Measurement of Micro-Strain in Nail Caused by Pulse Wave

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Abstract The micro-strains of a fingernail and toenail caused by pulse wave were measured by a conventional strain measuring method using a biaxial strain gauge. The strain fluctuations of nails were larger in the lateral direction than in the longitudinal direction. In a previous study, pulse wave measurement by a polyvinylidene difluoride (PVDF) film, which is a piezo film, attached to the nail surface was proposed as a new pulse wave measuring method with lower electrical power consumption. The piezo film can transform a nail surface micro-strain caused by pulse wave into an electrical signal. However, the optimal orientation of the piezo film on nails remains unclear. The experimental results of the present study showed that a larger displacement was generated from the nails to the piezo films by aligning the longitudinal direction of the piezo film with the lateral direction of the nails.

Keywords: nail micro-strain, piezo film, pulse wave, wearable sensor.

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1. Introduction

A pulse wave measurement method without a light source is extremely attractive for wearable pulse wave sensors attached to fingernail or toenail surfaces [1]. Since such a tiny wearable device can only house a small battery cell, the light source used by, for example, a photoplethysmographic (PPG) measuring circuit consumes most of the stored electricity in a short time [2]. The use of piezo films such as polyvinylidene difluoride (PVDF) film attached to the nail surface has been proposed as a new approach for measuring pulse wave without a light source [3]. In this method, the piezo film generates an electrical signal from the micro-strain of a nail surface created by the pulse wave. Considering that the piezo film has anisotropic piezoelectric sensitivity, it is necessary to determine the optimal orientation of placement of the piezo film on the nail surface.

In this study, we measured nail micro-strain caused by pulse wave using a biaxial strain gauge to investigate the orientation dependence of the nail strain. The optimal orientation of the piezo film based on experimental results is presented.

2. Methods

The subject was a healthy, 36-year-old male 169 cm in height. The dimensions of the subject’s nails are listed in Table 1. The radius of the nail curvature was measured by a radius gauge in the transverse plane at the central position. During the experiment, the subject maintained a resting supine position with arms extended along the trunk. His palms and heels were placed softly on the floor with floating toes.

After degreasing the nail surfaces with ethanol, biaxial strain gauges (FCA-5-11-1L, Tokyo Measuring Instruments Laboratory) were glued to the left thumb fingernail and left first toenail with standard procedures used in instrumentation (Fig. 1). The axis of the strain gauge was aligned with the lateral or longitudinal direction of the nail. The sensing elements of the strain gauges were in tight contact with the nail surface. Some areas of the circular base films with no sensing elements were not fully fitted to the nail curve, because the nails have a three-dimensional curved surface.

The strain gauges were connected to a data logger with 1 kHz sampling frequency through an amplifier.
A tiny PPG measuring circuit [1] was attached to the left index finger nail as reference and the signals were recorded simultaneously by the data logger. Recorded signals were processed by a digital band pass filter (0.5 to 30 Hz) to reduce noise. Five samples of 2- or 3-minute duration were recorded successively with resting intervals of several minutes.

This experiment was approved by the institutional review boards of the participating institution (10th June 2019). Informed consent was obtained from the subject.

### Results

Figure 2 shows the typical micro-strain signals recorded in a normal case (a) and a bad case (b), with PPG signals recorded simultaneously. The normal case shows that all four strain traces reflect cardiac activities, and the bad case shows that some of strain traces do not clearly reflect cyclic cardiac activity.

The four strain signals in Fig. 2(a) fluctuated cyclically and were synchronized with the PPG signal. The waveforms of strain in the lateral direction of the fingernail and toenail were similar to that of PPG signal, and the fingernail strain in the lateral direction had a dicrotic notch that is a typical feature of the pulse wave. The amplitude of the fingernail strain in this direction was $25 \times 10^{-6}$ and approximately twenty times larger than that of the toenail strain in the same direction.

The waveform of the fingernail strain in the longitudinal direction was sharper than that in the lateral direction, and the strain amplitude was approximately $0.8 \times 10^{-6}$. This amplitude was much smaller than that in the lateral direction. The longitudinal strain of the toenail had a cyclic fluctuation with amplitude of $0.6 \times 10^{-6}$. The small amplitude of the toenail strain was caused by the thickness of the first toenail. In general, the first toenail is thicker than the thumb nail in healthy persons, and the thickness of the subject’s first toenail nail was 150% of that of the thumb nail.

As shown in Fig. 2(b), strain signals from the fingernail were always stable, whereas strain signals from the toenail were occasionally weak. The reasons for the inhibition of pulse-induced strain remain unknown.

Figure 3 shows the nail micro-strains of the normal case in Fig. 2(a) over a period of thirty seconds. The subject’s average heart rate calculated from Fig. 3 was 70 beats per minute. The traces of the first second are expanded in Fig. 3 to show the waveforms and relative peak positions in detail. The local maximum of strain signals from the fingernail was synchronized with PPG signal. In contrast, the local maximum of the toenail strain had a time delay of approximately 0.1 s from that of the fingernail strain. The time delay was caused by the difference in distance from the heart to the measuring site. The lateral and longitudinal strains in the fingernail achieved maximum values at almost the same time, and the same was observed in the toenail. However, the longitudinal strain decreased more rapidly than the lateral strain in the fingernail.
4. Discussion

As shown in Figs. 2 and 3, the waveforms of the strain signals were different in the lateral and longitudinal directions. This anisotropic strain of the nails may be related to the anisotropic Young’s modulus of the nails, location of blood vessels under the nails, and curved geometry of the nails. The results suggest that in the pulse wave measurement using piezo film, strain of the nails can be transmitted effectively by placing the piezo film in the lateral direction, because a larger displacement can be obtained in this direction.

In a previous study, a piezo film placed in the lateral direction of the left thumb fingernail generated 75 mV with a strain of $10 \times 10^{-6}$ [3]. By applying the findings of the previous paper [3] to the toenail strain, a piezo film placed on the toenail is estimated to generate several mV. Thus, an amplifier or high resolution AD converter is required in the measuring circuit. In contrast, a piezo film placed on the fingernail can generate enough piezoelectric signals to measure the pulse wave without an amplifier, because more than $20 \times 10^{-6}$ of strain is obtained under current experimental conditions.

The strain of nail surface has been actively researched in various fields including robot hands with nails and health monitoring devices [4, 5]. In these fields, the nail strain generated by grasp with finger is measured and analyzed to obtain grasping force or motion states of the subject. The magnitudes of strain are around $10^{-3}$ to $10^{-5}$ in these reports, whereas that in this study is around $10^{-6}$. The present strain measuring experiments that focus on small nail strains demonstrated the acquisition of strain signals induced by the pulse wave. In other words, the pulse wave can be obtained from the strain signals recorded on nail surface.

To confirm reproducibility and stability, we measured the nail strains by the same procedures using new strain gauge elements on other days. Similar results as described in this report were obtained consistently. Through these measurements, strains lower than $10^{-6}$ were difficult to acquire clearly, due to noise in the strain signals with the present experimental set up. Various individual differences including nail size, thickness, curvature, and mechanical property such as Young’s modulus are expected. As a next step of the study, the effects of inter-subject differences of the above parameters on pulse signals would be investigated.

5. Conclusion

Pulse waves clearly induced micro-strain at the fingernail and toenail, and the micro-strain was observed easily by a conventional strain measuring method. Strain fluctuation in the lateral direction was greater than that in the longitudinal direction. A larger displacement was generated from the nails to piezo films by placing the longitudinal direction of the piezo film in the lateral direction of the nail. Considering the anisotropic piezoelectric sensitivity, a larger signal output can be obtained by aligning the sensitive direction of the piezo film with the lateral direction of the nail.
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