

Dynamic Analysis of Mental Sweating by the Time-Sequential Piled-Up En-Face OCT Images

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ABSTRACT

In this paper, the dynamic analysis of mental sweating for sound stimulus of a few tens of eccrine sweat glands is performed by the time-sequential piled-up en-face optical coherence tomography (OCT) images with the frame spacing of 3.3 sec. In the experiment, the amount of excess sweat can be evaluated simultaneously for a few tens of sweat glands by piling up of all the en-face OCT images. Strong non-uniformity is observed in mental sweating where the amount of sweat in response to sound stimulus is different for each sweat gland. Furthermore, the amount of sweat is significantly increased in proportion to the strength of the stimulus.

Keywords: Optical Coherence Tomography; En-Face OCT Images; Mental Sweating; Sweat Gland; Sympathetic Nerve

1. Introduction

Optical coherence tomography (OCT) enables cross sectional imaging of tissues *in vivo* with micron scale resolution, and now used for clinical diagnoses of retina diseases in ophthalmology and arteriosclerosis in circulatory medicine [1-3]. Besides the clinical applications, OCT was applied for brain science, in which the nerve response was detected by the OCT signals [4]. Recently, we demonstrated the dynamic OCT of skin physiology including the dynamics of sweat glands and peripheral vessels was tracked by time-sequential OCT images [5-7]. We discussed in detail mental sweating where mental or physical stress was applied to a subject to accelerate excess sweating. When a sound stress was used, we found internal mental sweating without ejection of excess sweat to the skin surface for evaluation of the nerve activity [8].

In our previous work, the dynamic OCT analysis of mental sweating of a single eccrine sweat gland was made using the time-domain OCT (TD-OCT) [5,8]. A lot of eccrine sweat glands align along the hill of fingerprint on human fingertips with the density of several hundred glands in cm^2 . Therefore, the 3-D image construction method with the so-called maximum intensity projection (MIP) of B-mode OCT images is proposed for *in vivo* dynamic analysis of mental sweating [9]. By use of the fast speed swept-source OCT (SS-OCT), we demonstrate

the dynamic OCT possible for a few tens of eccrine sweat glands. In this paper, the dynamic analysis of mental sweating for sound stimulus of a few tens of eccrine sweat glands is performed by the time-sequential piled-up en-face OCT images with the frame spacing of 3.3 sec.

2. Materials and Methods

In the dynamic analysis of mental sweating, the piled-up en-face OCT images are obtained time-sequentially for simultaneous tracking of the sweating dynamics of as many sweat glands as possible. The frame spacing of the time-sequential OCT imaging must be a few seconds. In the experiment, the swept-source (SS) OCT (Thorlabs OCM 1300SS) is used for the *in vivo* 3-D imaging of eccrine sweat glands on human fingertips, where the image resolution (or coherence length) is 12 μm with <50 frames/s at the center wavelength of 1.325 μm . The illuminating laser power on a human fingertip is 4 mW or less. The image construction method for the en-face OCT of a group of sweat glands is shown in **Figure 1**. 128 OCT images in the x-z plane are obtained with a spacing of 12.5 μm over the distance of 1.6 mm along the y direction, as shown in **Figure 1(a)**, where each OCT image size is $2.0 \times 1.5 \text{ mm}^2$ with the pixel size of $12.5 \times 5.9 \text{ mm}^2$. The imaging time is 3.3 s which is the frame spac-

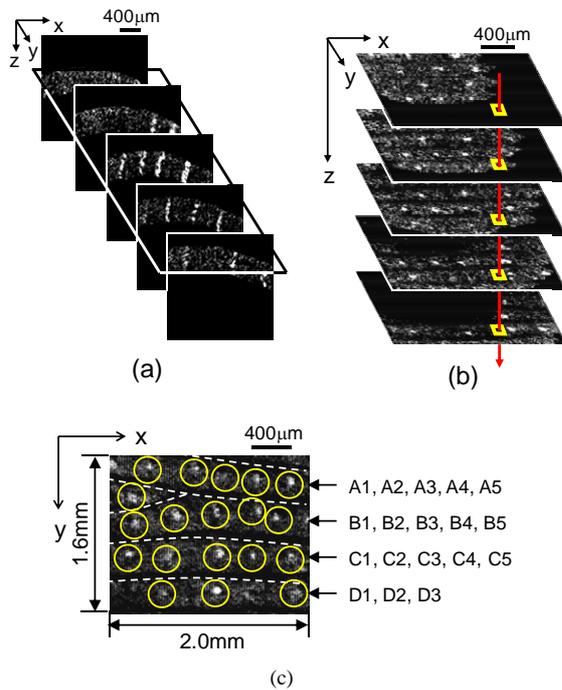


Figure 1. Image construction of en-face OCT. (a) 128 OCT images in the x-z plane are obtained with a spacing of 12.5 mm along the y direction; (b) The en-face OCT images in the x-y plane are extracted with the slice spacing of 5.9 mm, (c) Piled-up en-face OCT image of where nineteen eccrine sweat glands were imaged in the area of $2.0 \times 1.6 \text{ mm}^2$.

ing of the time-sequential piled-up en-face OCT images. From the 128 B-mode OCT images, the en-face OCT images in the x-y plane are extracted with the slice spacing of 5.9 mm, as shown in **Figure 1(b)**, where the number of en-face OCT images is 100 or more in epidermis. In the en-face OCT, the pixel size is 12.5 mm which is a proper image resolution for clear imaging of the spiral lumen of eccrine sweat glands. All en-face OCT images along the spiral lumen in stratum corneum of epidermis are piled up to evaluate the amount of excess sweat. In the resulting piled-up en-face OCT image, as shown in **Figure 1(c)**, the amount of excess sweat can be evaluated simultaneously for seventeen eccrine sweat glands which align along four lines of the fingerprint on a human fingertip.

3. Experimental Results

3.1. Simultaneous Tracking of Mental Sweating of a Few Tens of Sweat Glands by Dynamic OCT

The dynamic OCT analysis was made for mental sweating of a group of eccrine sweat glands in the area of $2.0 \times 1.6 \text{ mm}^2$ on the middle-finger tip, where a subject was a 23-year-old male. In the experiment, after confirmation of the resting state of the subject, mental stress is applied

to the volunteer where the stress is unpleasant sound of breaking glass for 0.5 sec at a sound level of 90 dB. **Figure 2** show time-sequential piled-up en-face OCT images with the frame spacing of 3.3 sec. In the sweat glands, marked by a yellow circle, the reflection light intensity increases suddenly in response to the sound stress.

The nineteen sweat glands are also classified by four lines of the fingerprint. **Figure 3** shows time variation of the reflection light intensity for the sweat glands from A1 to A5. In our previous study, an instantaneous amount of sweat stored in the sweat glands can be evaluated quantitatively by summation of the reflection light intensity of all pixels included in the spiral lumen [8]. These five sweat glands are active, but there is large difference in the amount of the stored sweat in the spiral lumen. It is thus found that the response to mental stress is different for each sweat gland even though the sweat glands are aligned to each other. Furthermore, **Figure 4** shows the time integrated value of the reflection light intensity during the experiment indicated by the red bars. These values are corresponding to the total excess sweat. From these results, strong non-uniformity is observed in mental sweating where the amount of excess sweat in response to sound stress is different for each sweat gland.

3.2. Influence of the Experience of the Sound Stimulus

In the next experiment, we consider the influence of the experience of the sound stimulus. The dynamic analysis for mental seating of sweat glands was performed for two times using the same experimental protocol of **Figure 2**, where a subject was a 23-year-old male. In this experiment, the sweating dynamics of sixteen eccrine sweat glands were measured simultaneously. **Figure 5** show the time variation of the total reflection light intensity by application of the sound stimulus of the first and second times. There is almost same in the response to the sound stimulus. In addition, the time integrated value of the reflection light intensity is indicated by the red and the pink bars in **Figure 6**. The values corresponding to the total excess sweat are almost equal. These results suggest that there is no influence of the experience of the sound

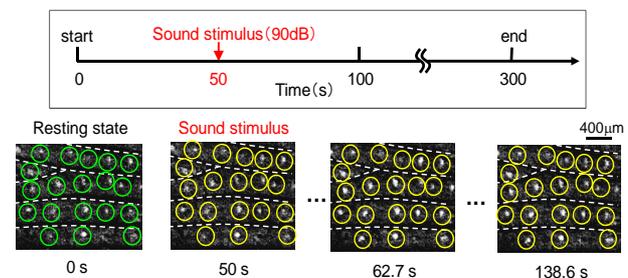


Figure 2. Experimental protocol and time-sequential piled-up en-face OCT images with the frame spacing of 3.3 sec.

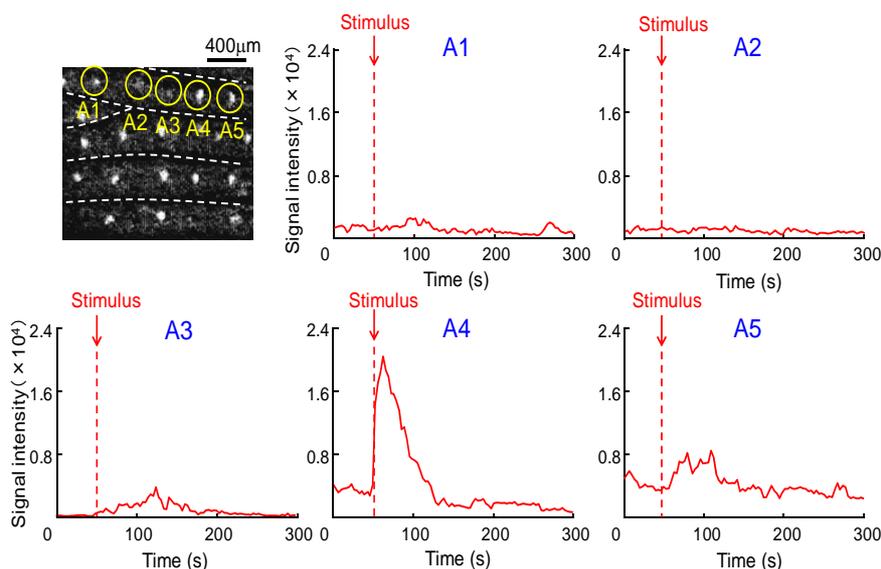


Figure 3. Time variation of the reflection light intensity of the sweat glands, corresponding to the amount of excess sweat in response to the sound stress.

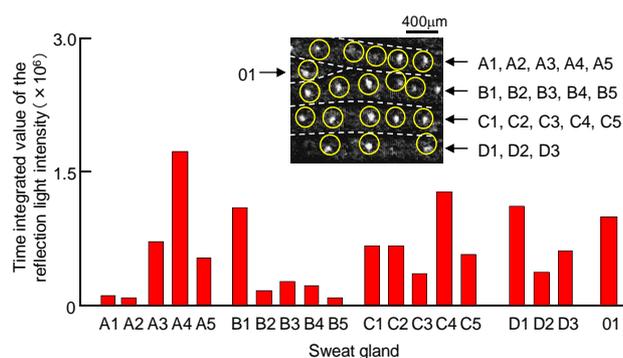


Figure 4. Time integrated values of the reflection light intensity, corresponding to the total amount of excess sweat.

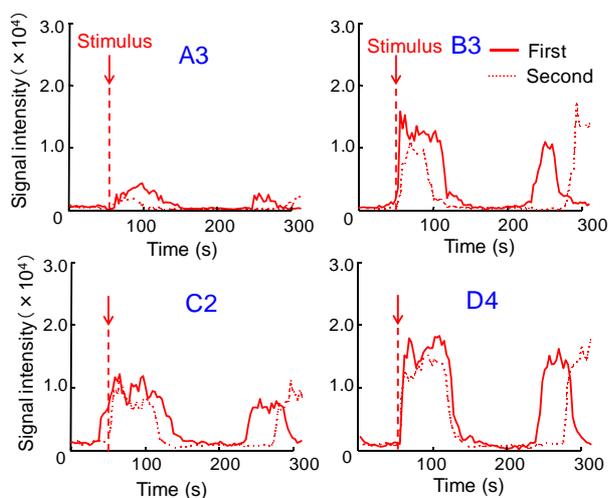


Figure 5. Time variation of the reflection light intensity by application of the sound stimulus of first and second.

stimulus to the subject.

3.3. Variation of the Amount of Mental Sweat for the Different Sound Stimulus

Finally, we consider the variation of the amount of sweat for different sound levels. The dynamic analysis for mental sweating of sweat glands was performed two times, where the first stimulus of sound level was 90 dB and the second sound stimulus was 60 dB. **Figure 7** show the time variation of the total reflection light intensity. There is large difference of time variation of the reflection light intensity of the sweat glands between 90 dB and 60 dB of the sound stimulus. The time integrated value of the reflection light intensity is also indicated by the red and the blue bars in **Figure 8**. The values corresponding to the total excess sweat are significantly increased in proportion to the sound levels. This result indicates that the activity of the sympathetic nerve is proportional to the strength of the sound stimulus.

4. Discussion and Conclusions

We have demonstrated the dynamic OCT analysis of mental sweating of sweat glands on a human fingertip. We have proposed a novel method for evaluation of the amount of excess sweat in response to stress, where the en-face OCT images of the sweat gland are constructed by the 128 B-mode OCT images. Amount of sweat can be evaluated simultaneously for a few tens of sweat glands by piling up of all the en-face OCT images. The dynamic analysis of mental sweating is performed by the time-sequential en-face OCT images with the frame spacing of 3.3 sec.

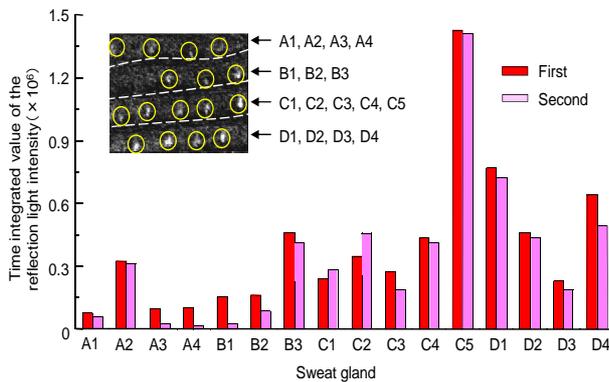


Figure 6. Time integrated values of amount of sweat stimulated by application of the sound stimulus of first and second times.

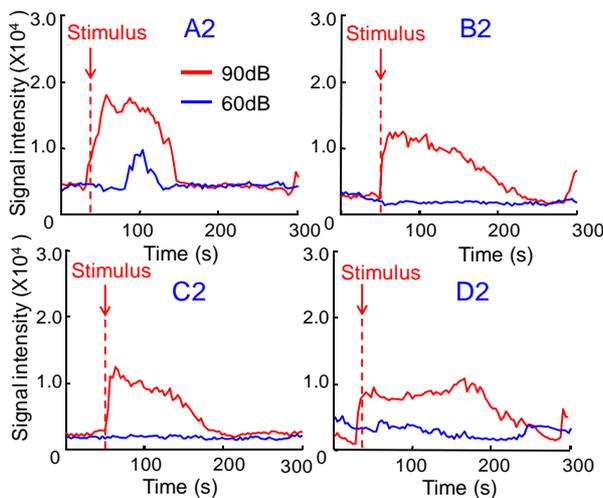


Figure 7. Time variation of the reflection light intensity by application of the sound stimulus of 90 dB and 60 dB.

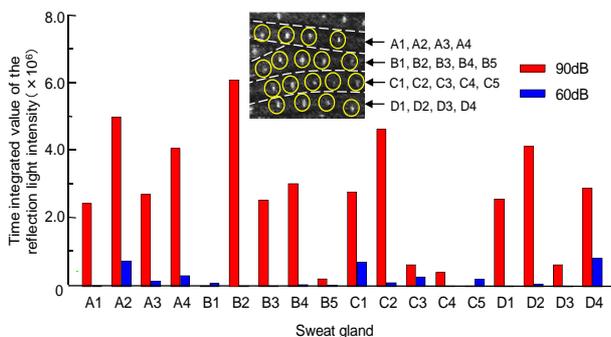


Figure 8. Time integrated values of amount of sweat stimulated by application of the sound stimulus of 90 dB and 60 dB.

From our experimental results, there are some interesting results of mental sweating in sweat glands on a human fingertip. 1) Strong non-uniformity is observed in mental sweating where the amount of excess sweat in

response to sound stress is different for each sweat gland. The non-uniformity may be necessary to adjust as precisely the total amount of excess sweat as possible through the sympathetic nerve in response to strength of the stress. 2) There is no influence of the experience of the sound stimulus to the volunteer. Our experimental protocol can be used frequently. 3) The amount of excess sweat of eccrine sweat glands is increased in proportion to the strength of the stimulus. This result suggests that the mental sweating varies quantitatively according to the stimulus.

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