Muscle Fatigue During Intermittent Stimulation, Using Catch-like Property; An Animal Study


*Department of Orthopedic Surgery, Akita University School of Medicine
**Rehabilitation Division, Akita University Hospital
***Second Department of Physiology, Akita University School of Medicine
****BIOTEC, LTD
1-1-1 Hondo, Akita 010-8543, JAPAN
itohiro@doc.med.akita-u.ac.jp

Abstract

The purpose of this study was to compare muscle fatigue resulting from constant-frequency stimulation with muscle fatigue resulting from catch-like inducing stimulation during intermittent fatigue tests. The isometric force in the rats was measured for the medial gastrocnemius muscle. The stimulation cycle was set at 4 sec. on / 15 sec. off. The constant-frequency train (CFT) with 20Hz, and a catch-like inducing train (CIT) that began with one 10-ms interpulse intervals (doublet) followed by CIT, were delivered alternately. % of initial peak force was used to assess muscle fatigue. Muscle fatigue was greater under constant-frequency stimulation than under catch-like inducing stimulation during intermittent stimulation.

1. Introduction

In the clinical use of functional electrical stimulation (FES), the appearance of muscle fatigue becomes a major problem. Stimulation frequency mainly influences muscle fatigue, so previous investigators studied the optimal stimulation frequency to resolve this problem. Benton et al reported that muscle fatigue occurred rapidly under continuous stimulation at frequencies higher than 30Hz to 40Hz [3]. Today, to obtain smooth shrinkage and to reduce fatigue, the low frequency of about 20Hz is clinically used. Using low frequency may reduce the rate of fatigue, but it may not lead to the development of sufficient forces for FES application. Some investigators have reported other attempts to reduce muscle fatigue, by decreasing the load on the antigravity muscles using a hybrid orthosis, and by introducing a closed-loop control system [1]. The amount of stimulation required under the closed-loop control system is less than that of continuous stimulation, therefore closed-loop control is expected to help reduce muscle fatigue. Matsunaga et al suggested that muscle fatigue was greater at lower frequency than at higher frequency during intermittent stimulation, so he suggested that high frequency had advantage in the closed-loop control [7]. The catch-like property is the tension enhancement on which initial high frequency bursts are delivered at the onset of a continuous stimulation [2]. Previous research has indicated that the catch-like property is more effective in a fatigued state [4, 5]. In these studies, short-duration stimulation trains (300-500msec) were used. To date, no studies have identified the muscle fatigue resulting from intermittent long-duration trains using catch-like property for clinical usage of FES. We hypothesize that the combination of high and low frequency trains (catch-like inducing train) under intermittent stimulation may cause less muscle fatigue than continuous frequency stimulation. The purpose of this study was to compare the muscle fatigue resulting from constant-frequency stimulation with muscle fatigue resulting from catch-like inducing stimulation during intermittent fatigue tests.

2. Methods

Ten adult male Wistar rats with average body weight of 277.3g were used in these experiments. Each rat was deeply anesthetized with an intraperitoneal injection of
pentobarbital sodium (40mg/kg). The isometric force was measured for the medial gastrocnemius muscle of the right hindlimbs. After opening the popliteal fossa, the sciatic nerve was carefully exposed and the common peroneal nerve was cut to eliminate the influence of the ankle dorsiflexion muscles. To protect the muscles from arefaction, the muscles were covered with a mineral oil. A drive electrode, made from silver chloride, with a 5-mm distance between the poles, was placed at the sciatic nerve in the middle thigh level. The distal tendon of the medial gastrocnemius muscle was attached to an isometric force transducer. The femur was secured to a rigid fixator to ensure no limb movement during testing. Throughout the experiment, the muscle was kept at the natural length using the resistance of 1N (Fig. 1). The medial gastrocnemius muscle was stimulated for 4 seconds with negative square waveforms, with a pulse width of 0.2ms and an amplitude of –4V. The stimulation cycle was set at 4 sec. on / 15 sec. off. CFT with 20Hz was initially delivered in 5cycles, until the muscle was potentiated. After potentiation, CFT with 20Hz, and CIT that begins with one 10-ms interpulse interval (doublet) followed by CFT, were delivered alternately (Fig. 2). Maximal contraction force was measured by the force transducer.

% of initial peak force was used to assess muscle fatigue. % of initial peak force was calculated by the formula: % of initial peak force (%) = Tt / Ti Where Ti = peak torque in the period of initial 4 seconds of stimulation and Tt = peak torque in the period of 4 seconds of stimulation at t cycles from initial stimulation. The data are reported as mean values ± standard deviation (SD). All data were analyzed statistically using a repeated measures analysis of variance (ANOVA). Criterion for significance was a p value < .01.

3. Results

During non-fatigued state, maximum contraction force of CFT and that of CIT were almost equal. Over time (as a fatigued state developed), maximum contraction force under CIT came to be greater than maximum contraction force under CFT. There were statistically significant differences in muscle fatigue between CIT and CFT (repeated measure ANOVA; p < .0001), and muscle fatigue was greater under CFT. Final force (% of initial force) was 28.31 ± 7.29% (Mean ± SD) with CFT and 42.82 ± 6.51% with CIT (Fig. 3).

![Fig 1: Schematic representation of the experimental procedure](Image)

![Fig 2: Schematic representation of fatigue test. The CFT with 20Hz and CIT were delivered alternately.](Image)

![Fig 3: Time course of % of initial peak force at during fatigue test.](Image)
4. Discussion/Conclusions

From a physiological viewpoint, muscle fatigue has been sub grouped into two types, low frequency fatigue (LFF) and high frequency fatigue (HFF). LFF was characterized by a slow rate of recovery for force-generating ability. On the contrary, HFF was characterized by a subsequent rapid recovery from loss of force-generation ability. So under intermittent stimulation cycles with high frequency, the rest time (off time) has an important role in the recovery from muscle fatigue. Based on these features, Mistuning et al compared muscle fatigue resulting from high frequency stimulation with that resulting from low frequency stimulation during intermittent stimulation. In his study, muscle fatigue was greater at low frequency stimulation than at high frequency stimulation, and the contraction force with high frequency was applicable for prevention of knee buckling under fatigued state. So he suggested that intermittent and high frequency electrical stimulation had advantage for clinical usage in restoration of standing using hybrid FES.

To restore standing-up motion using FES, long-duration stimulation trains were necessary. Nagoya et al analyzed the EMG data from lower extremities and back muscles in twelve healthy subjects and made a program for the restoration of standing-up using FES [6]. During standing-up motion, the duration of activity in the quadriceps muscle was measured. The activity of the quadriceps muscle was found to last throughout most of the stand-up time. The mean stand-up time with hands-assists was 2.6 ± 0.5sec. Based on these results, we selected long-duration stimulation trains for this study.

In our study, muscle fatigue was greater under constant-frequency stimulation than under catch-like inducing stimulation during intermittent electrical stimulation. CIT could get a strong contraction force in the fatigued state. These results suggested that intermittent stimulation using catch-like property might be applicable in the development of clinical usage for functional electrical stimulation.

Future work will find optimal stimulation methods by attempting to set different cycles and by changing the number and frequency of initial bursts.

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References