientific literatures, there have been intriguing reports on the remote sensing of mental stress using sub-terahertz electromagnetic waves [4, 5]. In these works, it was attributed that the presence of helical structured sweat gland in the skin, when filled with conducing sweat, acts as a low Q helical antenna and that it resonates in the terahertz (THz) frequency range as determined by its parameters such as the helix diameter and the helix length. As the sweat duct is controlled by the sympathetic nerve response, it was reported that, the reflection coefficient of THz waves should reflect any activity of the duct induced by stress. However, in these reports, the reflection measurements of terahertz radiation from the subjects have been performed in the relatively narrow spectral bandwidth and investigated the single mode of operation only. According to the antenna theory, when the duct works as a helical antenna, the dimension of the helix plays a key role to determine the frequency of resonance. Therefore, the accurate determination of dimension of sweat duct is crucially important to obtain the reliable frequency of resonance and modes of operations. Here, we performed the optical coherence tomography (OCT) of human subjects on their palm of hand and sole of foot and based on the dimension of ducts, we calculated the frequency of resonance of sweat duct.

2. Experiments and results

In our experiment, 12 healthy subjects with the average age of 30 year with the standard deviation of 8 have volunteered for the measurement on different regions of their palm and foot. We took OCT images of these subjects in vivo and for each measurement, a 3 dimensional data set consisting of 255×255×849 (x, y, z directions) pixels covering a volume of 2.5×2.5×3.6 mm^3 was recorded. The lateral pixel resolution is 9.8 μm, whereas as the depth resolution is 4.2 μm. The total recording time for each 3D data set was approximately 5 sec. Figure 1(a) shows the typical OCT image of the fingertip in x-z plane showing the stratum corneum, sweat ducts and epidermis. Here, the spiral lumens of five sweat

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ducts are clearly visible with the high reflection intensity. Similarly, a typical x-y plane image showing the numbers of sweat ducts arranged in matrix is shown in Figure 1(b). In the duct density calculation, we have used such images to count the number of duct per unit area.

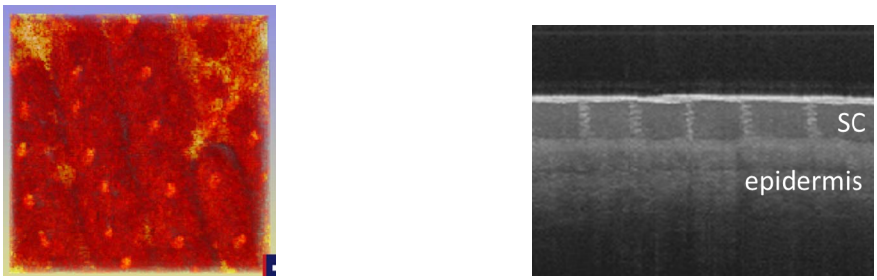

Figure 1: (a) Top view of the typical OCT image showing the distribution of sweat gland ducts. (b) OCT image of the fingertip showing the stratum cornum, sweat duct and epidermis

In our experiment, we measured the different regions in palm of hand and the sole of foot and these regions are numbered as 1 to 6 and shown in inset of figure 2(a). Figure 2 (a) shows the variation in the length of the sweat ducts for 12 subjects in different regions of measurement. Among these regions of measurement, the ducts in the mound of foot (region no. 5) are longer than in any other regions, whereas ducts of region in between thumb and wrist (region no. 2) are shorter. Figure 1(b) shows the variation in sweat duct diameter and we observed that the diameter of sweats ducts shows considerable resemblances. These results show that the even though the sweat ducts length varies significantly depending upon the region, duct diameters shows considerable consistency irrespective to the length of ducts. Based upon this information on diameter and length, we have calculated the frequency of resonance of sweat duct. According to antenna theory, the frequency of resonance of helical antenna with the consideration of dielectric properties of stratum corneum is calculated as $3C_0/4C\sqrt{\varepsilon}<f<4C_0/3C\sqrt{\varepsilon}$, where C_0 is velocity of light, C (=πD) is circumference of the duct, D is the duct diameter and ε is the dielectric constant of stratum corneum. Our numerical calculation showed that the duct resonates in axial mode with the frequency of resonance lying in the terahertz frequency region spanning from 0.39 to 0.70 THz. These results may guide to optimize the terahertz measurement system for the remote sensing of the sweat duct activity induced by stress.

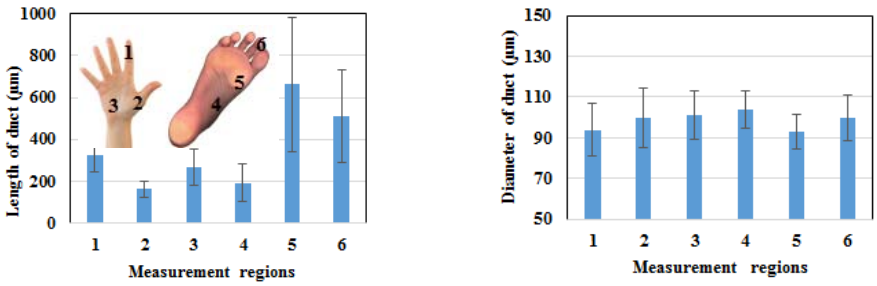

Figure 2: Length and diameter of human sweat duct in different measurement regions. The measurement regions are shown in the inset of first figure.

3. References

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