Response Of The Mobilized Latissimus Dorsi Muscle After Variations Of The Electrical Stimulation Regimen

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I. Introduction
Although introduced clinically 10 years ago, the usefulness of cardiomyoplasty continues to be debated today. Immediate and long-term results show promise in the management of patients with pre end stage congestive heart disease. However there is some discrepancy between the theoretical and actual benefits of this operation. There are two possible explanations of this situation. First, surgical mobilization of the latissimus dorsi muscle (LDM) results in the severing of part of its blood supply with resultant ischemia, which may remain for a long period of time. Electrical stimulation for 24 hours a day at a ratio of 1:2 (approximately 30-40 contractions per minute) may be too demanding for such a muscle. Secondly, the patient does not receive hemodynamic benefit after cardiomyoplasty for at least two months, because the LDM is not stimulated at all for the first two weeks (vascular delay period), and then when stimulation is begun (1, 2, or 3 impulses per burst), the muscle does not generate productive contractions but rather it only trembles.

II. Aims of Investigation
We investigated the physiological and morphological response of mobilized LDM to different regimen of electrical stimulation (ES) in order to determine which protocol allows for early stimulation and cardiac assistance.

III. Methods
All experiments were conducted on adult sheep. A 25 cm longitudinal skin incision was made in the left mid-axillary line to expose the LDM. All muscle attachments except the proximal pedicle and the distal attachment to the ribs and all vessels supplying the LDM except the thoraco-dorsalis artery were severed. The muscle was left in situ and two intramuscular electrodes (TeleMed, Inc., Englewood, CO) were inserted into the proximal and mid parts of the left LDM perpendicular to the neurovascular pedicle. The electrodes were connected to a Myostim 7220 pacing system (TeleMed, Inc., Englewood, CO) which was implanted in a subcutaneous pocket. Contractile force (CF) measurements of the LDM were performed in all animals. CF measurements were obtained at a preload of 20 g/kg and a pulse amplitude of 10 V. All measurements were acquired using a force transducer (Accu Force III, Ametec, FL) attached to the foreleg of the animal and were recorded on a Gould ES 1000 recording system (Gould Systems, Valley View, OH).

Before LDM mobilization, two hours after mobilization, 6 days and 16 days after mobilization, a fatigue test (10 V, 10 Hz, 20 g/kg preload, 6 pulses per burst) was performed for 30 minutes. Two regimen of stimulation, continuous (15, 30 or 60 contractions per minute) or work-rest (one minute work - one minute rest - one minute work... at 15, 30 or 60 contractions per minute) were applied.

After LDM mobilization one group of animals did not receive any electrical stimulation (the usual vascular delay period). The second group of animals received a special electrical stimulation regimen which began three hours after subtotal LDM mobilization using a single pulse with an amplitude of 5 V and a rate of 15 contractions per minute (CPM). The third group of animals, in addition to the above electrical stimulation protocol, received training which mimicked cardiac assistance (6 impulses per burst, 10 V, 30 Hz, 15 CPM, work - rest regimen) for 30 minutes each day.

IV. Results and Discussion
1. Non mobilized LDM.
A.) Continuous regimen of contraction. When the LDM was contracted in a continuous regimen for 30 minutes at a rate of 30 or 60 CPM, it lost 34 or 40% of its initial CF, respectively. However, if a slower rate was applied to the muscle (15 CPM), the
LDM lost only 7% of its initial CF. At this rate, the muscle was allowed to rest and restore its strength.

B.) Work - rest regimen of contraction. This regimen allowed the LDM to rest one minute after every minute of work. There was immediate improvement in the results of the fatigue test. At 15 CPM, the muscle fatigued minimally (3% loss of initial CF). Even at 60 CPM, CF after 30 minutes of the fatigue test decreased only 21%. However, the results from nonmobilized LDM cannot be extrapolated to muscle which was subtotally mobilized and transposed into the thoracic cavity, yet it leads to the conclusion that the work - rest regimen at 15 CPM may not lead to muscle fatigue after 30 minutes of work.

2. Two hours after LDM mobilization.

A.) Continuous regimen of contraction. After subtotal mobilization the LDM was in severe ischemic shock, and had a decreased fatigue resistance as compared to nonmobilized nonischemic LDM: -23% vs. -7% (15 CPM), -39% vs. -34% (30 CPM), -50% vs. 40% (60 BPM). Even at 15 CPM, this muscle could not be used for cardiac assistance if worked in a continuous regimen.

B.) Work -rest regimen. Performance of the LDM continued to be poor at 30 CPM (-25%) or 60 CPM (-34%). At these rates, a minute of rest after every minute of work was not enough for restoration of muscle strength when the muscle was in severe ischemic shock. This data was confirmed by light microscopy, which revealed the aggravation of edema, fiber deterioration, and margination of leukocytes (which can lead to endothelial damage). However, 15 CPM does not seem to be damaging to the newly mobilized LDM. During a 30 minute fatigue test, the LDM lost only 8% CF.

Since the continuous stimulation regimen (even at 15 CPM) proved to be damaging for the newly mobilized LDM and led to severe fatigue, all of the ensuing investigations utilized the new work - rest regimen at 15 CPM (60 CPM was used as a control).

3. Mobilized LDM with no electrical stimulation - 16 days (control).

After 30 minutes of fatigue testing in the work - rest regimen, the LDM lost 12% of initial CF (vs. 35% at 60 CPM continuous contractions) on day 6, and 14% of initial CF (vs. 37% at 60 CPM continuous contractions) on day 16. This data proved to be a little worse than immediately after muscle mobilization (-8%), however it showed that the unconditioned LDM could perform strong contractions in a work - rest regimen, if needed, for at least 30 minutes without a considerable loss in contractile force.

4. Mobilized LDM with electrical stimulation - 16 days.

A moderate electrical stimulation regimen did not aggravate the muscle damage after mobilization. Moreover, it may have activated the angiogenic process in the ischemic muscle resulting in the muscle's increased fatigue resistance. During the fatigue test using the work - rest regimen, the electrically stimulated LDM (15 CPM) lost only 5% of initial CF on Day 6, and 6% on Day 16. Light microscopy did not reveal any further damage to the mobilized muscle. Moderate electrical stimulation begun immediately after LDM mobilization helped keep the muscle in condition to produce strong contractions for a short period of cardiac assist.

5. Mobilized LDM with electrical stimulation and daily training - 16 days.

Immediately after LDM mobilization the animals in this group received two different stimulation protocols: 1) moderate electrical stimulation (15 CPM), and 2) 30 minutes of training daily which mimicked cardiac assistance (similar to the cardiac assistance that is normally performed two months after cardiomyoplasty). The LDM did not fatigue during 30 minutes of fatigue testing – the CF on average remained at 100% (as compared to initial CF) when tested on days 6 and 16. In two animals we continued the fatigue test an additional 30 minutes. After 60 minutes, the contractile force had dropped to 95 and 97% respectively.

V. Conclusions

1. If moderate electrical stimulation is used no tissue damage will be incurred if stimulation is begun immediately after LDM mobilization.

2. No fatigue is apparent after one hour of work per day when using a work - rest regimen and 15 contractions per minute.

3. It may be possible to begin partial cardiac assistance immediately after cardiomyoplasty, which would significantly improve early and long-term cardiomyoplasty results.