Enhancement of Tibialis Anterior Recovery by Intermittent Sequential Pneumatic Compression of the Legs

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Abstract

In this study we examined the effect of Intermittent Sequential Pneumatic Compression (ISPC) of the legs on the recovery of fatigued Tibialis Anterior (TA) muscles. Eight subjects performed 10 min fast walking on a treadmill, followed by 2 min sustained effort of the TA (load *A*). Immediately afterwards they took 3 min of resting time, during which one leg was treated by ISPC (active recovery) and the opposite one served as a control (passive recovery). A second sustained effort (load *B*), similar to load *A* in intensity and duration, followed the recovery period. Surface EMG of the TA was used to monitor muscle fatigue. The results indicate that the mean power frequency (MPF) of the actively recovering TA was significantly higher than that of the passively recovering TA, irrespective of the side on which ISPC was applied. An additional interesting result was the higher MPF in the beginning of load *B* compared to that of the end of load *A*. However, this difference was significant in the actively recovering leg, but not so in the passively recovering leg. It was concluded that ISPC treatment of fatigued muscle after a sustained effort improves its contractile capacity in comparison to passive recovery.

Key words: fatigue, intermittent sequential pneumatic compression, mean power frequency, recovery, water evacuation.

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Muscle fatigue is defined as failure to maintain the required or expected force [3]. At least two mechanisms are involved in muscle fatigue [10]. One is related to intracellular acidosis, acting directly on the myofibrils by suppressing their contractile force. The other is based on the interference with the excitation-contraction coupling process. Recovery from fatigue is sensitive to the muscular pH [13] and to the evacuation of water and metabolites in both the intracellular and the extracellular environments [14].

It is well accepted that active recovery is more effective than passive recovery [1, 2]. Active recovery facilitates the removal of metabolites by enhancing venous blood return [1]. It has been shown that applying intermittent sequential pneumatic compression (ISPC) on the lower limbs of volunteers immediately after they had experienced muscular fatigue through isotonic cycling yielded a 45% improvement in their muscular performance. It has therefore been suggested that the "milking effect" of the ISPC, yields a significant improvement of the venous return [15]. Other authors have shown that various devices of pneumatic compression of the legs increased maximal venous velocity (MVV) in the major veins through draining of the lower limbs [4, 8].

The efficacy of ISPC on the recovery of fatigued muscle by isometric exercise through systematic testing protocols and fatigue indicators has not as yet been studied. A well-established fatigue indicator at high levels of muscle activity is the mean power frequency (MPF) of the myo-electric signals, as recorded by EMG [12]. For instance, a sustained isometric contraction of 80% or higher of the maximal voluntary contraction (MVC) is associated with a decrease in MPF, reflecting the development of muscle fatigue.

In this study we quantified the effect of ISPC on Tibialis Anterior (TA) recovery after a fatiguing sustained effort bout by making use of EMG fatigue indicators. We postulated that enhancing MVV in the veins of the lower limbs by ISPC would result in a faster TA recovery. This study should provide a better insight into the role of accelerated evacuation of water and metabolites from the muscle tissue in the recovery of fatigued muscles.

Subjects

Eight male subjects of 25.2 ± 5.2 years of age, height 175.5 ± 6.0 cm, and body mass of 70.5 ± 8.8 kg volunteered to participate in this study. Although none of the subjects was an active competitive sportsman, all were in an excellent state of health and had no previous histories of any of the following: obesity, muscle weakness or injury, bone disease or injury, neurological diseases, drug consumption or therapy. Each subject provided informal consent according to the local ethical committee's guidelines of the Technion. In all the subjects the right hand and leg were the dominant limbs.

Methodology

The testing procedure was as follows. (a) Ten min of fast walking on a treadmill, each subject at his maximum walking speed; (b) Transition time of 1 min, during which the subject was prepared for the next test; (c) Two min of sustained effort, referred to as 'load *A*'; (d) Three min of recovery (active and passive); (e) Two min of a second sustained effort, referred to as 'load *B*'.

The above procedure was repeated after a period of one week, resulting together in two sets of measurements: first set and repeat set.

Fast walking

The walking test was intended to induce fatigue of the TA and was performed on a treadmill (Quinton Q55) to allow repetitive monitoring of the data. To assure uniformity of their testing conditions all subjects were provided with the same manufacturer and type of walking shoes. Prior to the walking test in the first set of measurements, the maximum speed of level walking for each subject was determined as follows. While walking, the speed of the treadmill was increased from an initial of 5.0 km/h every one minute by increments of 0.25 km/h, until the subjectively sensed maximum walking speed for each subject was reached [5]. The actual walking test was begun after 10 min rest and consisted of fast level walking on the treadmill for 10 min at the individually determined speed.

First sustained effort (load A)

Following the fast walking test the subjects were asked to sit in an upright trunk position on an elevated surface with the popliteal aspect of the knee leaning against the edge of the surface. A dead weight of 10 Kg was suspended on the dorsal aspect of each foot by means of straps. The location of the straps was adjusted to coincide with the distal third of the metatarsals. The sustained effort consisted of holding these weights for 2 min, while maintaining the knee and ankle angles at the respective levels of 100 deg and 90 deg approximately, resulting in a quasi-isometric effort. Neither backrest, nor armrest were provided and the subjects were instructed to keep their hands on their laps during this test.

Active and passive recovery

Immediately after the weights were removed, the subjects were asked to sit on a reclining chair with the lower limbs extending forward. The angle between the thighs and the trunk was set to 145 deg approximately. In this position the muscles of the legs were allowed to recover for a period of 3 min. In one leg recovery was assisted by ISPC, resulting in active recovery. In the other leg recovery was passive. Efforts were made to minimize the transition time required to change from one position to another and to adjust the device. In the first set of measurements the right leg was in active recovery and the left one was in passive recovery and in the repeat set of measurements the sides were interchanged.

The ISPC device used in this study was a Lympha Wave (model 301 ET, Mego Afek, Israel) and consisted of a sleeve worn on the treated leg. The part of the sleeve used included 7 annular overlapping cells covering the foot and shank. These cells were fed separately from a compressor and distributor which provided continuous cycles of ascending pressure waves reaching the level of 80 mm Hg. The sequential activation of the cells results in a "milking" effect of the treated limb [15]. There were two compression cycles per min and each cycle was divided into two phases: 21 s inflation followed by a deflation period of 9 s. Thus, for the 3 min active recovery six cycles of "milking" of the leg were completed.

Second sustained effort (load B)

Immediately after the recovery period each subject wore his shoes again and returned to the seated position to perform the second sustained effort (load *B*) in a similar way as described for the sustained effort (load *A*).

EMG Measurements

Electro-myography (EMG) of the Tibialis Anterior (TA) muscles of both legs was monitored during fast walking and the two sustained efforts. Two pairs of small bipolar disposable Ag/AgCl snap surface electrodes (10mm diameter, Promedico Ltd.) were used and the signals were routed to an eight-channel surface electrode system (Atlas Research Ltd., Raanana, Israel). The EMG data were collected at a sampling rate of 1667Hz per channel over time windows of 5 s in the beginning and in the end of the fast walking test and in the beginning and in the end of each of the sustained efforts.

For processing, the EMG signal was filtered by a bandpass Butterworth filter, with a band frequency of 10-500 Hz using the Hanning window. Fast Fourier transform (FFT) analysis was performed to calculate the mean power frequency (MPF) of the signals.

Statistical analysis

Differences were tested using within-subject repeated-measures analysis of variants (ANOVA), with a significance level of $p < 0.05$.

Results

Averages for all the subjects of the MPF of the TA EMG are summarized in Table 1.

Pre-load fast walking

The average speed of fast walking for all the subjects was 8.3 km/h (SD = 0.6, range 7.3-9.0 km/h). As a result of the fast walking test, the MPF of the TA EMG decreased significantly in both legs ($p < 0.05$) from the beginning to the end of the walking session.

First sustained effort (load A)

At the end of the 'load *A*' session the MPF was lower in comparison to its level at the beginning of the session. This difference was significant ($p < 0.05$) in both legs in the first set of the tests. However, in the repeat set of the tests it was significant in the right leg only.

Second sustained effort (load B)

At the end of the 'load *B*' session the MPF was lower in comparison to its level at the beginning of the session. The difference was significant ($p < 0.05$) in the two legs both in the first and the repeat sets of the tests.

Active versus passive recovery

The MPF of the actively recovering leg (as assisted by ISPC) was significantly higher than that of the passively recovering leg, in both the first and repeat sets of the tests, i.e. irrespective of the side on which ISPC was applied. An additional interesting result was the higher MPF in the beginning of 'load *B*' compared to that of the end of 'load *A*'. However, this difference was significant in the actively recovering leg, but not so in the passively recovering leg, in both the first and repeat sets of the tests, i.e. irrespective of the side on which ISPC was applied.

Discussion

This study was designed to induce substantial fatigue on the TA muscle in order to assess the role of rapid removal of water and metabolites in the process of active recovery of this muscle. Fast walking is known to induce fatigue of the TA [11]; therefore it was performed to enhance the fatiguing process of this muscle. Indeed, at the end of the fast walking session there was a significant decrease in MPF of the myo-electric signal. Thereafter, following the first sustained load, the TA underwent a much higher degree of fatigue, as reflected by the additional decrease in the MPF. This fatigue was experienced by all the tested subjects, who sensed considerable difficulties to complete the walking session. It can thus be assumed that in our experimental protocol the TA muscles reached substantial levels of muscular fatigue. Fatigue is characterized by the accumulation of water and catabolites in both the intra- and extra-cellular compartments of the muscular tissue [6]. Therefore, active recovery of the fatigued muscle yielded, by enhancing water removal out of the muscle tissue, better muscle performance than passive recovery. In a previous work, Zelikovsky et al [15] demonstrated a 45% increment in muscular performance during isotonic bicycling exercise, following ISPC of the fatigued muscles. In their research, however, muscular fatigue was not measured directly. Furthermore, their study did not specify the muscle groups that experienced fatigue. Ad-

Table 1. Summary of the average MPF (Hz) of the Tibialis Anterior after active and passive recovery for all the subjects (n = 8). The values given are means (SD).

		First set		Repeat set	
Test		Right leg	Left leg	Right leg	Left leg
Fast walking (10 min)	Initial	107.6 (11.4)	106.7 (17.2)	110.3 (10.0)	106.6 (8.5)
00	End	86.6 (9.5)*	86.7 (14.8)*	99.0 (6.8)*	90.9 (10.3)*
Transition Time (1 min)					
Load *A* (2 min)#	Initial	101.4 (12.4)	95.6 (11.5)	103.4 (6.5)	97.5 (14.0)
	End	74.9 (11.8)*	69.3 (11.9)*	88.5 (10.3)*	86.0 (14.2)
Recovery (3 min)		Active	Passive	Passive	Active
Load *B* (2 min)#	Initial	95.9 (12.5)***	79.3 (12.5)	95.4 (9.4)	102.9 (12.1)***
	End	77.5 (15.9)*	62.1 (11.2)*, **	81.0 (10.8)*	93.0 (10.5)*, **

sustained quasi-isometric effort
* Significant difference between beginning and end of pre-load ($p < 0.05$)
** Significant difference between the two legs ($p < 0.05$), within each set
*** Significant difference between end time of 'load *A*' and initial time of 'load *B*' ($p < 0.05$)

ditionally, there was no control group in their study.

The role of removal of water and metabolites in the recovery of fatigued muscle after isometric load has not as yet been studied. Isometric or quasi-isometric exercise, such as in prolonged constrained standing, is characterized by an interference with the venous pumping mechanism exerted by the static effort. Also the role of speed at which the water is drained out of the muscle in the recovery process has not been studied. We thus assumed that enhancing venous return after an isometric-static muscle contraction would provide us the opportunity to assess the role of elimination of water and fatigue related-metabolites out of the muscular tissue.

The results of the present study showed that the application of ISPC to the lower limbs yielded a significant enhancement of performance, presumably by increasing the MVV in the major veins of the legs. In the initial part of 'load *B*' the degree of muscular recovery of the ISPC treated leg was significantly more effective in comparison to the untreated leg. This finding was reconfirmed independently of the dominance of the treated lower limb. Moreover, at the end of 'load *B*' the TA of the ISPC treated leg achieved higher levels of muscular power than the opposite, passively recovering leg. This clearly indicates that the enhancement of venous return from the lower limbs yielded rapid recovery of the fatigued muscles.

Enhancement of venous return improves the perfusion of the tissue. According the laws of Starling, this is attributed to a decrement in the hydrostatic pressure at the post-capillary vein, yielding a higher difference in pressures between the pre-, and post-capillary vessels [7]. Improved oxygenation of the muscular cells might accelerate recovery in cases where the muscle cell shifts to anaerobic metabolism. Levy et al [9] described a progressive intracellular pH decrement and inorganic phosphate increment in muscle fatigue induced by functional electrical stimulation (FES). These biochemical changes represented depletion in the energy storing molecules, such as, creatine phosphate CrP and ATP. It is thus clear that muscular fatigue is a complex phenomenon, characterized by intracellular changes accompanied by a gradual deterioration of the muscle performance. Future studies would have to incorporate intracellular measures of fatigue and recovery to gain more specific information on the process taking place by the application of ISPC.

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