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A MODEL FOR MYOELECTRIC SIGNAL WITH LOCALIZED MUSCLE FATIGUING

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ABSTRACT

A myoelectric signal, under sustained isometric contraction of muscle the modelled as the output of a linear time-varying system whose input is constant number of pulse train. The proposed model considered localized muscle fatigue by metabolic by-products during sustained fatiguing contraction. To characterize muscle fatiguing model of myoelectric signal, We calculated median frequency of generated signal as fatiguing index of muscle during sustained isometric contraction.

1. Introduction

The human skeletal muscle is composed of numerous thread like fibers. These fibers do not event a constant contractile force, but rather contract and relax at high rate. The fibers rarely, if ever, act individually. In fact, they are innervated in group is innervated by a signal nerve axon. This group of fibers, together with the axon and nerve-cell body, is called a motor unit. The motor unit is the smallest subdivision of the muscle which can undergo a conscious contraction[1].

If a pair of electrodes is placed in a muscle and a conscious effort is made to activate only one motor unit in the vicinity of the electrodes, a varying potential will be recorded. This potential is known as the motor unit action potential(MUAP).
The MUAPs have time durations varying form 5 to 20ms and the amplitude may have any value between +200μV and -200μV. This MUAP is a summation of temporally and spatially dispersed action potentials travelling in the muscle fiber in the vicinity of electrodes[2].

Key word : Myoelectric signal, Muscle fatigue, MUAP
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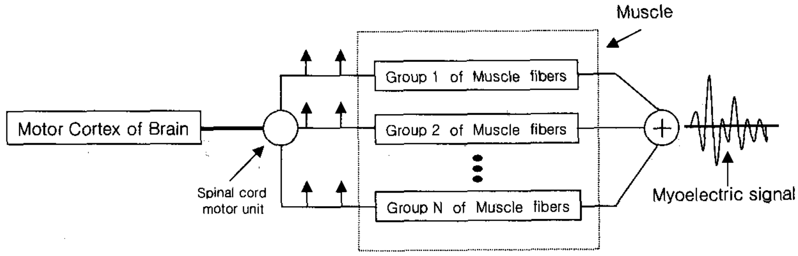

Fig. 1. Schematic representation of myoelectric signal generation

Fig. 1 Shows the schematic representation of myoelectric signal generation. The myoelectric signal as summation of MUAPs, is a results of biochemical reactions. When a muscle fiber is triggered by nerve impulse to contract, there is a movement of ions between the inner and outer membrane of muscle cell. This depolarization generates an electromagnetic field in the vicinity of muscle fiber which rapidly propagates along the length of the fiber. The myoelectric signal pattern has characteristics similar to bandpass filtered of their amplitude and duration as a function of time.

2. Fatigue

The amplitude of the signal observed an the surface of the skin reflects the number of muscle fiber groups actively contributing to the contraction. Physiologically, one associates increase in the amplitude with increased levels of farce production. The duration of MUAP is a function of velocity at which the MUAPs production along the muscle fibers.

Clinically, the duration of MUAP reflects both fiber type and net metabolic state of the muscle. This can be used to determine muscle endurance. During the of the sustained contraction, increasing metabolic by products cause the propagation velocity of MUAP to decrease resulting in longer duration of MUAP.

This means the characteristic changes in the myoelectric signal detected during a sustained fatiguing contraction with the force of the muscle held constant. As a practical matter, it is extremely difficult to visually discern the individual shape of contributing MUAPs[3]. This is due to the complex time superposition of MUAPs detected at the skin's surface. However, by mathematically transforming the signal from the domain into the frequency domain, one can calculate the spectral power distribution of the signal as a function of frequency. Using this transformation, changes in the frequency components of myoelectric signal occurring during the contraction can be observer.

3. Spectral characteristic of myoelectric signal

In frequency domain analysis, one can observe a shift in frequency spectrum of the myoelectric signal towards the lower frequencies. This is caused by the accumulation of metabolic by-products in muscle tissue. That is metabolic by-products cause a decrease in the conduction velocity(CV) or propagation speed of MUAPs along the muscle fiber.

As the contraction proceeds the shape of spectrum predominantly shift to the lower frequencies. This reflects the lengthening pulse durations resulting from the increase in metabolic by-products. The a mount of this spectral shift may be measured by tracking the median frequency parameter of the spectrum. The median frequency is defined as the frequency at which the power density spectrum is divided into portions of equal energy, the median frequency as a function of contraction time represents the metabolic fatigue process[4].

The slope of median frequency plot indicates the rate which the muscle is fatiguing. Thus the slope of median frequency plot provides away to monitor the metabolic changes in the muscle during fatiguing contractions.

4. Model description

E. Shwedyk proposed a generation model of myoelectric signals Fig. 2[5]. In this model, the neural pulse train go through different linear time invariant systems, characterized by impulse responses $h_1(t) \cdot\cdot\cdot h_n(t)$ to generate the MUAPs which are summed the myoelectric signal. The weighting coefficients k_i are assume to be random and a function of electrode placement. It is also assumed that the neural pulse trains are uncorrelated and That each, train is a renewal point process with identical interval statistics. The number of active motor unit's n(t) contributing to the myoelectric signal is a function of time, which imply that the output signal $e(t)$ is a nonstationary stochastic process.

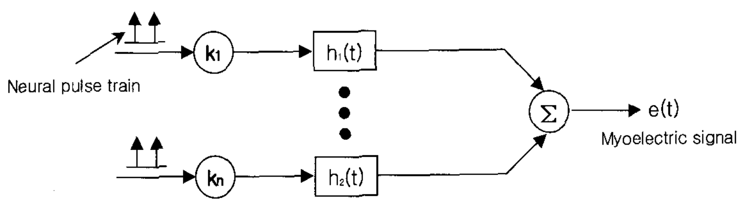

Fig 2. Model for myoelectric signal generation.

If the linear systems are assumed identical, then Fig. 2 reduces to Fig. 3.

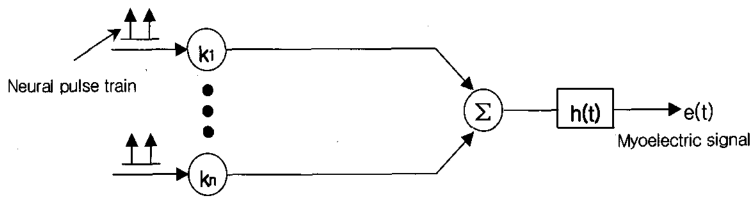

Fig 3. Reduced model for myoelectric signal generation.

E. Shwedyk derived the model for myoelectric signal generation in terms of it's mean and variance as following formula.

$$F[\sigma_e^2] = E[k_j^2]\, k_a \cdot N(jw)[H(jw) * H(jw)] \qquad (1)$$

where $\sigma_e^2(t)$ is variance of myoelectiric signal, K_a is average firing rate of neural pulse train and $N(jw)$ is Fourier transform of the number of contributing motor unit.

The model of Shwedyk is assumed under dynamic contraction of muscle. But, In the isometric contraction of muscle is fatiguing by metabolic by-products. Then frequency band of impulse response $h(t)$ shifted to lower frequencies. ie the impulse response $h(t)$ not time-invariant system but time-varying system during sustained isometric contraction, and also, the number of involved motor unit $n(t)$ and variance of myoelectric signal $\sigma_e^2(t)$ are constant during contraction respectively.

We propose a new model for myoelectric signal generation considering with muscle fatigue. The proposed model is linear time-varying system as Fig. 4.

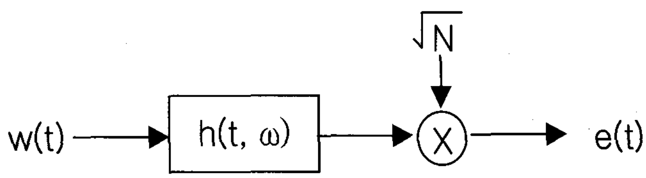

Fig. 4 The model for myoelectric signal considering with muscle fatigue.

Where $h(t, w)$ is time-varying impulse response during isometric contraction of muscle, and N, the number of involved motor unit is constant number.

In the model, increasing the muscle fatigue, impulse response $h(t, w)$ is shifted to lower frequencies.

5. Simulations

Physiologically increasing muscle fatiguing, the muscle conduction velocity and amplitude of myoelectric signal are linearly decreasing respectively. It induces the shift of median frequency of myoelectric signal to low frequency Inhuman muscles, the median frequency during sustained contraction of 100% MVC(maximum voluntary contraction) level is shifted from 200Hz at initial time to 30Hz at ending time.

Especially, The biceps brachii of human skeletal muscle has the median frequency shifting of 150Hz to 50Hz during fatiguing of 100% MVC level.

To generate myoelectric signal during fatiging, we extract the typical motor unit action potentials from initial and ending time of real myoelectric signal at biceps brachii(30% MVC level) by needle electrode. By control system analyzer, The impulse response function of extracted motor unit action potentials are calculated as formula (2) and (3).

$$h_i(t) = 0.8t\, e^{-4t}(8-4t) \qquad (2)$$

$$h_e(t) = 0.5t\, e^{-1t}(8-1t) \qquad (3)$$

where $h_i(t)$ is the impulse function of initial time of myoelectric signal, $h_e(t)$ is that of ending time. The impulse response functions $h_i(t)$ and $h_e(t)$ are similar form as (4).

$$h(t) = K \cdot t\, e^{-at}(R - at) \qquad (4)$$

From formula (4), Amplitude and median frequency of extracted MUAPs are function of parameter K and a , respectively. It means that parameter K is decreasing and parameter a is also decreasing during fatiguing of muscle.

The amplitude parameter K and frequency parameter a are considered linearly decreasing in relation the reported physiological experiments. The myoelectric signal during fatiguing is generated by two parameters K and a using generation model in Figure 4., where the number of involved motor units N is set 14.

To calculate median frequency-shifting of generated myoelectric signal, we divide to data blocks of 1024 data sample and each block data is transformed to frequency domain by Fourier transform to calculate median frequency. Table 1. shows averaged median frequencies of each block for 10 ensembles of generated myoelectric signals. By fatiguing, the median frequencies is linearly decreasing 130Hz at block 1 to 50Hz at block 30.

Table 1. The averaged median frequencies of generated myoelectric signal.

Block	med. freq.(Hz)	Block	med. freq.(Hz)	Block	med. freq.(Hz)
1	128.5	11	103.6	21	71.2
2	126.4	12	92.4	22	65.7
3	119.6	13	90.6	23	63.2
4	120.3	14	91.2	24	60.0
5	122.2	15	85.6	25	59.8
6	115.2	16	82.3	26	60.4
7	108.6	17	81.7	27	56.2
8	101.7	18	75.2	28	54.3
9	102.9	19	70.6	29	51.2
10	100.8	20	71.4	30	50.2

Table 2. The median frequencies of real myoelectric signal

Block	med. freq.(Hz)	Block	med. freq.(Hz)	Block	med. freq.(Hz)
1	110.8	11	79.6	21	49.8
2	96.2	12	75.4	22	45.2
3	93.6	13	73.2	23	43.1
4	91.6	14	69.3	24	39.8
5	85.4	15	66.1	25	35.5
6	85.2	16	59.4	26	34.2
7	83.6	17	55.6	27	29.6
8	81.2	18	56.7	28	26.4
9	82.5	19	55.2	29	22.1
10	80.7	20	52.6	30	20.5

To compare to median frequency of real myoelectric signal, we acquisited myoelectric signal by surface electrode from biceps brachii at 100% MVC level and calculated median frequency by the same method Table 2. shows median frequencies. In the case of real myoelectric signal, the change of median frequency is 110Hz to 20Hz. From the results of Table 1. and Table 2., the median frequencies of real myoelectric signal slowly changes comparing to that of generated signal. It results from low pass filtering effect of myoelectric signal by skin.

6. Conclusions

In this paper, we modeled myoelectric signal for muscle fatiguing. The model is considered amplitude parameter and frequency parameter of myoelectric signal in relation to physiological results of muscle for fatiguing. The change of parameters for fatiguing is analyzed by median frequency calculation of the generated and real myoelectric signals.

The median frequencies of both signals are shifted to low frequency by time and it means that physiologically the muscle fatiguing during sustained isometric contraction is progressed.

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