The Relation of the MC Sensor and Dynamometer Responses

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Abstract – Natural motion of people is a complex process involving the entire psychophysical system. Its analysis contributes to a better and more comprehensive understanding of specific activities and behavior in general. The estimation of skeletal muscle tension during contraction is an important element in understanding human motion. A novel MC sensor that enables non-invasive in situ (examine the phenomenon exactly in place where it occurs) determination of the biomechanical, contractile and viscoelastic properties of all surface skeletal muscles, muscle parts, tendons and ligaments has been developed. With the MC sensor, muscle properties determination is achieved by measuring muscle force at the skin surface above the subject of measurement. The relationship between forces measured with the MC sensor and a dynamometer is nearly linear in static conditions. In this paper we show that this nearly linear relationship also holds when forces dynamically change in time during voluntary isometric contraction.

NOTE

The measurement method and supporting device described in this paper are a part of the patent »Method and device for non-invasive and selective determination of skeletal muscles biomechanical, contractile and viscoelastic properties of surface skeletal muscles« granted by World Intellectual Property Organization in January 2012.

1. INTRODUCTION

Natural motion of people is a complex process involving the entire psychophysical system. Its analysis contributes to a better and more comprehensive understanding of specific activities and behavior in general. In motion analysis we strive to identify different motion patterns. The latter can be defined as the process of identification and classification of ways of implementing a particular movement on the basis of various motion data.

Undoubtedly, the identification of motion patterns and its analysis is potentially widely applicable and useful. It helps, for example, in improving the quality of life of participants with limited physical ability. Detection of human motion and precise identification of motion patterns helps objectively determine the level of functional capabilities of individuals and therefore plays an important role in ambulatory monitoring [1]. This can benefit the elderly population in assisted living. Identification of motion patterns can help in determining specific activities and their evaluation. Precise identification and effective evaluation of motion patterns can help in training athletes and recovery of individuals after injury. Characterization of the locomotors pattern can also help to discern the specific injuries of the psychophysical system.

Because of its wide applicability in recent decades, the identification of motion patterns is a subject of many studies. One of the first methods for identification of motor patterns have been designed to use light markers and motion capture with cameras [2-5]. Markers fixed to the individual parts of the body emit light allowing subsequent motion analysis. The current state of technology allows more advanced methods of motion capture. The development and availability of various low-cost wearable sensors and more powerful processors at the same time, open the way for more efficient and precise motion patterns identification procedures. Developing sufficiently efficient algorithms in real time could provide for bio-feedback applications.

The potential benefits of identification of motion patterns when using wearable sensors raise the challenge of identifying sensors best suited for this purpose. Gyroscopes and accelerometers are widely used for capturing motion kinematic data [6-9]. For estimating muscle properties, a new MC sensor has been developed. This sensor is applicable for measurements as on still individuals as on individuals engaged in some activity and in this way provides for a more comprehensive activity analysis. In the following text, we give a brief overview of this sensor functioning principals and its appliance advantages.

2. THE MC SENSOR

The innovative muscle contraction (MC) sensor [10] considers force measurement performed in order to obtain biomechanical, contractile and viscoelastic properties (BCVP) of all surface skeletal muscles, muscle parts, tendons and ligaments (in further text referred to as the subjects of measurement). During skeletal muscle activity the tension of that muscle, generated by muscle fiber, changes. Skeletal muscles are able to produce varying levels of contractile force which induces different tension of the skeletal muscle. The tension change measurement is achieved by performing force measurement on the subject's skin above the skeletal muscle or muscle part that is of interest. Using the measurement device enables skeletal muscle BCVP establishment in a completely non invasive in situ way.

The MC measuring device is presented in Figure 1. The device consists of a sensor (1) with a sensor tip (2), microprocessor (3), and a supporting part (4), which binds together all of the device parts. The measuring device is pressed on the subject's skin surface (5) above the intermediate layer (6) and the measuring skeletal muscle (7). The measuring device is constructed in such a way that its pressing on the individual's skin surface (5) above the subject of measurement (7) causes the device sensor (1) and sensor tip (2) to strain the surface of the measuring individual's skin (5) and the intermediate layer (6), ultimately putting pressure on the subject of measurement (7). The depth to which the sensor tip (2) presses into the skin surface varies with the different physical characteristics of measuring individuals. If the initial sensor tip (2) position is not adequate, other tissue and fat surrounding the skeletal muscle will interfere with BCVP determination. The sensor tip (2) is shaped in such a way that the required depth of penetration is non-invasive and should not cause any pain or discomfort to the individual.

The supporting part (4) along with a specially designed attaching part provides for a suitable attachment and fixation of the device on the measuring subject's skin surface.

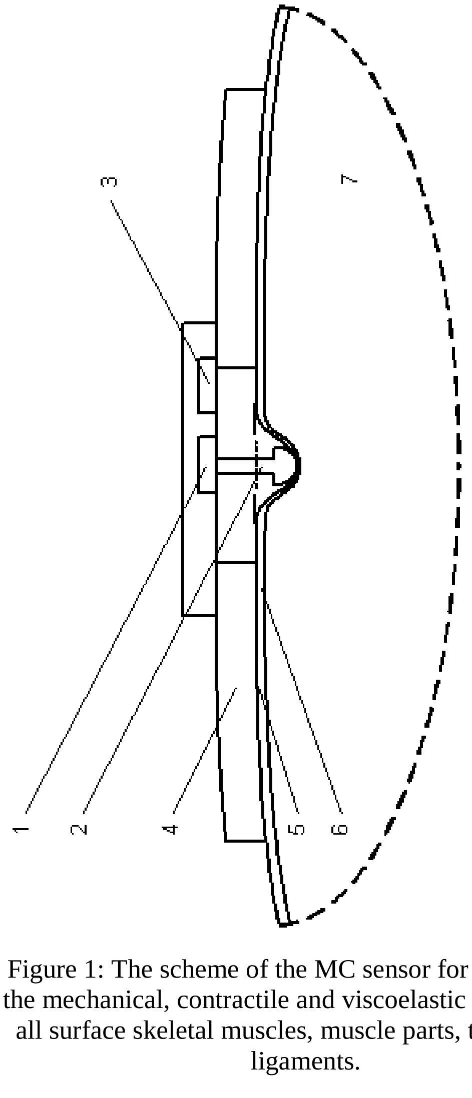

Figure 1: The scheme of the MC sensor for determining the mechanical, contractile and viscoelastic properties of all surface skeletal muscles, muscle parts, tendons and ligaments.

Deepening a suitably shaped sensor tip (2) into the skin surface (2) above the subject of measurement (7) produces a force on the tip. During subject (7) activity, which is manifested by repeating contractions and retractions, the force acting on the sensor tip (2) changes. If the sensor tip (2) depth is suitable and does not change during measurement, the force change detected is entirely due to the subject of measurement (7) activity.

3. MC SENSOR RESPONSE

In the study presented in [10] authors established that the timing of the MC and integrated electromyogram (iEMG) signals matched closely, indicating that the dynamic behaviour of the MC sensor is comparable to the dynamic behaviour of EMG. This study further concludes that the MC sensor can be used to determine the relative force of the muscle biceps brachii experimental model under isometric conditions (elbow angle 90°).

In [10] it was also shown that the relationship between forces F_{MC} measured with the MC sensor and F_D measured with a dynamometer is nearly linear in static conditions, so that it holds:

$$F_{MC} \approx kF_D \tag{1}$$

where k is the sensitivity of the system.

In this paper we would like to show that this nearly linear relationship also holds when forces dynamically change in time during voluntary isometric contraction, i.e., that:

$$\mathbf{F}_{\mathrm{MC}} \approx k\mathbf{F}_{\mathrm{D}} \tag{2}$$

where $\mathbf{F}_{\mathbf{MC}}$ and $\mathbf{F}_{\mathbf{D}}$ are signal vectors of forces measured with the MC sensor and a dynamometer respectively. In order to show that, we calculate the crosscorelation $R$of $\mathbf{F}_{\mathbf{MC}}$ and $\mathbf{F}_{\mathbf{D}}$. If R is high, we conclude that relationship is nearly linear.

If we want to determine $\mathbf{F}_{\mathbf{MC}}$ from measurements of $\mathbf{F}_{\mathbf{D}}$ using Equation (2), we must first find the sensitivity k which minimizes the mean square error:

$$MSE(k) = \frac{(\mathbf{F}_{\mathrm{MC}} - k\mathbf{F}_{\mathrm{D}}) \cdot (\mathbf{F}_{\mathrm{MC}} - k\mathbf{F}_{\mathrm{D}})}{N} \tag{3}$$

where N denotes the length of signal vectors $\mathbf{F}_{\mathbf{MC}}$ and $\mathbf{F}_{\mathbf{D}}$.

MSE(k) is minimal when its first derivative is equal to zero:

$$\frac{\partial MSE(k)}{\partial k} = \frac{2(k\mathbf{F}_{\mathrm{D}} - \mathbf{F}_{\mathrm{MC}}) \cdot \mathbf{F}_{\mathrm{D}}}{N} = 0 \tag{4}$$

and

$$k = \frac{\mathbf{F}_{\mathrm{MC}} \cdot \mathbf{F}_{\mathrm{D}}}{\mathbf{F}_{\mathrm{D}} \cdot \mathbf{F}_{\mathrm{D}}} \qquad (5)$$

Substituting k from (5) for k in (3) yields minimal MSE. Standard deviation of error σ can now be expressed as:

$$\pm = \sqrt{MSE(k_{opt})} \qquad (6)$$

As a measure of linearity we can use with the maximal value $\mathbf{F}_{\mathbf{D}}$ normalized standard deviation:

$$\pm_N = \frac{\pm}{\max(\mathbf{F}_{\mathrm{MC}})} \qquad (7)$$

It is worth to note, that the sensitivity $k$depends on many different factors, for example on the quality of tissue above the subject of measurement muscle. The values of k can also reveal certain properties of the measured system. Small σ_N, when forces dynamically change in time, also indicate good dynamical behavior of the MC sensor itself, as it is capable to dynamically follow the changing muscle contraction.

Measurements were performed according to the setup presented in Figure 2. The obtained $\mathbf{F}_{\mathbf{MC}}$ and $\mathbf{F}_{\mathbf{D}}$ are presented in Figure 3, where the $\mathbf{F}_{\mathbf{D}}$ signal is multiplied with the obtained k = 0.0033832. The obtained σ_N was equal to 6.07753 %.

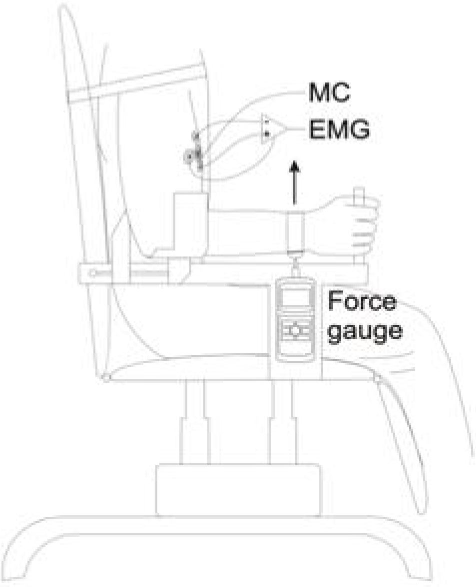

Figure 2: The measurement setup.

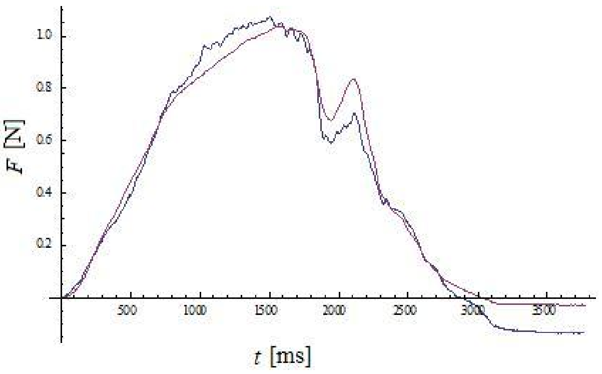

Figure 3: The MC sensor (blue curve) and dynamometer response (red curve). The dynamometer response is multiplied with the obtained sensitivity of the system k = 0.0033832.

4. CONCLUSION

Until now, measuring methods for muscle force has represented a significant technical problem. None of the measuring methods in use today features a dominant advantage that would make it generally applicable. The MC sensor enables selective and non-invasive detection and estimation of surface skeletal muscles, muscle parts, tendons and ligaments biomechanical, contractile, and viscoelastic properties. Being applicable during different activities and body movements, the MC sensor enables a better understanding of surface skeletal muscle properties during motion and a better functional diagnostics. The described characteristics provide for a distinctive advantage of the MC sensor over devices that are in use today.

The relationship between forces measured with the MC sensor and a dynamometer are nearly linear in static conditions. In this paper we established that this nearly linear relationship also holds when forces dynamically change in time during voluntary isometric contraction. Considering this we can conclude that the measurements obtained with the MC sensor are relevant and accurate and can benefit different fields like medicine, physiotherapy, etc.

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