Simultaneous Measurement of Displacement-MMG/EMG during Exercise

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Abstract: A surface electromyogram (sEMG) is a time-related and spatial aggregate of the action potentials of a muscle’s motor units. A mechano-myogram (MMG) directly reflects the mechanical contraction function of a muscle. A displacement-MMG is useful to examine the characteristics of muscle contraction. To evaluate muscle contraction, it is necessary to measure both EMG and MMG signals (EMG: input to muscles that will contract, MMG: resulting output from contraction). The authors developed a wireless MMG/EMG hybrid transducer (45 L x 16 W x 12 mmH, 2.5 g) composed of a small photo-reflector, two EMG electrodes, and a wireless transmission module. It can measure both EMG and MMG signals simultaneously. The authors applied the transducer to the measurement of displacement-MMG/EMG signals during subjects’ squatting-jumping, ergometer pedaling and running on a treadmill. The authors also examined the relationship between the MMG and EMG signals recorded.

Key Words: mechanomyogram, displacement-MMG, electromyogram, exercise.

1. Introduction

Myoelectric signals can be recorded by a needle electrode penetrating the muscle or by a surface electrode placed on the skin surface. A surface electromyogram (sEMG) is a time-related and spatial aggregate of the action potentials of these motor units. The contraction of a muscle increases the muscle’s internal pressure and transforms the skin surface when the pressure wave in the muscle propagates to the side of the muscle fiber [1],[2]. A recording of this phenomenon is a mechano-myogram (MMG), and this phenomenon can be measured by accelerometers, microphones, displacement transducers and other devices [3],[4]. An MMG directly reflects the mechanical contraction function of the muscle [5]–[10].

To evaluate muscle contractions, it is necessary to measure both EMG and MMG signals [11]–[14]. Since body movement causes a large artifact, the measured body portion or posture must be fixed securely when MMG signals are being recorded. As a result, MMG measurement cannot be widely applied in daily activities, sports evaluations or rehabilitation, like EMG measurement can. When MMG measurements are used in healthcare settings such as clinical medicine or sports-related science, it is necessary to measure the MMG during involuntary body movement or exercise. The authors previously proposed a displacement-MMG transducer using a photo-reflector [15]. The measurement of a displacement-MMG (d-MMG) is useful to examine the characteristics of muscle contraction, because the continuous enlargement-deformation of muscle (as shown in tetanus) can be observed by this method [16]. The purposes of the present study are to develop a wireless MMG/EMG hybrid transducer that can measure both signals simultaneously, and to apply the transducer to the measurement of d-MMG/EMG signals during subjects’ squatting and jumping movements, ergometer pedaling, and running on a treadmill [17].

2. Methods

2.1 Design of MMG/EMG Hybrid Transducer

The MMG/EMG hybrid transducer is composed of a small photo-reflector (TCRT1000, Vishay, Galco Industrial Products, Madison Heights, MI, USA), two Ag-AgCl electrodes (NT-211U, Nihon Kohden, Tokyo), and a wireless transmission module. Figure 1 shows the design of the displacement-MMG transducer. The reflector (7 x 4 x 2.5 mm) has an infrared emitter (950 nm) and a daylight blocking filter. Though the photo-reflector is originally a binary sensor, this study used it as a displacement transducer [18].

When the distance from a piece of white lamina placed on a measurement plate to the photo-reflector of the transducer is changed, the output voltage of the transducer is measured, as shown in Fig. 2. The displacement dynamic range of the photo-reflector is 1–8 mm, and we approximated the displacement-output voltage curve by a cubic equation. The resolution was about 10 μm because of the dark current of the reflector and the

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In this displacement transducer, both legs of the housing are considered fixed points, and displacement of the central active point on the skin is measured. The bilateral distance between the legs of the transducer housing, which is stuck on the skin, is 30 mm, and the height is 10 mm. Two EMG bipolar electrodes (φ8 mm) are placed on one of a subject’s legs. The hybrid transducer measures 45 mm L × 16 mm W × 12 mm H and weighs 2.5 g. The transducer is connected to a wireless transmission module (LP-WS1002, Logical Product, Fukuoka, Japan). The d-MMG and EMG signals were connected to a logger module (LP-WS1002, Logical Product, Fukuoka, Japan). The d-MMG and EMG signals were sampled at 1000 Hz and transmitted at 2.4 GHz.

### 2.2 MMG/EMG Measurement during Exercises

By using this hybrid transducer, the d-MMG and EMG signals of three subjects aged 20’s and a subject aged 50’s were measured during three exercises (squatting and jumping, ergometer pedaling, and treadmill running), after the subjects provided informed consent to participate in the experiment shown in Fig. 3. In order to calculate the joint angle, reflection markers were placed on the acromion, the great trochanter, outside of the patella, on the lateral malleolus of ankle, and on the head of the fifth metatarsal bone on the right side of the subject’s body, and the movement images were acquired in a motion capture system (Move-tr3D, Library, Tokyo). The experiment was performed with the approval of the Ethics Committee of Okayama University.

### 3. Results and Discussion

#### 3.1 Squatting and Jumping

Figure 4 shows typical results of a subject’s joint angles (hip, knee and ankle), MMGs (MMGDC and MMGAC) and EMGARV of the rectus femoris muscle during light squatting and jumping. The knee angle (0° at the maximal extended position of knee joint angle) is about 75° during light squatting (about 100° in a deep squat). The rectus femoris muscle is a bi-articular muscle which facilitates bending the hip joint and extending the knee joint. Because the body’s center of gravity descends during a light squat, hardly any EMGARV was observed at that time. The MMGDC, however, increased and decreased because the rectus femoris muscle cross-section increased and decreased passively corresponding to the flexion/extension of knee joint. In the case of deep squating, the marked muscle activity of the rectus femoris muscle was observed with the flexion/extension of the knee, and then the MMGDC became larger [21].

When the subject prepared to jump, the EMGARV of his rectus femoris muscle increased gradually and reached the maximum at the maximal extension of the knee joint. The MMGDC increased prior to the EMGARV because of the passive flexion of the knee joint. The EMGARV increased suddenly because the
rectus femoris muscle contracted strongly at knee and hip joint extension, and the MMGDC decreased but was larger than that at standing. The height of jumping was 39.4 cm on the average for five times. In the air, both the MMGDC and EMGARV became considerably small. When the subject made the landing, the rectus femoris muscle became active for shock absorption and the EMGARV and MMGDC increased at the hip joint flexion.

3.2 Ergometer Pedaling

Figure 5 shows typical results of the joint angles (hip, knee and ankle), MMGs (MMGDC and MMGAC) and EMGARV of the same subject’s right rectus femoris muscle during passive pedaling (60 rpm, 30 W) when his left leg was free of pedaling. The top dead center of the crank is at $180^\circ$, and the hip joint reached approximately maximal flexion a little later. There was no EMGARV of the right leg because of the passive pedaling. However, the MMGDC of the rectus femoris muscle changed because the muscle cross-section increased passively (caused by the hip joint flexion) but it was not synchronized with the changes of the knee joint angle.

Figure 6 shows the joint angles (hip, knee and ankle), MMGs (MMGDC and MMGAC) and EMGARV of the rectus femoris muscle of the same subject during fast ergometer pedaling at a heavy load (90 rpm, 60 W). The ±30° of the top dead center (180°) of the crank is the period of pushing down the leg. The ±30° of the bottom dead center (0 or 360°) is the period of backward pulling. The pushing-down of the leg comprises 50% of the whole muscle activity, and it involves the gluteus maximus and quadriceps femoris muscle. The backward-pulling accounts for 10% of the whole muscle activity, and it involves the gastrocnemius and tibialis anterior muscle. The pulling-up of leg is 30%, and the biceps femoris and iliopsoas muscle are involved; the front-pushing accounts for 10% and involves the iliopsoas muscle and gluteus maximus muscle.

The knee joint reached maximum flexion before the top dead center, and the hip joint reached maximum flexion after the top dead center. Around these crank angles, there was hardly any EMGARV signal from the rectus femoris muscle, but the MMGDC became maximum at the top dead center. Since the rectus femoris muscle is a bi-articular muscle and is involved in hip joint flexion and knee joint extension, we consider that the MMGDC shows the changes as a sum of hip joint angles and knee joint angles. Subsequently the EMGARV of the rectus femoris muscle increased with the pushing-down of the leg, and it reached its maximum at about 300° of the crank angle. This result agreed with the reports [22]–[24] that the effective pedal effort became maximum at 270° of the crank angle, but it was late (at 10°–20°), and afterwards an invalid pedal effort (more than required) occurred and became an effective force of pulling-up the leg at around 90°.

In the gongycampsis phase and the ankle dorsiflexion phase (pulling-up), the EMGARV of the gastrocnemius was rather decreased and the knee joint began to extend (pushing-down). When the ankle joint became plantar flexion, the EMGARV of the gastrocnemius began to increase. This result was observed in the case of both heavier load and faster pedaling.

The MMGDC of the gastrocnemius showed changes similar to those of the EMGARV. The triceps sura muscle works on pedal pushing in the plantar flexion of the ankle joint. The gastrocnemius (fast muscle) is associated with the plantar flexion of the ankle joint and the flexion of the knee joint. The EMGARV trended to increase with heavier loads and with faster pedaling generally, but the MMGDC hardly changed. Because the EMGARV increased since the higher strength was required depending on heavier loads. On the other hand, the MMGDC hardly changed because the cross-sectional expansion of muscle was saturated.

3.3 Treadmill Running

Figure 7 shows the joint angles (hip, knee and ankle), MMGs (MMGDC and MMGAC) and EMGARV of a subject’s rectus femoris muscle during normal walking (3.8 km/h) and fast running (16 km/h) on the treadmill. One stride is comprised of a stance-phase and a swing-phase of the right leg [25].
stance-phase starts from an initial contact (HC: heel-contact; maximal extension of the knee joint), and the swing-phase starts from a pre-swing (TO: toe-off; maximal plantar flexion of the ankle joint). The EMG$_{ARV}$ of the rectus femoris muscle became maximal after each HC, but the MMG$_{DC}$ increased before HCs because of knee joint extension. When the walking or running speed changed, the stride ratio between the TO and HC changed and the MMG/EMG ratio also changed. Figure 7(a) shows the long stance-phase of walking and the MMG$_{DC}$ of rectus femoris muscle was slightly high because of a single leg stance. But the EMG$_{ARV}$ was little found. Figure 7(b) shows the short stance phase and the MMG$_{DC}$ was slightly larger than that of walking but the EMG$_{ARV}$ was considerably larger than that of walking, because the rectus femoris muscle took shock of initial contact and prepared the swing phase.

Thus we succeeded in simultaneous measurement of MMG and EMG during exercise, using the developed hybrid transducer. The future study is to discuss mechanism of the muscle contraction in each movement from a viewpoint of EMG (input signal to muscles that will contract) and MMG (resulting output signal from contraction).

4. Conclusions

The authors developed a wireless displacement-MMG transducer with two EMG electrodes that can measure MMG and EMG signals simultaneously. Using this wireless MMG/EMG hybrid transducer, the authors measured several subjects’ d-MMG/EMG signals during squatting-jumping, ergometer pedaling and running on a treadmill, and examined the relationship between d-MMG and EMG. In the future, we will be able to apply this transducer successfully to the study of both daily life and rehabilitation because it is free from the errors that result from body movements or artifacts.
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References


