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Detection of Fast Fiber Recruitment by Multiresolution Analysis of Surface Electromyograms

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***Abstract*— This paper suggests possibility for detecting recruitment of fast muscle fiber on increasing load tests by multiresolution analysis of surface electromyograms (sEMGs). Recruitment of the muscle fiber can be guessed from a graph of power ratio *vs* % maximum voluntary contraction concerning the detail at each level, RPD(j). RPD(j)s are extracted parameters from multiresolution analysis of sEMGs. The sEMGs were recorded from the biceps brachii in five healthy males.**

I. INTRODUCTION

The surface electromyograms(sEMGs) can be assumed as a linear sum of individual motor unit(MU) action potential trains, generated by active MUs in the muscle. Spectral analysis of EMGs has been widely used to determine local muscle fatigue, force production, muscle fiber type proportion, and diagnosis[1,6]. Continuous wavelet transforms have been used in the time-frequency analysis of the sEMGs[5,6,7]. Studies for estimating motor unit action potentials(MUAPs) and crosstalks from EMGs or needle EMGs are actively performed now[2,3,4,8,9,10]. MUAPs are reconstructed using cepstrums of bispectrum of any EMG[9]. In this paper, we suggest possibility for detecting recruitment of fast muscle fiber based on parameters extracted from multiresolution analysis(MRA) of sEMGs on increasing load tests. Recruitment of the muscle fiber can be guessed from a graph of power ratio *vs* % maximum voluntary contraction (MVC) concerning the detail at each level, RPD(j)[11].

II. MULTIRESOLUTION ANALYSIS OF SIGNAL

MRA of a signal associated with the dyadic wavelet transform is explained below assuming level 5 decomposition as an example. Let A_5 be the approximation subspace (or scaling subspace) of level 5 in L^2. Let W_5 be the wavelet subspace of level 5 in L^2. Then $A_6 = A_5 \oplus W_5$. The symbol $\oplus$ means a direct sum. The subspace W_5 is spanned by the orthonormal basis $\{\psi_{5,k}(t) = 2^{5/2}\psi(2^5 t - k); k \in Z_F\}$, where $\psi(t)$ is the basic wavelet and $\psi_{j,k}(t)$ is the wavelet of level j at $k \in Z_F$. Z_F is a finite set of integers. The basis satisfies orthogonality conditions. Let $s(t)$ be a sEMG and let us perform a level 5 decomposition. The $s(t)$ can be expressed as follows: $s(t) = a_5(t) + D_5(t)$. Where $a_5(t) \in A_5$, the level 5 approximation, and $D_5(t) \in W_5 \oplus W_4 \oplus W_3 \oplus W_2 \oplus W_1$. The $D_5(t)$ is a sum of $d_j(t)$ with respect to j, where the j level detail $d_j(t) \in W_j$. Let $\{c(j,k)\}$ be the wavelet coefficients of $s(t)$ with respect to the wavelets $\{\psi_{j,k}(t); k \in Z_F\}$, the $D_5(t)$ can be expressed as follows:

$$D_5(t) = \sum_{j=1}^{5} \sum_{k \in Z_F} c(j,k)\psi_{j,k}(t) \ . \quad (1)$$

Let $PD(j)$ be power of $d_j(t)$, then it is defined as follows: $PD(j) = \sum_{k \in Z_F} c(j,k)^2$. Let TPw be total power of $D_5(t)$, then it is defined as follows: $TPw = \sum_{j=1}^{5} \sum_{k \in Z_F} c(j,k)^2$. Power ratio of the $PD(j)$ to the TPw at level j is defined by

$$RPD(j) = \frac{PD(j)}{TPw} \ . \quad (2)$$

Development of muscle fatigue can be assessed based on $\{RPD(j); j = 1, 2, ., 5\}$ [11].

III. sEMG ACQUISITION

The sEMGs were recorded from the biceps brachii in five healthy males during increasing load test. The sEMGs were recorded by the Digital Bio-Amplifier System (NF Corporation Ltd., Japan), sampled at 1000 Hz, and stored in a personal computer. The distance between a pair of surface bipolar electrodes was $20mm$ and diameters of the both electrodes were $10mm$. The subjects were asked to perform a maximal voluntary isometric elbow flexion torque at 90 ° with the upperarm vertical. The maximum forces were assumed to be 100%MVC (maximum voluntary contraction). On increasing load test, 5%MVC, 10%MVC, 15%MVC, 20%MVC, 25%MVC, 30%MVC, 35%MVC, 40%MVC, 45%MVC, 50%MVC, 60%MVC, 70%MVC were performed and data of 10 seconds duration were recorded. The MRA of the sEMGs were done with MATLAB 6.5; Wavelet Toolbox (The MathWorks, MA) using the Daubechies orthogonal wavelets of order 3(db3) and order 5(db5) mainly and of other orders afterwards for confirmation.

IV. RESULTS AND DISCUSSION

On increasing load test, TPw of the sEMGs increased rapidly from 35%MVC to 70%MVC. The graphs of the means of $RPD(3)$ and $RPD(4)$ with respect to five subjects are shown in **Fig. 1** and **Fig. 2**. Abscissa of each graph is %MVC. Ranges of variance, are also shown by vertical bars in the figures. The $RPD(3)$, $RPD(4)$ were calculated about the Daubechies orthogonal wavelets of various order from db3 to db8. On 3, 4, 5 orders, decomposition levels were 5. On 6, 7, 8 orders, the decomposition levels were 6, 7, 8, respectively. On larger value of j, corresponding to lower frequencies, the shape of $RPD(j)$ was convex and

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that of $RPD(j+1)$ was concave, in spite of increases in TPw. On smaller value of j, the shapes of $\{RPD(j)\}$ were convex. These figures indicate that components of lower frequencies increase much larger than increases in TPw according with increment in $\%MVC$. These are very interesting phenomena on MRA for sEMGs, although meanings of them are not obvious.

One capable interpretation is recruitments of type I (slow-twitch) fiber and type II (fast-twitch) fiber. We interpret that type II fibers were recruited from $35\%MVC$ point on increasing load test. As fiber of type I are recruited earlier and ones of type II are recruited afterwards[2]. We also interpret that the convex shapes of $RPD(3)$ together with $RPD(2), RPD(1)$ indicate the recruitment of MUs in the type I fiber. Firstly because, components of higher frequencies (corresponding to lower decomposition levels) in a sEMG decrease according with development of muscle fatigue. Secondly because, decreases in $RPD(3), RPD(2), RPD(1)$ curves on higher $\%MVC$ domain are caused by rapid increases in TPw. We refer only type I, type II and do not distinguish type IIa and type IIb. This interpretation does not contradict to results of other studies[2,3,4,8,9,10]. To check power increase on lower frequencies concerning $60\%MVC$ sEMG of one person, we calculated two power spectrums of sEMGs coresponding to the valley bottom and peak on $RPD(4)$ using MATLAB 6.5; Signal Processing Toolbox. Power spectrums of sEMGs at $30\%MVC$ and $60\%MVC$ for one person showed power shift toward lower frequencies. This fact indicates that recruitment of type II fiber can be seen in sEMG of $60\%MVC$.

V. Conclusion

This study suggests possibility for detecting recruitment of fast muscle fibers on increasing load test by MRA of the sEMGs, although experiments are not enough. Recruitment of the muscle fiber can be guessed from a graph of power ratio - %MVC concerning the detail at each level, RPD(j). The power ratios $\{RPD(j)\}$ indicate development of muscle fatigue and suggest recruitments of type II motor units in muscle fibers. For detecting recruitment of the fibers, the power ratios are superior to the power spectrums of sEMGs. Relations between sEMGs and firing rates of MU of various fiber types are subjects of investigations in future.

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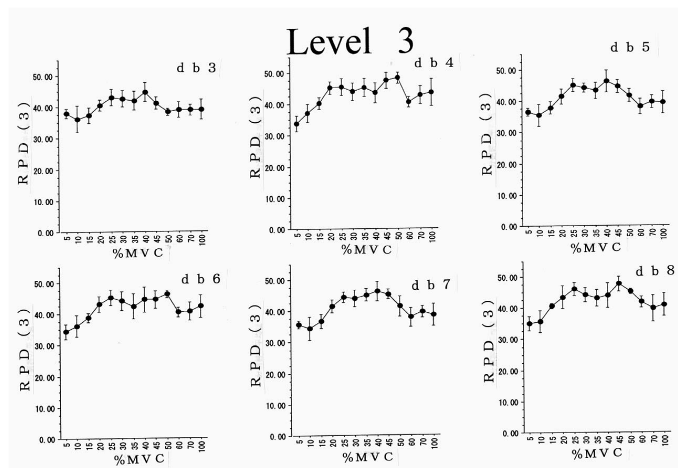

Fig. 1. RPD(3) Curves by Various Orders of the Daubechies Wavelets [db3,4,5: L5 Decom. ; db6,7,8: L6,L7,L8; respectively]

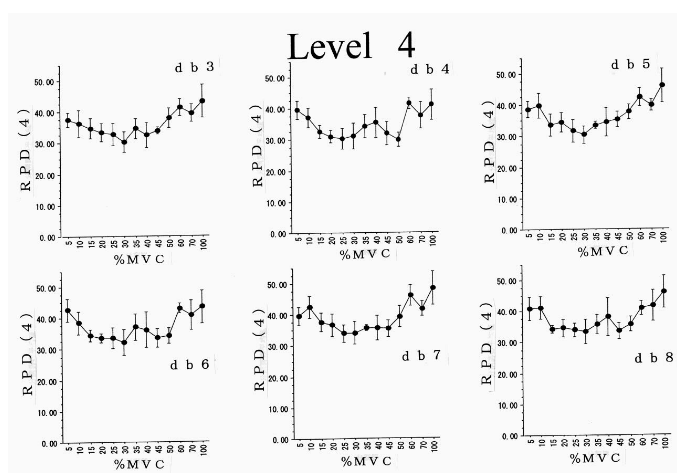

Fig. 2. RPD(4) Curves by Various Orders of the Daubechies Wavelets [db3,4,5: L5 Decom.; db6,7,8: L6,L7,L8 Decom.; respectively]