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5.7.1: EMG and Muscular Fatigue

# Estimation of Muscle Fatigue by Using EMG and Muscle Stiffness

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*Abstract* -- This study aims at the measurement and estimation of muscle fatigue. Viscoelasticity is calculated from the biomechanical impedance spectrum and EMG are measured. When isometric and isotonic muscle fatigue are created in the forearm, elasticity, viscosity and IEMG increase, and MNF decreases. Each variable change rate, however, is different In order to estimate muscle fatigue synthetically, PCA is calculated by using viscoelasticity and EMG. As a result, it is suggested that the 1st component expresses a change in muscle stiffness and the 2nd component expresses objective fatigue. The slope of the approximation line seems to correspond to the degree of muscle fatigue.

## I. Introduction

Many people have experienced muscle fatigue in daily life, including low back and shoulder pain. The degree of such pain can be estimated by a patient's subjective symptoms or by examining muscle stiffness utilizing manual palpation. These methods, however, are not necessarily reliable, and manual palpation is particularly dependent upon operator experience. Quantifying muscle fatigue is vital to the suppression or reduction of pain. The purpose of this study is to measure and estimate muscle fatigue utilizing EMG and muscle viscoelasticity. This paper deals with a change in muscle fatigue which is transitory, not chronic. EMG and muscle viscoelasticity, which is calculated from biomechanical impedance on the skin surface are measured simultaneously. Changes in these variables are examined for both isometric and isotonic muscle fatigue, and the author proposes an analytical method using PCA (Principal Component Analysis) with them. The final goal of this study is to propose an objective muscle fatigue index based on PCA.

## II. EMG and Viscoelasticity of Muscle

### A. EMG

In general, when a muscle becomes fatigued, the bandwidth of the EMG spectrum seems to decrease, and its amplitude seems to increase. In this paper, two variations of EMG are examined. One is a change in the median frequency of the EMG spectrum (MNF). The MNF value is different for individual muscles, but is 40 - 60Hz in the low back. The other variation is a change in EMG amplitude. The IEMG is measured every 0.2 seconds to examine the amount of EMG electrical discharge at short intervals. Hence when a muscle becomes fatigued, the MNF value becomes lower and the IEMG value increases.

### B. Viscoelasticity

When a muscle becomes fatigued, its stiffness will change. In order to detect this change, mechanical impedance is measured on the skin surface. The biomechanical impedance measuring system [1] consists of a measuring probe, an amplifier and a personal computer. The random vibration which is restricted from 30 to 1000 Hz is applied on a living body vertically through the vibrating tip which is driven by the vibrator. The vibration amplitude is about 0.02μm. Acceleration and force responses at a skin surface are detected by a measuring probe, and then the data is entered into a personal computer and sampled at 3kHz. The mechanical impedance is calculated by using the FFT of these signals. The measured biomechanical impedance spectrum in the low back changes before and after muscle fatigue. To evaluate this spectrum change, coefficients of shear elasticity $\mu_1$ ($N/m^2$) and shear viscosity $\mu_2$ ($Ns/m^2$) are introduced. The spectrum is a curve-fitted by the equation proposed by Oestreicher [2], which is the radiation impedance of a vibrating sphere in the infinite homogeneous medium.

## III. Experiments

### A. Two types of Muscle Fatigue

There are two types of muscle fatigue. One is isometric muscle fatigue and the other is isotonic. A contraction without a change in muscle length is called an isometric contraction, and a contraction with a change in muscle length is called an isotonic contraction. Isometric muscle fatigue occurs in the forearm, for example. by maintaining a horizontal arm position while holding a weight. Isotonic muscle fatigue occurs, for example, in the upper arm during a push-up. The muscle which is active is different in the two types of muscle fatigue. The experiment, which causes a subject to undergo fatigue in his forearm, examines both types of muscle fatigue.

### B. Variables Change in Muscle Fatigue

Figure 1(a) shows the measurement of isometric muscle fatigue. With holding a weight (1kg), the subject keeps his forearm at a 30 degree angle to the horizontal line for 30 minutes. The experiment is performed with the non-dominant hand, which increases muscle fatigue. The EMG electrodes are attached with a distance between electrodes of 4 cm. The flexor carpi radialis is the site for measurement. The subject subjectively rates pain in his forearm by utilizing a 4-grade rating system, from 0 to 3. Figure 2(b) shows the measurement of isotonic muscle fatigue. While holding a weight (1kg), the

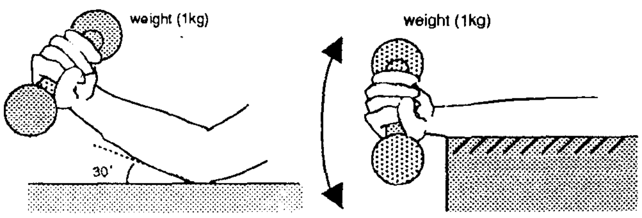
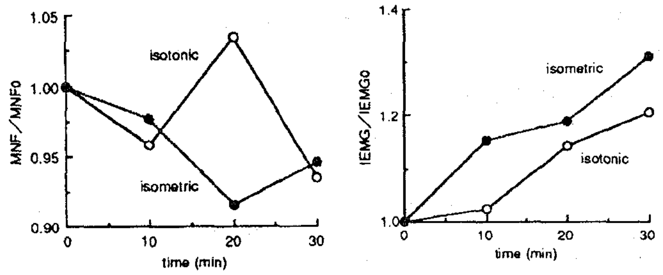
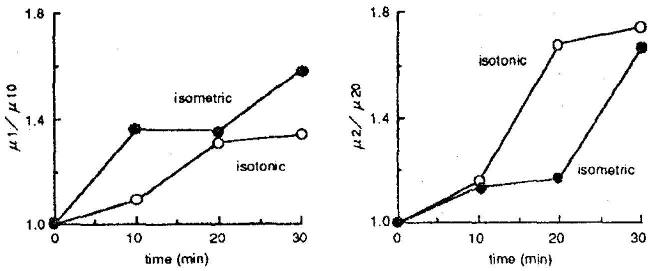



Fig.1 Isometric and isotonic muscle fatigue.




(a) MNF (b) IEMG

Fig.2 Changes of EMG in muscle fatigue.




(a) elasticity $\mu_1$ (b) viscosity $\mu_2$

Fig.3 Changes of viscoelasticity in muscle fatigue.

subject moves his wrist up and down. The subject's posture is kept the same during the measurements for both types of muscle fatigue. The wrist bending exercise is performed at two second intervals for approximately 5 minutes. Table 1 shows the change in variables. These results are obtained from the same subject. In the case of EMG, MNF decreases and IEMG increases along with the muscle fatigue. Figure 2 (a) and (b) show the change in MNF and IEMG. The y-axis is normalized by the value of each variable at 0 minutes. These phenomena is generally reported when the muscle becomes fatigued. But the change rate of MNF is less and the MNF value varies along with a slight variation of EMG spectrum. Hence the reliability of MNF seems to be less. On the other hand, the change rate of IEMG is greater and the change process of IEMG is similar to that of viscoelasticity. Hence IEMG is appropriate for estimating muscle fatigue. Figure 3 (a) and (b) show the change in elasticity and viscosity. They increase along with the muscle fatigue. Since viscoelasticity is the index which expresses muscle stiffness, increases in these variables mean that the muscle is becoming stiff. The change in muscle stiffness can be detected in detail by a change in viscoelasticity. In case of isometric muscle fatigue the muscle becomes stiffer at 20 - 30 minutes, and in case of isotonic fatigue at 10 - 20 minutes. Since the change rate of variables increases, viscoelasticity and muscle fatigue are probably mutually related. Hence these variables are appropriate for estimating the muscle fatigue. In case of isometric muscle fatigue, the subject complained of hard exhaustion and $\mu_1$ and IEMG increased.

## IV. Discussion

Muscle fatigue is estimated by using PCA with $\mu_1$, $\mu_2$, IEMG and MNF. Table 2 and Fig.4 show the results of PCA in the same subject. Since the cumulative proportion is 0.833 within

Table 1 Changes of EMG and viscoelasticity in muscle fatigue.

| variable | change rate after 30min (%) | |
|---|---|---|
| | isometric | isotonic |
| $\mu_1$ | 33.9 | 57.9 |
| $\mu_2$ | 74.9 | 66.7 |
| MNF | -6.50 | -5.40 |
| IEMG | 20.8 | 31.1 |

Table 2 Eigenvectors and eigenvalues of correlation matrix.

| variable \ comp. | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| $\mu$1 | 0.647 | -0.185 | -0.354 | -0.649 |
| $\mu$2 | 0.671 | -0.079 | -0.075 | 0.733 |
| MNF | 0.067 | -0.751 | 0.653 | -0.075 |
| IEMG | 0.355 | 0.629 | 0.666 | -0.189 |
| eigenvalue | 1.884 | 1.447 | 0.409 | 0.260 |
| propo. | 0.471 | 0.362 | 0.102 | 0.065 |
| cum.prop. | 0.471 | 0.833 | 0.935 | 1.000 |

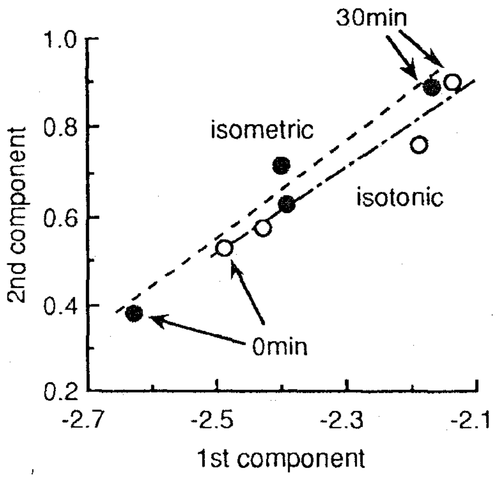



Fig.4 1st and 2nd component of PCA in isometric and isotonic muscle fatigue.

the 2nd component, the 1st and 2nd component should be considered. The author proposes that the 1st component (the x-axis) shows a change in muscle stiffness and the 2nd component (the y-axis) shows the change of objective fatigue in consideration of Fig.2 and 3. The straight lines in the same figure are used for approximation. The component scores of PCA increase along the line. The slope of the line seems to correspond to the degree of muscle fatigue and is larger in the case of isometric fatigue. Hence synthetic muscle fatigue can be estimated by the slope of the straight line.

## References

[1] H. Oka, T. Yamamoto and Y. Okumura, "Measuring device of biomechanical impedance for portable use," *Innov. Tech. Biol. Med.*, vol. 8, pp. 1-11, 1987.

[2] H. L. Oestreicher, "Field and impedance of an oscillating sphere in a viscoelastic medium with an application to biophysics, *J. Acoust. Soc. Am.*, vol. 26, pp. 707-714, 1951.