The effects of low frequency block stimulation for muscle fatigue

ABSTRACT: In electrical stimulation the muscles contract in order, from more fatigable motor units (fast twitch) to fatigue resistant motor units (slow twitch), since the fast twitch motor units have the lowest thresholds for electrical stimulation. Block stimulation theoretically has the effect of reducing muscle fatigue by blocking the contraction of more fatigable motor units under the electrical stimulation. To apply block stimulation for clinical use, we reported muscle fatigue below 100 Hz in block stimulation frequency using 100 Hz of drive stimulation frequency. Muscle fatigue under the 50 and 100 Hz block stimulations were reduced than that of drive stimulation only by blocking the contraction of more fatigable motor units. Our results suggest that block stimulation below 100 Hz in frequency is a more favorable method to reduce muscle fatigue when used together with intermittent high frequency stimulation.

Index Terms: functional electrical stimulation, block stimulation, muscle fatigue.

I. INTRODUCTION

In electrical stimulation the muscles contract in order, from more fatigable motor units (fast twitch) to fatigue resistant motor units (slow twitch), since the fast twitch motor units have the lowest thresholds for electrical stimulation [1], [5]-[7], [10]. Therefore, the muscles are prone to fatigue regardless of the weak stimulation amplitude [6], [7], [10]. Block stimulation has the effect of blocking the contraction of more fatigable motor units by being superimposed drive stimulation on the muscle nerve [6], [7]. Previous work reported the optimal block stimulation frequency to induce the greatest decrease of muscle contraction force was 600 Hz [5], [10]. We reported the effects of reduction of muscle contraction force below 600 Hz in block stimulation frequency using 3 kinds of drive stimulation frequency [3]. Block stimulation below 100 Hz in frequency reduced maximal tetanic force at 100 Hz drive stimulation frequency. On the other hand, the effects of block stimulation below 100 Hz in frequency to muscle fatigue has not yet been reported.

The purpose of this study was to investigate the effects of block stimulation below 100 Hz in frequency on muscle fatigue.

II. METHODS AND MATERIALS

Twenty five extremities of fifteen Whistar rats were used in this study. The animals were anesthetized intraperitoneally with Nembutal (30 mg/kg body weight). After opening the popliteal fossa, the sciatic nerve was clearly exposed and the common peroneal nerve was cut to eliminate the influence of the ankle dorsiflexion muscles. A drive electrode was placed at the sciatic nerve in the middle thigh level and a block electrode located 1 cm distally. Two cuff electrodes with a distance between poles of 5.0 mm were used. The muscle used here was the medial gastrocnemius muscle, a muscle having both fast and slow twitch motor units. The contraction force of the medial gastrocnemius muscle of the rat was measured isometrically using a force transducer. Negative square-wave stimulation was applied to both drive and block stimulation. The drive stimulation pulse width and amplitude was set at 0.2 ms and -2 V, respectively. The block stimulation pulse width and amplitude was set at 0.1 ms and -2 V, respectively. The frequency of drive stimulation was set at 100 Hz. In each group, block stimulation frequency was varied at 20, 50, 100 Hz. The stimulation sequence is shown in Fig. 1. Initially only drive stimulation was applied for 2 sec, 2 sec later block stimulation was superimposed for 15 sec. We measured maximal tetanic force induced by drive stimulation (Fm) and muscle force when block stimulation was superimposed (Fr), and Fr/Fm was calculated. The useful pattern of maximal tetanic force showed a reduction in residual force below the 100% Fr/Fm level when block stimulation was applied. And we measured muscle force at 4, 10, 14 sec later and calculated strength decrement index (SDI). SDI was defined as the percentage of the decrease of muscle force, or SDI= (Fr - Ft) / Fr X 100 percent where Fr = residual force at 2.4 sec later, and Ft = residual force at 4, 10, 14 sec later.

The protocols for animal experimentation described in this paper were previously approved by the Animal Research Committee, Akita University School of Medicine; All subsequent animal experiments adhered to the Guidelines for Animal Experimentation of the University.
III. RESULTS

The changing degree of attenuation achieved when the block stimulation frequency was varied 20 to 100 Hz. Fr/Fm decreased from about 80 to 40% with the increase in block stimulation frequency (Fig. 2).

As the stimulation time passed, SDI was increased all 4 cases (Fig.3). SDI was decreased with the increase of block stimulation frequency at each time. When the 50 and 100 Hz block stimulations were applied to drive stimulation, SDI was decreased significantly compared to drive stimulation only (repeated measure ANOVA; p<0.05).

IV. DISCUSSION

Block stimulation has been studied to achieve graduated control of muscle contraction force [5]-[7], [10]. Block stimulation theoretically has the effect of reducing muscle fatigue by blocking the contraction of more fatigable motor units [6], [7], [10]. A major limitation when using functional electrical stimulation (FES) is muscle fatigue [2], [3], [4], [7], [8]. We have used FES to restore paralyzed muscles in the lower extremities with closed-loop control.

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Fig. 1. Schema of the stimulation. Initially only drive stimulation was applied for 2 sec, 2 sec later block stimulation was superimposed for 15 sec. We measured maximal tetanic force induced by drive stimulation (Fm) and muscle force when block stimulation was superimposed (Fr, F4, F10, F14), and calculated Fr/Fm and SDI.

Fig. 2. Change in Fr/Fm. The useful pattern of maximal tetanic force shows a reduction in residual force below the 100% Fr/Fm level when block stimulation is applied.

Fig. 3. Time course of SDI. The upper trace shows the curve of SDI when only 100Hz drive stimulation was applied. The next three traces show the curves of SDI when the 20, 50, and 100 Hz block stimulations were applied.
Matsunaga, et al, [4] have reported that intermittent electrical stimulation using 100 Hz drive stimulation frequency is one of the strategies for reducing muscle fatigue. Therefore, we have introduced high-frequency stimulation into closed-loop control for standing in paraplegics[2], [4], [8], [9]. Block stimulation below 100 Hz reduced 40-80% of maximal tetanic force at 100 Hz drive stimulation frequency. In addition, muscle fatigue under the 50 and 100 Hz block stimulations were reduced than that of drive stimulation only by blocking the contraction of more fatigable motor units. We suppose that block stimulation below 100Hz in frequency is a more favorable method to avoid muscle fatigue when used together with intermittent high frequency stimulation. Our results suggest that block stimulation may be valuable in the development of closed-loop control for FES.

REFERENCES
