Estimation of individual muscle force within forearm in applying external load at each finger

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Abstract: The study aimed to develop a method to estimate the muscle force distribution within the forearm. Loads of 0.1 to 1.0 kgf were applied to the fingers of the right hand of four subjects. Surface electromyography (EMG) signals in the forearm were recorded during finger motions using multiple surface electrodes, which were bound around the subject's forearm. An EMG conduction model was formulated for reverse-estimation of muscle activities based on the distribution of surface EMG from the skin surface. In order to estimate the muscle force from the calculated muscle activities, a mathematical model based on linear regression relationship between muscle force and muscle activity was proposed. After performing the calibration process by gripping tasks, the distribution of muscle forces within the forearm was estimated. The muscle force tomographic images were generated for each load condition. The results show that different muscle force distribution patterns were obtained when applied different loads.

Key Words: EMG, Finger, Tomography, Muscle force

1. Introduction

Human hand is essential for performing daily activities. The complex movement of human hand is generated by many muscles and tendons within the forearm. In vivo estimation of muscle force is important to understanding the mechanism of muscle force generation. The muscle activity during muscle contraction can be detected non-invasively by surface electrode. Electromyography (EMG) signal is well known to be related to muscle force generation. The main problem is that surface EMG signals in a region where large number of muscles lie close together are superimposed. Make it difficult to observe individual muscle activities within the forearm. To overcome this problem, the EMG conduction model was developed to estimate muscle activity [1]. The reduction characteristics of the surface EMG power have been studied. The power of the attenuation in relation to the distance between the surface electrode and a source of muscle action potential were calculated using finite element analysis with a cylindrical conduction model [2]. The position and the activity of the source in the model have been reverse-estimated using optimization method.

This paper proposes a method to estimate muscle force distribution within the forearm using surface EMG. The development of this method will be very useful in the studying of muscular, which may potentially be used for evaluation of neuromuscular rehabilitation and clinical application

2. Method

2.1 Experiment procedure

Four healthy subjects (age: 21.8 ± 0.8 years) participated in the experiment. Firstly, the subjects performed gripping tasks using a hand grip; the force was held for 5 seconds and repeated trice. The gripping loads were 5, 10 and 20 kg. Then, the subjects sat on a chair with their forearm placed on a horizontal table. A load was applied to subject's finger by weight and pulley system (Fig.1). A load was applied for 5 seconds and repeated thrice. The weights of load were 0.1, 0.5 and 1.0 kg. Table 1 shows types of load that applied to the subject fingers.

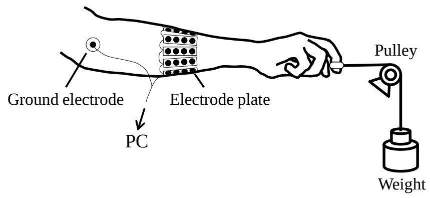

Fig. 1 Schematic diagram of the experimental setup. A load was applied to the subject's finger using weight and pulley system. A total of 20 electrode plates were bound around the forearm to detect the surface EMG.

Table 1 Load direction and load position at various fingers during the experiment

No.	Loaded finger	Load direction	Load position
M1-EDP	Thumb	Extension	Distal phalanx
M2-FPP	Index	Flexion	Proximal phalanx
M3-FPP	Middle	Flexion	Proximal phalanx
M5-FPP	Small	Flexion	Proximal phalanx

The surface EMG signals from the forearm were recorded with EMG band which consist of 20 custom-built electrode plates. The electrode plate comprised four aligned 3 mm diameter. The inter-electrode distance of the differential biopolar electrodes were 15 and 45 mm. All EMG signals were sampled at 1000 Hz, filtered with third order 9 Hz Butterworth high pass filter then second order 570 Hz Butterworth low pass filter. The root mean square (RMS) value and mean power of each channel were calculated from the recorded signals in 500 ms window.

2.2 EMG conduction model

The muscle region within the forearm was divided into calculation cell. The previous study shown that the RMS value of the muscle action potential V_i changes in proportion to the power exponent of attenuation b, exponentiated with L_{ij}.[3]

$$\bar{V}_i^2 = V_0^2 \cdot m_j^2 \cdot \sum_{k \in muscle\, j} \left(\frac{L_{ij}}{L_0} \right)^{2b} \qquad (1)$$

where L_0 is the unit length (1mm), m_j is the strength of the muscle activation (mA dipole/mm^2), and V_0 is a transformation coefficient [mV/(mA dipole/mm^2)]. This equation represents the EMG conduction model.

2.3 Calibration process

In order to estimate the muscle force from the calculated muscle activity, a mathematical model based on linear regression was proposed;

$$F_j = \alpha \cdot m_j \cdot A_j \qquad (2)$$

where F_j is muscle force of element j (N), α is muscle force coefficient (N/mA dipole), A_j is area of element j (mm^2). The static calibration was performed by gripping tasks. The total muscle activation (MA) was defined as the summation of muscle activation m_j within the forearm area calculated by

$$MA = \sum_j m_j \cdot A_j \qquad (3)$$

The change in total muscle activation between each load condition can be used to calculate α. Thus, for calibration process;

$$\Delta F_e = \Delta \cdot \alpha \cdot MA \qquad (4)$$

where F_e is external load (N). After calibration, muscle force of each element can be calculated by equation 2. The summation of muscle force within the forearm F_m was calculated by

$$F_m = \sum_j F_j \qquad (5)$$

3. Results and discussion

Figure 2 shows the relationship between external load and total muscle activation during the gripping task. The summation of muscle activation represents the muscle effort to resist the external load. A linear relation between external load and total muscle activation was computed. The regression equation was

$$F_e = 0.035 \cdot MA - 96.5 \qquad (6)$$

The relation had a good correlation (R^2 = 0.98). After calibration process, the value of α was 0.035 N/mA dipole.

Figure 3 shows muscle force distribution within the forearm during finger motions. The pattern of muscle force distribution changed with load condition. There was a variation of summation of muscle force between each load condition. This might due to the difference in muscle cocontraction pattern between each load condition. During finger motion, muscle's actions may be subdivided into agonistic, antagonistic and synergistic activity. The high summation of force indicates that there was high cocontraction of muscles.

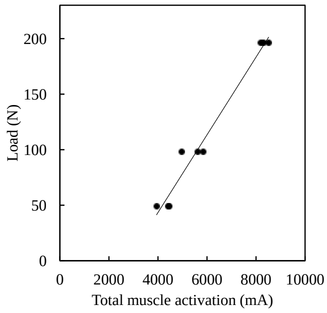

Fig. 2. Relationship between external load and total muscle activation during gripping task.

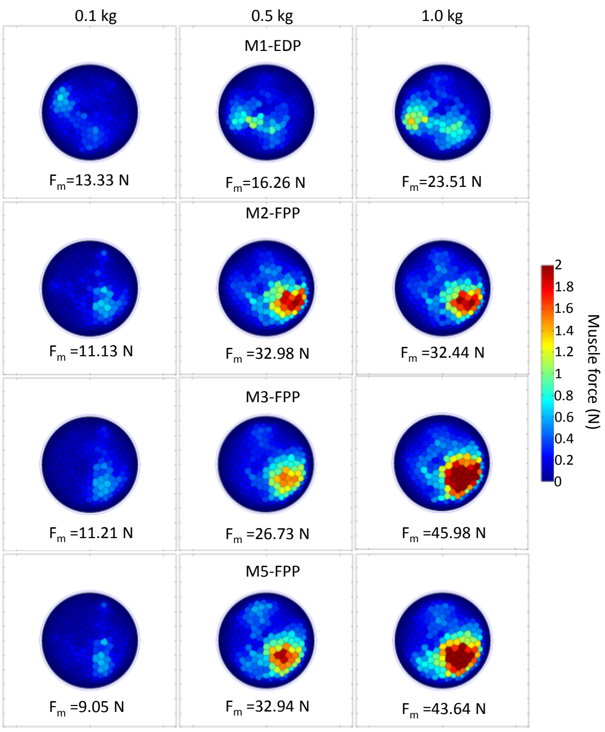

Fig. 3. Muscle force tomographic image during finger motion.

In summary, this study has shown that it is possible to estimate muscle force distribution within the forearm using surface EMG. A mathematical model to estimate muscle force from muscle activation was developed using a linear regression model. This method is very useful for studying muscular mechanism which potentially be used for clinical application.

4. Reference

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