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Preliminary Study of Skeletal Muscle with Multi-signals during Isometric Contraction

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Abstract—**Electromyography (EMG) has been widely used for the functional assessment of muscles. On the other hand, sonography has been commonly used to detect the morphological information of human muscles in both static and dynamic conditions. In this study, we demonstrated the feasibility to use the continuous signals about the architectural changes of muscles detected in real-time from ultrasound images to characterize muscles under isometric contraction. We named this signal as sonomyography (SMG). Synchronized ultrasound images and surface EMG (SEMG) signals were continuously collected from the right biceps brachii during the isometric contraction and subsequent relaxation periods together with the generated torque. The relationships among the SEMG, the muscle deformation SMG and the torque were investigated for the contraction phase. The results suggested that the SMG together with EMG signals may potentially provide a more comprehensive assessment for the muscle functions.**

I. INTRODUCTION

SURFACE electromyography (SEMG) signal is generated from the neuromuscular activation associated with muscle contraction. Therefore, analysis of SEMG signals is a valuable approach to study muscle contraction. Many studies have been previously reported on the relationships between the SEMG and muscle forc[1], length[1], and muscle fiber conduction velocity[2], etc. In fact, the muscle architecture is one of the primary determination of muscle function, and the architectural changes of skeletal muscle are always relative to the muscle activities[3], but the SEMG signal only represents the electrophysiological features, and can not characterize the morphological properties. Sonography, i.e. ultrasound imaging, is widely used to detect human muscles and nerve in both static and dynamic conditions. In recent years, sonography has been used to measure the muscle thickness[4], muscle fiber pennation angle[5], muscle dimension[6], and muscle fascicle length[2][5], etc. during isometric and dynamic contractions. Since these architectural parameters change obviously with contraction, they could potentially provide a noninvasive method of recording activities from deep muscles without the complication of the cross-talk from adjacent muscles suffered in the SEMG analysis[4]. Only recently, some studies have been reported on the relationship between the EMG activity and the muscle architectural parameters extracted from sonography in a quasi-static way[4][7].

The aim of this study was to investigate the relationships among the torque, parameter of SEMG, deformation of muscle during the continuous contraction process. We named this sonography-derived signal about muscle architectural changes as sonomyography (SMG), such as muscle deformation SMG.

II. METHODS

A. *Experimental protocol*

Seven healthy male subjects participated in this study (age: 27±2 years; height: 172±4 cm; weight: 65±6 kg). Each gave written informed consent prior to the experiment.

As shown in Fig.1, the subject was seated comfortably in the adjustable chair of a Cybex machine (Cybex Norm Testing & Rehabilitation System, Cybex Norm Int. Inc., Ronkonkoma, USA) with his trunk fixed by a strap onto the back of chair to limit position changes during the tests. The forearm was fixed on a forearm holder and the hand was arranged to grip a vertical lever arm. The elbow was flexed at 90° with the upper arm vertical, next to the trunk, and the forearm oriented horizontal. The axis of the lever arm was mounted to be parallel with the rotational axis of the elbow joint. After several familiarization contractions, the subject was asked to perform an elbow flexion against the lever arm and to increase the contraction gradually to the maximal contraction and then to relax gradually. The generated torque was shown on the PC screen and could be monitored by the subject. The maximal torque value was considered as the maximal voluntary contractions (MVC). Three repeated voluntary contractions were performed continuously within each trial and totally more than three trials were performed.

B. *Data acquisition*

A dynamometer in Cybex was used to measure the elbow flexion torques. The torque signal from the dynamometer was amplified by a custom-made amplifier and digitized by a data acquisition card (NI PCI-6024E, National Instruments, Austin, USA) installed in the PC.

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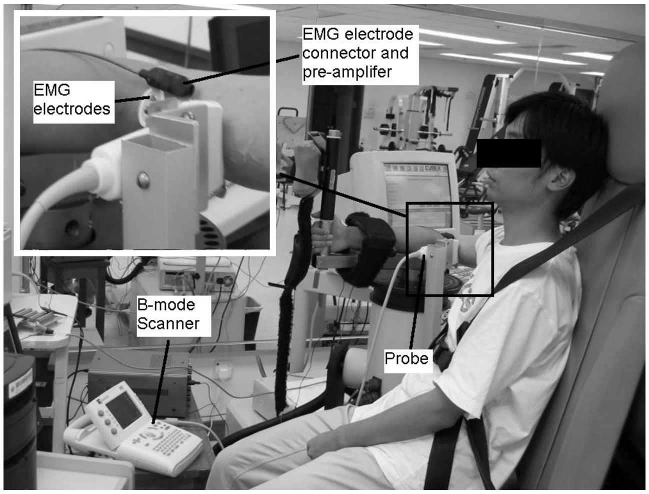


Fig. 1 The experimental setup for the measurement of muscle isometric contraction with sonomyography and surface electromyography. The area labeled with the small rectangle is magnified in the upper-left corner.

The sonography of a cross-sectional area of the biceps brachii was recorded using a portable B-mode ultrasound scanner (180 Plus, Sonosite Inc., Washington, USA) with a 7.5 MHz 38mm linear probe. The probe was fixed using a custom-made bracket. It was perpendicular to the skin surface of the biceps brachii region and its image plane was arranged vertically to the orientation of the biceps brachii muscle. There was a gap between the probe surface and the skin surface with filling the ultrasound gel to avoid any compression on the tissue during the whole contraction period. The video output of B-mode ultrasound scanner was digitized by a video captured card (NI PCI-1411, National Instruments, Autstin, USA) with a rate of 8 frames per second.

A pair of SEMG biploar Ag-Agcl electrodes (Axon Systems, Inc., New York, USA) was placed between the transducer and the elbow joint and along the orientation of the biceps brachii muscle. The distance between the two electrodes was 20 mm. The EMG reference electrode was placed on the proximal head of the ulna. The SEMG signal was amplified and filtered by a custom-made device with a gain of 10 and bandwidth of 10-800Hz before being digitized by the A/D card (NI PCI-6024E National Instruments, Austin, USA), and an additional gain of 10 was provided by the data acquisition card. The sample rate for SEMG data collection was 4 kHz.

The data acquisition was controlled by the custom-developed software for the ultrasonic measurement of motion and elasticity (UMME). Multithread technology was applied in UMME software to insure the synchronization among the ultrasound image, torque, and SEMG. Ultrasound image was sampled frame by frame, and each frame was accompanied by an SEMG epoch of 125 ms and a torque value.

C. Data analysis

All the ultrasound, SEMG and torque signals were processed off-line with the UMME software and another program written in MATLAB (Version 6.5, MathWorks, Inc., Massachusetts, USA). Two rectangular blocks were selected along the upper and lower boundaries of the cross-sectional image of the biceps brachii. The 2D cross-correlation algorithm was used to track the movement of each selected block frame by frame and the equation is as follow:

$$R(i,j)=\frac{\sum_{m=0}^{M-1}\sum_{n=0}^{N-1}[x(m,n)-\bar{X}][y(m,n)-\bar{Y}]}{\sqrt{\sum_{m=0}^{M-1}\sum_{n=0}^{N-1}[x(m,n)-\bar{X}]^2\sum_{m=0}^{M-1}\sum_{n=0}^{N-1}[y(m+i,n+j)-\bar{Y}]^2}} \quad (1)$$

where $\bar{X}$ and $\bar{Y}$ are the means of $x(m,n)$ and $y(m+in+,j)$, respectively.

The distance between the centres of the two selected blocks was calculated for each frame, which represented the muscle thickness measured in each frame. The percentage deformation of the muscle dimension was defined as:

$$\rho=\frac{(d-d_0)}{d}\times 100\% \quad (2)$$

where d_0 is the initial muscle thickness, d is the muscle thickness of each frame. The root mean square (RMS) of the SEMG amplitude was calculated for each epoch.

The correlations among the torque, SEMG RMS and muscle deformation were studied. Each contraction-relaxation cycle of each trial was analyzed individually. Two-factor ANOVA was used to test the significance of the differences of the results obtained among different cycles and among different subjects.

III. RESULT

A. Relationship between muscle deformation and RMS of SEMG

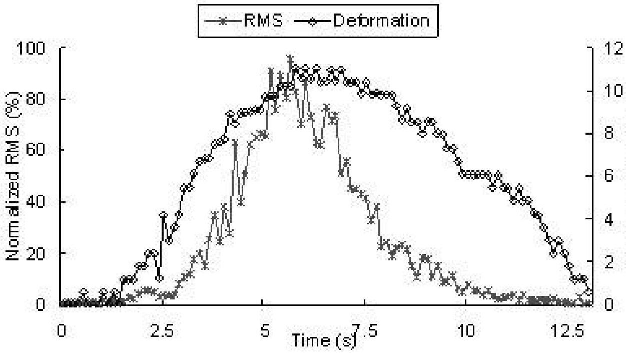
Because many researchers have study the relationship between RMS of SEMG and torque, we would not study it again. Fig. 2a and 2b showed a typical result of the SEMG RMS normalized by the value at MVC and the muscle deformation. The result of other subjects showed similar trends. The exponential function shown in equation (3) was used to represent the nonlinear relationship between the SEMG RMS and the muscle deformation during the contraction phase, which was consistent with the results previously reported[4]:

$$Y=a(1-e^{-bX}) \quad (3)$$

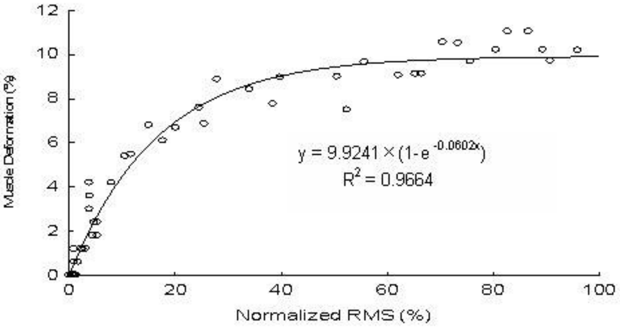
Where Y represents the normalized muscle deformation, X is the normalized RMS, a is the asymptotic value of Y when X is large enough, and the exponent coefficient b determines the curvature of the relationship. In order to evaluate the regression result by equation (3), the correlation coefficient (R2) and relative root mean square error (RRMSE)[8] were calculated, which were shown in Fig. 3a and Fig. 3b, respectively. The mean R2 value of the correlation was 0.880±0.084 and the mean RRMSE was 0.142±0.061. Two-factor ANOVA showed that there was a significant ($p<0.001$) difference of the exponent coefficients among the 7 subjects but not among the 9 cycles of the 3 trials (p>0.05).

B. Relationship between muscle deformation and torque

The relationship between the normalized torque and the muscle deformation in the contraction phase could be well represented by a linear regression which was shown in Fig. 2c and Fig. 2d. The mean R2 value of the correlation was 0.869±0.048 and the mean RRMSE was 0.126±0.034, which were shown in Fig. 3a and Fig. 3b, respectively. Again, there was a significant ($p<0.001$) difference of the ratios among the 7 subjects but not among the 9 cycles of the 3 trials ($p>0.05$).



(a)



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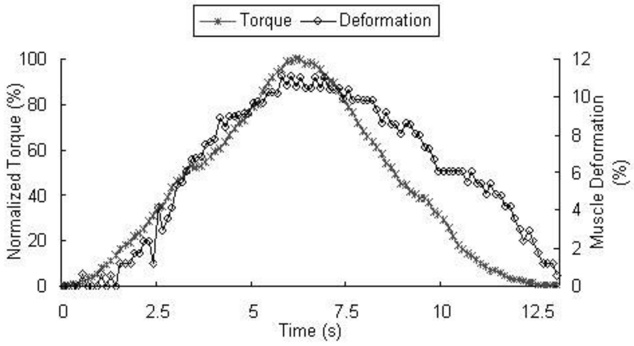
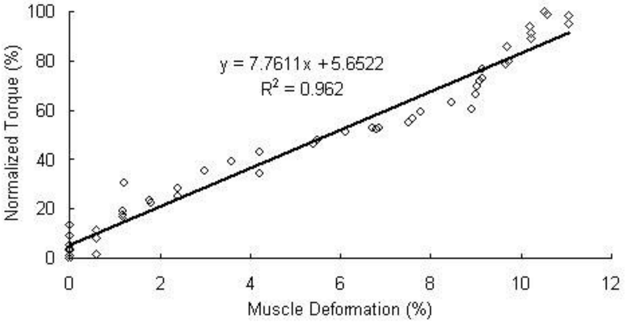
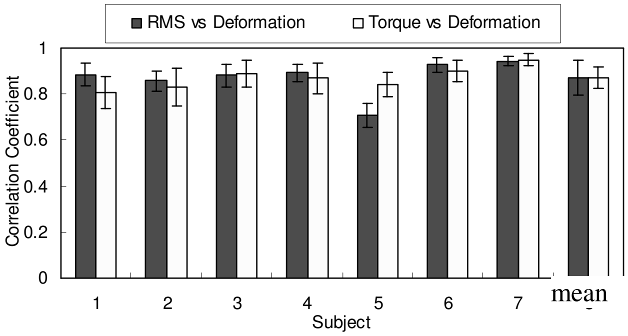


(c)

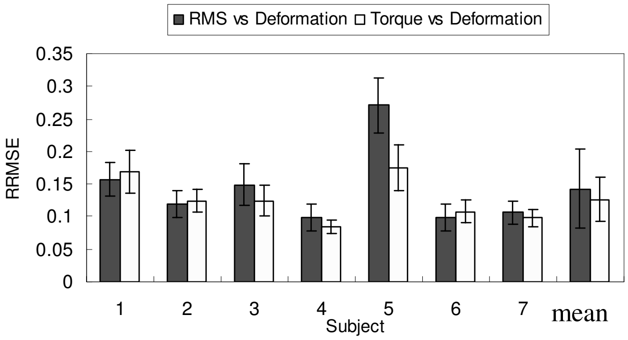


(d)

Fig. 2 The relationships among normalized torque, normalized RMS of SEMG and muscle deformation SMG.



(a)



(b)

Fig. 3 a) The overall correlation coefficient (R2); b) the overall RRMSE of different subjects. The last bars are the means.

IV. DISCUSSION

In this paper, we described a method to simultaneously collect the SEMG signals, torque and ultrasound images of the biceps brachii muscle during the continuous isometric contraction. The results of the contraction phase showed exponential relationships between the normalized RMS and the muscle deformation SMG. The mean R2 values were larger than 0.85 and the mean RRMSE values were less than 15% for all the linear and exponential regression, showing that good correlations could be achieved using the proposed regressions.

Our results demonstrated exponential relationship between the RMS and the muscle deformation for the biceps in the contraction phase. These result was consistent with those previous reports[4]. We further demonstrated that there was a linear relationship between the torque and the muscle deformation during the contraction phase. Our results appeared to imply that there was better linear relationship between the architectural changes of the muscle and the generated torque, which is related to the muscle force. Further studies with more subjects should be followed to consolidate these findings.

The architectural changes of skeletal muscle are always relative to the muscle activities. The medical imaging technology is a useful way to study the muscle architecture. Comparing with the MRI[9] and CT[10][11], sonography has many advantages to investigate the morphology of skeletal muscle[9][12]. For instance, sonography is noninvasive and no radiation exposure for human body. It is cheap and easy to use the sonography, especially the probe is small and convenient to be placed on the human body to measure the architectural parameters. In addition, it is relatively easy to combine sonography with other equipments to study the skeletal muscle. At present, the relationships between the structure parameters and other relative parameters such as SEMG, torque are very lacking, and they were usually investigated by experiments in the static or quasi-static way. In our study, we successfully acquired the SMG, SEMG and torque continuously and simultaneously in a dynamic way using the UMME system. The study with multi-parameters has shown its advantages, and we can understand the skeletal muscle more deeply from more aspects such as morphologic, electrophysiology and mechanics. Though we only give the experimental equations about the relationship among muscle thickness, SEMG and torque temporarily, we aim to study the skeletal muscle with multi-parameters from more aspects and model the structure parameters of skeletal muscle. Further studies with more subjects and more kinds of experiments should be followed to consolidate these findings, to model the skeletal muscle, and to apply the techniques for the rehabilitation engineering and physical training.

V. CONCLUSION

In conclusion, we investigated the contractile process of the biceps brachii with continuously sampled ultrasound image, torque, and SEMG. The results showed an exponential relationship between the RMS and muscle deformation SMG, and a linear relationship between the torque and the muscle deformation. The underlying mechanism for such relationships requires further investigations. Future studies are also necessary to investigate whether the results observed from the biceps brachii can be applied to other muscles as well. Our results suggested that the sonomyography signals, i.e. the muscle deformation detected using ultrasound, could potentially provide complementary information for the muscle assessment together with the widely used parameters including EMG and torque signals.

REFERENCES

[1] A. F. Mannion and P. Dolan, “The effects of muscle length and force output on the EMG power spectrum of the erector spinae,” J. Electromyogr. Kinesiol., vol. 6, pp. 159-168, 1996.

[2] D. Farina and R. Merletti, “A novel approach for estimating muscle fiber conduction velocity by spatial and temporal filtering of surface EMG signals, ” IEEE Trans. Biomed. Eng., vol. 50, pp. 1340-1351, 2003.

[3] Richard L. Lieber, Jan Friden. Functional and clinical significance of skeletal muscle architecture. Muscle & Nerve. 2000, 23: 1647-1666.

[4] P. W. Hodges, L. H. M. Pengel, R. D. Herbert, and S.C. Gandevia. “Measurement of muscle contraction with ultrasound imaging,” Muscle Nerve, vol. 27, pp. 682-692, 2003.

[5] T. Fukunaga, Y. Ichinose, M. Ito, Y. Kawakami and S. Fukashiro, “Determination of fascicle length and pennation in a contracting human muscle in vivo,” J. Appl. Physiol., vol. 82, pp. 354-358, 1997.

[6] N. D. Reeves, C. N. Maganaris and M. V. Narici. “Ultrasonographic assessment of human skeletal muscle size,” Eur. J. Appl. Physiol., vol. 91, pp. 116-118, 2004.

[7] J. M. McMeeken, I. D. Beith and D. J. Newham. “The relationship between EMG and change in thickness of transversus abdominis,” Clin. Biomech., vol. 19, pp. 337-342, 2004.

[8] J.J. Luh, G.C. Chang, C.K. Cheng, J.S. Lai and e-Son Kuo, “Isokinetic elbow joint torques estimation from surface EMG and joint kinematic data: using an artificial neural network model,” Journal of Electromyography and Kinesiology, vol. 9, pp. 173-183, 1999.

[9] N. Mitsiopoulos, R.N. Baumgartner, S.B. Heymsfield, W. Lyons, D. Gallagher, R. Ross, “Cadaver validation of skeletal muscle measurement by magnetic resonance imaging and computerized tomography,” J Appl Physiol, vol. 85, pp.115-122, 1998.

[10] M. Miyatani, H. Kanehisa, T. Fukunaga, “Validity of bioelectrical impedance and ultrasonographic methods for estimating the muscle volume of the upper arm,” Eur J Appl Physiol, vol. 82, pp. 391-396, 2000.

[11] B.H. Goodpaster, F.L. Thaete, D.E. Kelley, “Composition of skeletal muscle evaluated with computed tomography,” Annals of the New York Academy of Sciences, vol. 904, pp. 18-24, 2000.

[12] T. Fukunaga, M. Miyatani, M. Tachi, M. Kouzaki, Y. Kawakami nd H. Kanehisa, “Muscle volume is a major determinant of joint torque in humans,” Acta Physiol scand, vol. 172, pp. 249-255, 2001.