35th Annual International Conference of the IEEE EMBS
Osaka, Japan, 3 - 7 July, 2013

Development of Multichannel Array Transducer of Displacement Mechanical-Myogram*

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Abstract— **The myoelectric signal (EMG) recorded on the skin surface is a time-related and spatial aggregate of the action potentials of motor units of skeletal muscle, and it indicates the input information for muscle contraction. The mechano-myographic signal (MMG) is a vibration of skin/muscle surface caused by muscle contraction and it directly reflects the activity of muscle contraction. The two-dimensional generation mechanism of MMG is still not clarified in detail. In this study, the displacement MMGs were recorded at 25 measuring points using 5x5 displacement MMG array transducer within 50x50 mm, while the motor point of the biceps brachii was electro-stimulated. The spatial propagation map of twitch waveform of displacement MMG was drawn.**

I. Introduction

The electromyogram (EMG) is widely used to evaluate the contractile function of skeletal muscle, but this EMG is the input signal for muscle contraction. The mechanomyogram (MMG) is the resulting vibration associated with muscle contraction [1]-[4]. C. Orizio evaluated the mechanical activity of each recruited motor unit [2] and A. R. Ng et al. applied to a post-activation potentiation in myopathies [5]. Two-dimensional propagation of a surface electromyogram (sEMG) waveform was clarified by multipoint measurements of sEMG (e.g. high-density EMG). On the other hand, D. Farina et al. described the multipoint measurement of MMG using piezoelectric accelerometers [6], but the target portion and posture must be fixed securely for the acceleration-MMG measurement, because body movement causes a large artifact. The aim of this study was to develop a displacement-MMG (d-MMG) array transducer to measure two-dimensional propagation waveforms of d-MMG on the skin surface.

II. Methods

A. Multichannel Array Transducer

When we measure a MMG using an accelerometer generally, we should fix the target portion or posture securely, because a slight movement of the body results in a large artifact. As a result, MMG measurement cannot be widely applied to the field of daily life or sport science like EMG measurement. The authors proposed a d-MMG transducer using a photo-reflector [7], and it could avoid the errors caused by the body movements or artifacts. In this study, we have developed a 5x5 d-MMG array transducer composed of 25 photo-reflectors (TCRT1000, VISHAY), nine sEMG electrodes, and electronic circuits. Though the photo-reflector (7 x 4 x 2.5 mm) was originally designed to function as binary sensor, the authors utilized it as displacement transducer. The reflectors were located every 10 mm two-dimensionally and 8 mm away from the skin surface (Figure 1).

The reflector includes an infrared emitter (950 nm) and a daylight blocking filter. Nine sEMG electrodes were located around the d-MMG array. The electronic circuits (driving circuit and the amplifier for the reflector, sEMG amplifier, and analog-multiplexer) were located near the transducer and were connected to an ADC (USB-6341, NI) and the computer with a USB cable. The d-MMG waveforms were sampled at 10 kHz. To avoid lighting interference among neighboring reflectors, five of the 25 reflectors were made to turn on sequentially and the d-MMG was measured in turn (Figure 2).

First the basic characteristics of the transducer (mainly photo-reflector) were confirmed [8].

- Displacement-output characteristic: The displacement-output characteristic of the transducer was measured. When the distance from a piece of white lamina, which was placed on the measurement plate, to the reflector of the transducer was changed, the output voltage of transducer was measured.
- Frequency characteristics: The frequency characteristics of the transducer and the effect of vibrational disturbance were measured. The driving voltage, sinusoidally swept from DC to 200 Hz, was put into a vibrator. The distance from the vibrating plate of vibrator to the transducer was measured.
- Effect of daylight blocking filter: The effect of indoor light to the reflector was examined. The reflector includes an infrared emitter and a daylight blocking filter. As the transducer was utilized inside/outside the laboratory, the output voltage of transducer was measured in covering with black cloth and under an indoor light.

B. Measurement of Displacement Mechanical-Myogram

After two subjects in their 20's provided informed consent to participate in the experiment, the biceps brachii (BB) muscles of their right (dominant) arms were examined. Their elbow joints were fixed at 60 degrees. The d-MMG signals

*Research partially supported by Japan Society for the Promotion of Science (JSPS).

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were recorded with a LPF of DC-142 Hz (-6dB/oct) for 4 seconds and sampled at a rate of 10 kHz. As the application of the single photo-reflector, the d-MMG in twitch contraction and the d-MMG waveform of tetanic contraction were measured. Finally the d-MMG waveforms of 5x5 multichannel array transducer on the BB muscle of the subject B were measured. This experiment was undertaken with the approval of the ethics committee of Okayama University.

- D-MMG in twitch contraction: In the measurement of the d-MMG in twitch contraction, the transducer was put on the BB muscle of the subject A. The motor point of the BB muscle above the cutaneous brachii medialis nerve was stimulated electrically with a negative pulse for 3 ms, at a repeat frequency of 1 Hz and a stimulus intensity of 1.8 mA.

- D-MMG waveform of tetanic contraction: The d-MMG waveform of tetanic contraction of the subject A was measured under the electro-stimulation for 10 s. The pre-sweep twitches were induced for the first two seconds at 1Hz, and incomplete/complete tetanus was induced for the next five seconds. The stimulation frequency was logarithmically increased from 1-50 Hz. Then, after relaxation for one second, the post-sweep twitches were induced for three seconds, in order to confirm that the muscles were not fatigued in the post-sweep twitch. The stimulus intensity was 1.8 mA.

- D-MMG waveforms of 5x5 points on the BB muscle: Figure 3 shows the 25 measuring points of 5x5 on the center of the BB muscle of the subject B at 10 mm intervals. The electro-stimulation point was close to the internal and proximal side. The distal side was made to be the first row. The average waveform was obtained from at least four d-MMG waveforms measured for 4 seconds each, because the electro-stimulation was sometimes unequal.

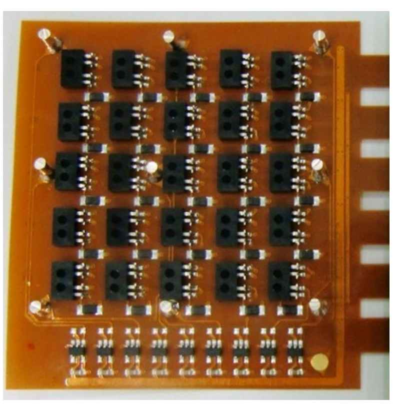


Figure 1. 5×5 d-MMG array transducer composed of 25 photo-reflectors and nine sEMG electrodes.

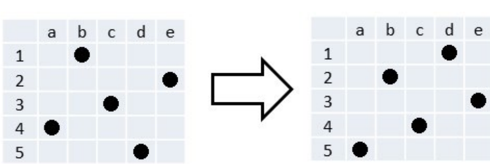


Figure 2. Five of the 25 reflectors were made to turn on sequentially and the d-MMG was measured in turn, in order to avoid lighting interference among neighboring reflectors.

III. Results and Discussions

A. Basic Characteristics of the transducer (photo-reflector)

- Displacement-output characteristic: The displacement dynamic range of the photo-reflector was 2-8 mm, shown in Figure 4, and the displacement-output curve was approximated by a cubic equation. The resolution was about 10 μm because of the dark current of the reflector and the electronic circuit noise.

- Frequency characteristics: Figure 5 shows the frequency characteristics of the photo-reflector and it was good approximately below100 Hz. There was no effect of shock disturbance on the output.

- Effect of daylight blocking filter: The coefficient of correlation between the output voltage of transducer in covering with black cloth and under an indoor light was 0.9994 and the built-in daylight blocking filter was effective for the indoor light.

B. Displacement MMG on the biceps brachii muscle

- Twitch waveform of d-MMG: Figure 6 shows the twitch waveform of d-MMG on the BB muscle. During a twitch contraction or voluntary contraction, the d-MMG waveform was smaller than that obtained by the laser displacement transducer [2], because it was a relative displacement using the bilateral housing legs as fixed points (nine sEMG electrodes), as shown in Fig. 1. But the obtained twitch waveform

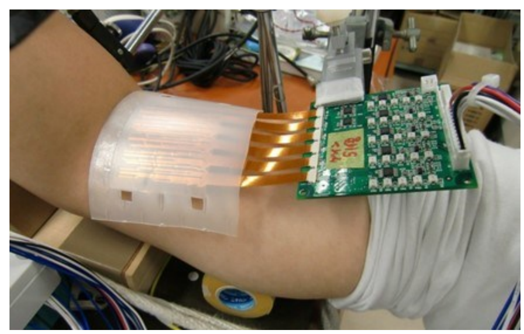


Figure 3. The d-MMG signals of 5×5 were measured on the center of the BB muscle for four seconds and the elbow joint was fixed at 60 degrees. The side close to the electro-stimulation point was the internal/proximal row.

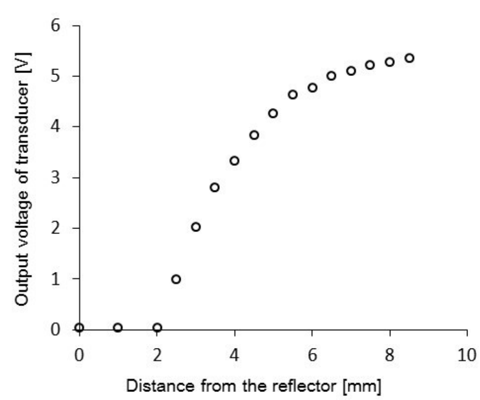


Figure 4. Relationship between the output voltage of transducer and the distance from the photo-reflector.

was similar to that measured by the laser displacement transducer. The latency of MMG waveform from the start of electro-stimulation was about 20 ms. The second derivative waveform of d-MMG was similar to the a-MMG waveform measured in an accelerometer.

- D-MMG waveform of tetanic contraction: Figure 7(a) shows a tetanic contraction curve of d-MMG. The baseline of the curve gradually increased, and the amplitude of twitch waveform gradually decreased as the stimulation frequency in the incomplete tetanus increased. Finally it reached a complete tetanus. The tetanic progression was quantified using the fusion index (FI) [9]. The FI is calculated from the minimum value (A) and maximum value (B) of the twitch waveform between each electro-stimulation interval in incomplete/complete tetanus. FI [%] is given by FI = (A/B)×100 [%]. The FI increased gradually when the stimulation frequency continuously increased, because muscle contraction shifted to incomplete tetanus from the twitch contraction. The FI remained at 100% in complete tetanus. This relationship between FI and the stimulation frequency was called the FI – frequency curve (FFC) and produced an S-shaped curve. Figure 7(b) shows the obtained FFC which was similar to the conventional report [10].

- D-MMG waveforms of 5 x 5 points on the BB muscle: Figure 8 shows the twitch waveforms of d-MMG of 25 points of 5 x 5 on the BB muscle surface. They were the average of three waveforms, each of which was adjusted to the electro-stimulation trigger. Figure 9 shows the two-dimensional aspect of 5 x 5 points at 25, 50, 75, 100, 125, 150 ms after the stimulation. The vertical axis is the amplitude of d-MMG. The amplitude at the point "b-5" on the internal/proximal side was the greatest, as shown in Fig. 8 and 9, because it was close to the electro-stimulation point. The maximum amplitude decreased when the twitch waveform was propagated to the distal and external side. It was clarified that the amplitude of any point did not always increase or decrease similarly and simultaneously (b-1, a-5).

IV. CONCLUSION

The displacement MMG array transducer was developed to measure two-dimensional propagation waveforms of MMG. A state of the two-dimensional propagation of a muscle contraction waveform was considered with these results of d-MMGs. In future, the propagation of high-density EMG signals and the axis of the muscle fiber estimated by the ultrasonic echo imaging should be considered with d-MMG

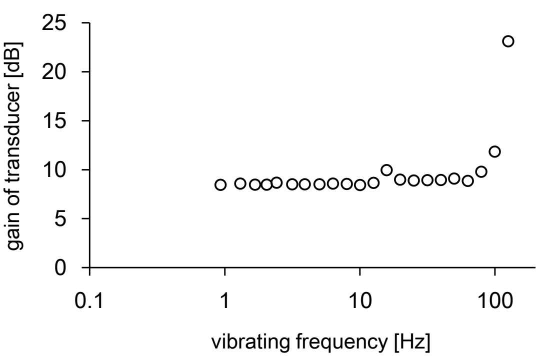


Figure 5. Frequency characteristic of the photo-reflector.

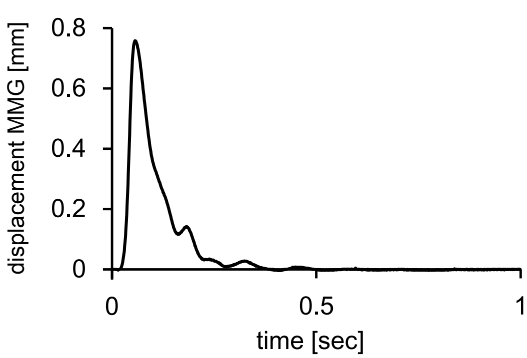
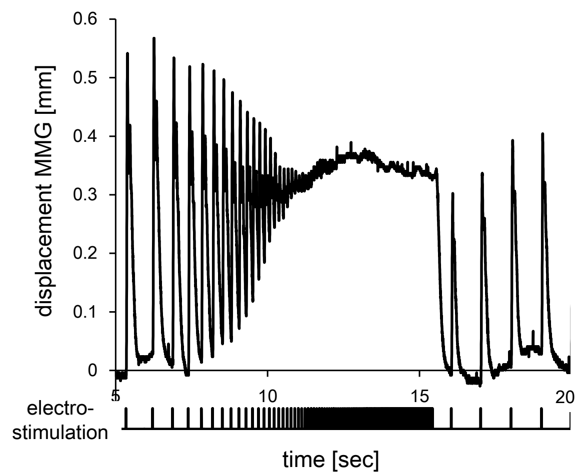
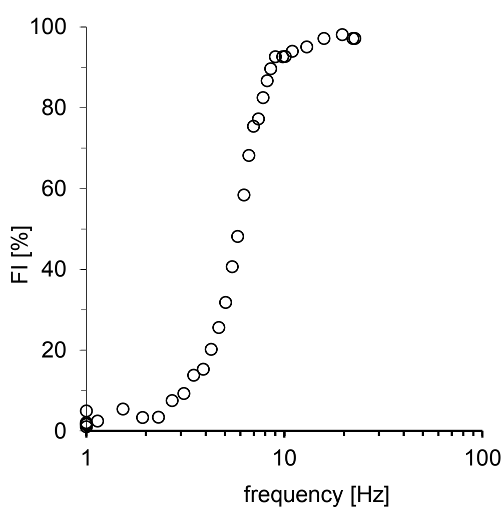


Figure 6. Twitch waveform of displacement-MMG.



(a) tetanic contraction of d-MMG



(b) Fusion-Index frequency curve

Figure 7. Tetanic contraction of d-MMG and Fusion-Index frequency curve in tetanic contraction.

signal simultaneously.

ACKNOWLEDGMENT

The authors thank Prof. M. Okamoto of Okayama University and Dr. T. Hattori of Nara Institute of Science and Technology for their experimental support.

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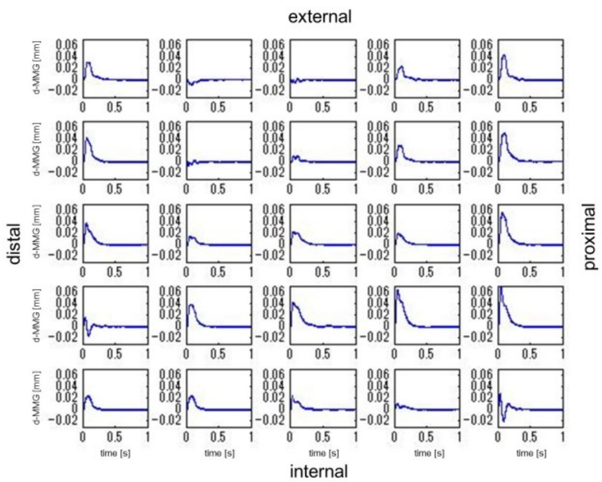

Figure 8. Twitch waveforms of d-MMG of 25 points of 5x5.

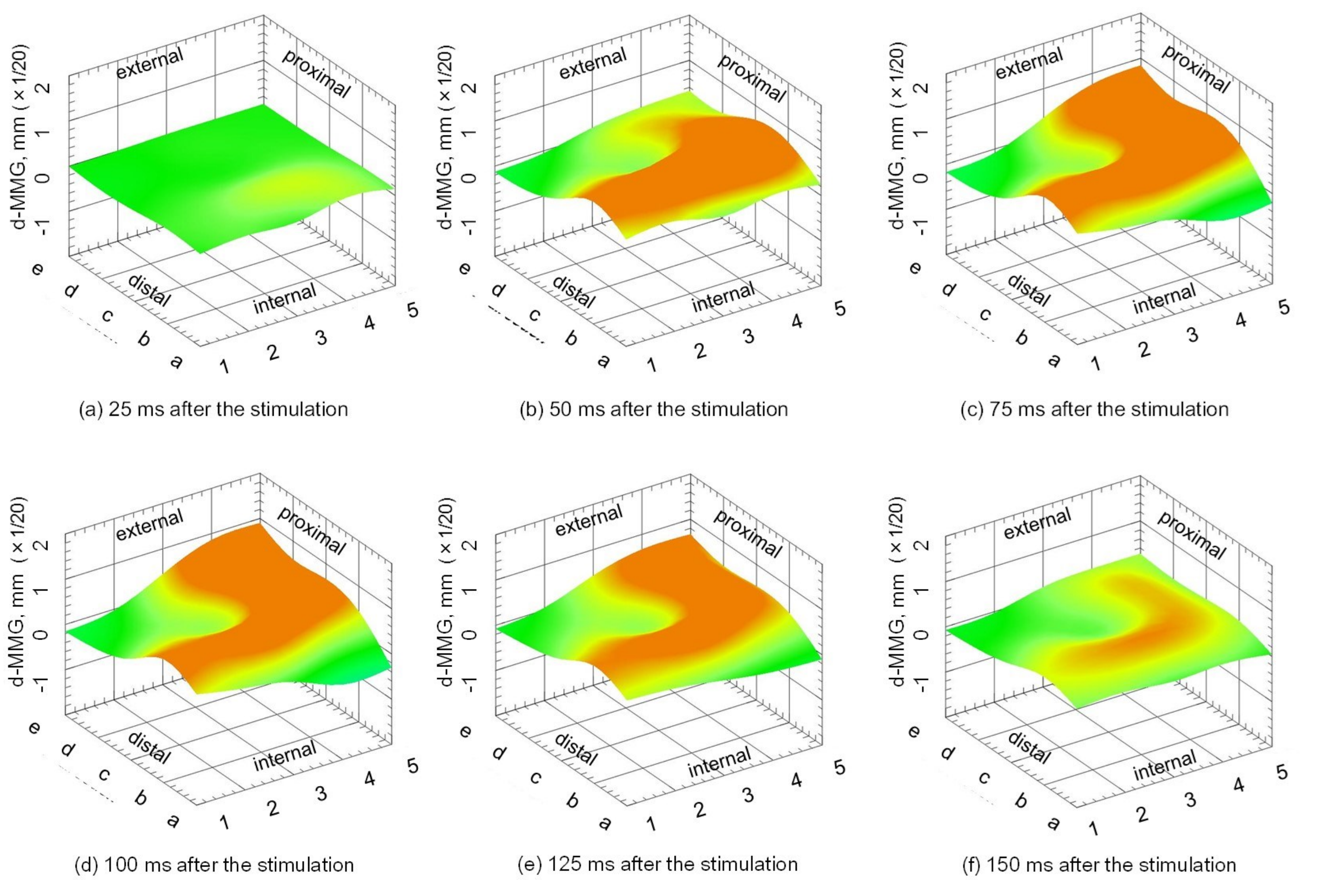

Figure 9. Two-dimensional aspect of 5x5 d-MMG of the BB muscle surface at 25, 50, 75, 100, 125, 150 ms after the stimulation.