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TRANSFORMATION OF SKELETAL MUSCLE INTO A FATIGUE RESISTANT MUSCLE THROUGH ELECTRICAL STIMULATION

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ABSTRACT -- To investigate skeletal muscle capacity for performing cardiac type work gross contractile properties of electrically conditioned and normal muscle (Lastissimus dorsi/seven dogs) were compared. Optimum pacing parameters were found to be the same for both type of muscle (50 Hz, 150 ms, supramaximal stimulus amplitude). The force of contraction measured during an isometric tension state was decreased for conditioned muscle as compared to normal muscle (2.8 ± 0.3 vs 3.8 ± 0.4 Kgf/100 g in control).

INTRODUCTION

Cardiac transplantation and mechanically driving circulatory assist devices are usually meant as the only possible treatment of end-stage cardiac disease. While the former is dependent on donor supply the latter requires the patient to be tethered to external powering devices.

The use of a muscle graft wrapped around the heart as a powering organ has been studied as a simpler alternative approach to both above mentioned therapy. Utilization of an autologous tissue for performing cardiac type work is limited by muscle fatigue. Investigation of this possibility was pioneered by Kantrowitz (1958). His work was based on the fact that skeletal muscle could be conditioned through electrical stimulation and have its fatigue-sensitive (type II) fibers transformed into fatigue-resistant (type I) fibers. This approach has been further studied by other investigators (Dewar, 1984; Neilson, 1985 and Acker, 1986). In this work a preliminary study of the characteristic properties of skeletal muscle was carried out.

MATERIALS AND METHODS

In this study the electrical stimulation parameters for conditioning the lastissimus dorsi of dogs and muscle fatigability were investigated.

This study consisted of a) determining stimulus magnitude, pulse width, and pulse train repetition rate that caused least

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fatigue of the normal muscle during acute experiments and b) comparison of these values with those obtained for conditioned muscle.

Muscle fatigability was determined as the decline in isometric peak force produced by tetanic contraction. Contraction was elicited by stimulation of the muscle at the proximity of the motor nerve. Stimulation pattern was selected as to match the summation frequency of the muscle.

THE ELECTRICAL STIMULATOR

An electrical stimulator was designed for short term stimulation during fatigue experiments while a comercial unity was implanted for conditioning purpose. In this particular application, the muscle must actuate as an extension of the heart providing a steady effort within a given period. Unlike cardiac muscle whose contraction is triggered by a single pulse which spreads through the syncitium type muscle, the contraction of skeletal muscle is modulated acoording to the electrical pattern of stimulation.

Contraction of skeletal muscle is the mechanical counterpart of the electrical depolarization of motor units. Smoothness and strength of contraction are determined by the rate at which these motor units are being activated and the numbers of motor units that are being activated at a time (Vrbova, 1985). A myocardium like contraction may be achieved by summation of sucessive contractions of skeletal muscle.

Optimal pacing was defined as the rate of stimulation at which a higher and smooth twicth was obtained and the muscle was allowed to rest. It was defined in terms of interpulse period and pulse train frequency for supramaximal current stimulation.

The myostimulator built allowed great variability of electrical parameters. Its operation is adjusted either for synchronous or asynchronous mode and its operation resembles that of a pacemaker as far its timing synchronism is concerned.

When it is operated in synchronous mode a refractory period (300 - 1000 ms) is generated after R wave detection to prevent any other stimulus generated, during cardiac systole to initiate muscle contraction. Duration of this period determines the ratio of muscle pacing to cardiac systole. Simultaneously to the refractory period a delay pulse (0 - 300 ms) is generated. Refractory period falling edge triggers an oscilator whose output yields a burst of pulses for muscle stimulation (burst duration: 50 - 500 ms; pulse width: 0.1 - 1.0 ms and pulse amplitude: -1 to -10 volts).

Thus a phase synchronism between cardiac cycle and muscle contraction can be attained. For operation in asynchronous mode the frequency of stimulation is not heart rate dependent.

THE EXPERIMENTAL PROTOCOL

Six adult mongrel dogs (12 - 18 Kg) underwent implantation of an Itrel programmable pacemaker (Medtronics, Inc., Neuro Division, MN) to continuously stimulate (intramuscular electrodes) the left lastissimuss dorsi muscle for six weeks (50 Hz, 125 msec., 60 bpm increased to 120 bpm 3 weeks later) while its contralateral was left intact.

After this period the muscle was assumed to be conditioned and a fatigue experiment was performed. The implanted stimulator was removed and the external stimulator was utilized. Fatigue was quantified as the decrease in peak force produced by continuous electrical stimulation. Conditioned muscle was compared to the contralateral control under a particular set of electrical stimulation.

FORCE MEASUREMENT

A device was specially designed for measuring with great accuracy the force produced by the muscle under isometric contraction. The device built is shown in figure 1. It consists of a) two force transducers assembled with strain gauge sensors bonded to a U-shaped piece b) an alignment frame mechanicaly coupled to allow free movement and a bar for attaching the muscle c) two struts for fixing the device to the surgical bed.

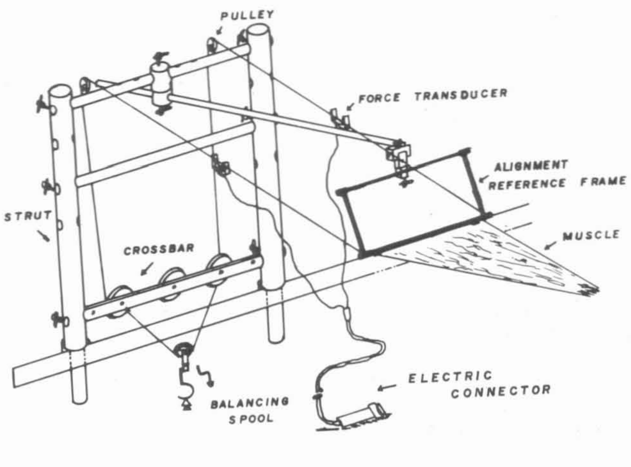

Figure 1. Force Measurement Device

The dissected free extremity of muscle is attached to the same bar of the frame where the sensors are so that they behave in series. The sensors are interconected with a cable that holds a balancing spool to which known masses are attached for calibration purpose and muscle pre-loading. During the time of measurement the cable is held fixed using a crossbar so that the stress transmitted to the signal conditioner is proportional to the sum of the force actuating on each sensor.

Force measurements were performed with muscles pre-stretched to exert a passive force of 0.5 kgF which was found to be the optimum length for peak twitch force.

RESULTS

Figure 2 depicts typical waveshape of simultaneous recordings of the electromyogram (A) and the contraction force (B), generated by electrical stimulation (C) of normal muscle. As it is seen on it, the force of contraction is proportional to stimulus repetition rate.

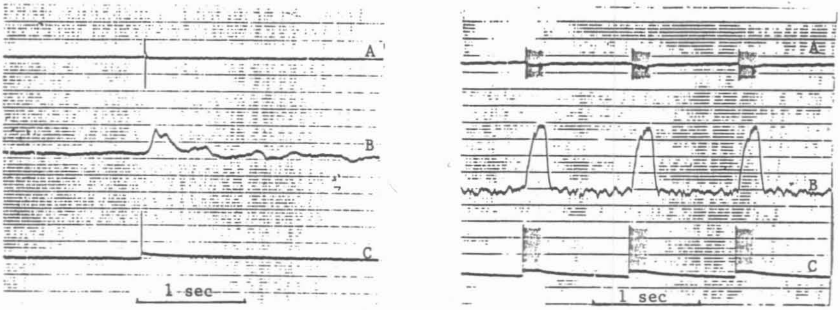

Figure 2. Simultaneous recordings of EMG, force of contraction and stimulus for normal muscle.

Tetanic contraction was reached at 50 Hz burst frequency (150 ms burst duration) for normal muscle and for conditioned muscle this frequency was found to be lower.

The force of contraction was measured for normal and conditioned muscle during continuous stimulation according to the electrical parameters defined earlier. Figure 3 depicts the percentual decrease in force, plotted against time of continuous stimulation for normal (dashed marks) and conditioned muscle (50 Hz, 125 msec., 75 cpm).

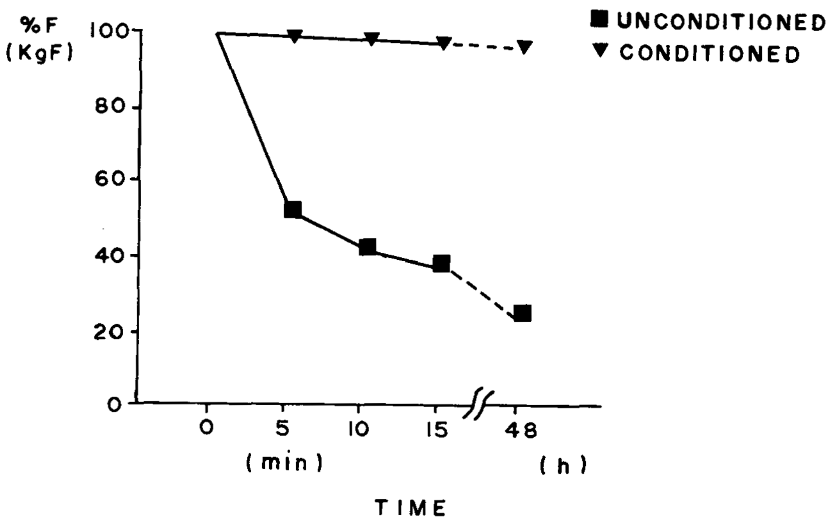

Figure 3. Force decrease as function of time (duty cycle: 75 cpm) measured under isometric contraction for normal (dashed marks) and conditioned muscle (n = 6).

For 50 Hz burst and 150 ms train duration the force measured was 3.8± 0.4 Kgf/100g and 2.8 ± 0.3 Kgf/100g for normal and conditioned muscle respectively. A marked decrease in force was observed during the first 30 min. After this period more stable force magnitude were found for both normal and conditioned muscle.

CONCLUSION

For both conditioned and unconditioned muscle the greatest reduction in force ocurred during the first 30 minutes of continuous stimulation. The force of contraction measured at its plateau was reduced for conditioned muscle (approximatelly 30%) while its contraction time increased. This is in agreement with the fact that when fast muscles are made to perform a more tonic type of task, their contraction become slower (Vrbova, 1985).

As already expected the contractile properties of the muscle changed after conditioning. This may be an evidence that the activity imposed by the motoneurons determines physiological and biochemical properties of the muscle.

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