EFFECT OF ELECTRO-MOTOR STIMULATION ON THE POWER PRODUCTION OF A MAXIMALLY STRETCHED MUSCLE

Katsuhiko Tachino,1 Toshio Susaki2 and Toshiaki Yamazaki2

From the 1Division of Physical Therapy, School of Health Sciences, the University of Kansai, Kansai, Japan, the 2Department of Physical Therapy, the University of Kansai Hospital, Kansai, Japan

ABSTRACT. The effect of electro-motor stimulation (EMS) upon the increase in power production of the tibialis anterior muscle (TA) of healthy individuals in both the maximally stretched (ST) and shortened (SH) group positions was investigated. The effect of cross-education upon the contralateral muscle was also examined. EMS with a frequency of 50 hertz, a duration of 0.2 milliseconds, and a rectangular wave was applied for ten seconds with a ten-second interval and repeated ten times per day for six weeks. The ST group gained significantly 9.4%, 15.5%, and 16.4% after two, four, and six weeks of stimulation, respectively, while the SH group also showed a significant gain of 5.1%, 8.3%, and 3.0%. When comparing the two groups at the end of the six-week period the ST group’s gain was significantly greater. The increase in power production of the unstimulated TA was 5.5%, 8.8%, and 4.3% in the ST group, which was significant at the end of the second and fourth week of stimulation. The SH group, however, registered no significant increase of −2.3%, 1.8%, and −1.5%. Comparison between the two groups showed a significant increase in the power production of the unstimulated TA in the ST group commencing the second week. Conclusion EMS of the TA in the maximally stretched position is a more effective way to gain strength.

Key words: electro-motor stimulation, stretched position of a muscle, shortened position of a muscle, cross-education.

Studies have been carried out in the past by many researchers to find effective methods for muscle strengthening (1, 2). However, the fact should be recognized that the various types of muscle contraction differ considerably in producing different results. Among the various strengthening techniques, electro-motor stimulation (EMS) is in the one that is done passively. Even this modality brings about different results according to the wave form used, conditions of application, duration of stimuli, type of muscle, sex and age of the subject, and method of assessment. It is, therefore, difficult to present to compare results obtained by various researchers (3, 4, 5).

It is known that a muscle can atrophy significantly if it is immobilized in a shortened position, but that it may atrophy less, or become hypertrophied, if it is immobilized in a stretched position (6, 7). The author has devised a method by which the state of the muscle to be stimulated is changed rather than the properties of EMS. Accordingly, an experiment was carried out on the tibialis anterior muscle (TA) in a maximally stretched position.

SUBJECTS AND METHODS

The subjects consisted of 20 healthy female college students who were not engaged in any specific sport before or during the study and they were divided equally into two groups. The subject was kept in a sitting position and the left ankle joint was immobilised by a specially constructed ankle-stretching machine in a fully plantar-flexed position in one group (ST), and in a fully dorsiflexed position in the other group (SH), so that the left TA was maximally stretched in the former group and maximally shortened in the latter. The TA was electrically stimulated with a frequency of 50 hertz, for a duration of 0.2 milliseconds, and a rectangular wave was produced by an isolator CF36 type made by Sure-1 Measurement Equipment Co., Japan and SS102J type made by Nihon Kohden Industry Co., Japan. Electrical leads were connected to a 28-mm dish electrode made of silver. The active electrode was placed on the motor point of the TA and the inactive one on the lower part of the thigh. Electrical stimuli were applied to the maximum intensity tolerated by the subject. One session consisted of ten seconds each for the stimulation and the interval, and this was repeated ten times per day. The procedure was carried out at least four sessions per week for six weeks, and more than two days of consecutive non-treatment were avoided.

The strength of the TA was tested before the experiment and at two-week intervals during the experiment, using a CYBEX II isokinetic dynamometer (Lumex, Inc.) which was set at one revolution per minute. A computation was done for the torque, work capacity, and the coefficient of fatigue of the muscle. The baseline for the measurement was set at a pre-experimental value of 100%.
RESULTS

There was no statistically significant difference in the subjects' age, height, weight, and strength of the TA between the two groups (Table I). The torque of the TA in the ST group increased to 109.4±12.1%, 115.5±16.1%, and 116.4±16.2% after two, four, and six weeks of stimulation, respectively. The SH group showed a similar increase of 105.1±7.8%, 108.3±7.8%, and 103.6±6.5%. Both increases were statistically significant. In comparing the two groups the ST group's increase was significant at the beginning of the six-week period (Fig. 1). The work capacity of the TA in the ST group significantly increased to 114.2±16.2%, 118.2±23.0%, and 116.2±23.0% after two, four, and six weeks, respectively. The SH group showed an increase of 101.6±10.6%, 112.3±12.5%, and 108.0±12.4%, of which the values after four and six weeks were significant. In comparing the two groups the ST group's increase in work capacity was significant after two weeks (Fig. 2). The coefficient of fatigue of the TA showed no statistical significance when comparing the rate of increase in the torque for each group and for each period in both groups (Fig. 3).

The torque of the unstimulated TA in the ST group increased to 105.5±6.4%, 108.0±7.7%, and 104.3±7.5% after two, four, and six weeks, respectively, of which the values at the end of the two- and four-week periods were significant. The SH group, however, showed a non-significant increase of 97.3±9.7%, 101.8±9.6%, and 98.5±11.1%. The comparison between the two groups showed that the torque value at the end of the two-week period was significant (Fig. 4).

Intensity of the EMS varied from subject to subject according to the individual's threshold of pain and diurnal change in pain tolerance. There was, however, no significant difference in the amount of intensity tolerated by the two groups.

DISCUSSION

Although the types of muscles and/or conditions for EMS vary, many researchers have reported methods of muscle strengthening by means of EMS to be effective: a minimum increase of 6% obtained by Singer (8) and a maximum increase of 44% obtained by Sellnowitz (9) as summarized by Lloyd (10). These reports, however, do not mention the state of the muscle. Studies on the state of muscles include the experiments by Summers et al. on the cat's soleus muscle in a stretched position (11), and by Fargenson on the rabbit's TA immobilized with tension (12), as well as Thomsen's similar animal experiment (13), all of which were effective in producing hypertrophy of the muscle. Furthermore, our experiment resulted in an increase of 32% of the wet weight of a rat's soleus muscle which was maintained in a stretched position (7). The author therefore assumed that it might be possible to stimulate electrically a muscle in the stretched position so as to increase the power production effectively, and at the same time to ascertain the effect upon cross-education.

According to the animal experiment by Williams et al., electrical stimulation combined with stretch for a period as short as four days on fast contracting muscle showed that reprogramming of the synthesis of fiber type-specific contractile proteins could be achieved (14).

Application of the EMS to the TA increased the force production in both the ST and SH groups, the result being the same as that reported by the other researchers (8), though the ST group's increase was significantly larger at the end of the six-week period. This fact suggests that trophic activity is at work from the muscle to the nerve. The increase in power production in the stretched position is, therefore, thought to have been brought about by the addition of contractile activity produced by EMS on the metabolic activity mentioned above (15).

The fact that the ST group had a significant gain in power production in their unstimulated TA after two- and four-week periods suggests the presence of a cross-educational effect. Moritani considered cross-education was to be neurological (16). Stromberg investigated the effect upon the contralateral side in exercise therapy for the upper limb and reported especially the fact that the grip strength increased to 150% after one month compared with the control group (17). He thus stated that this phenomenon could be explained by contralateral motoneurone excitability, involvement of synergic movement, or the psychological effect of training. Hellebrandt et al. have argued that the effect of cross-education is brought about not by the training period but by the training intensity, and that the cross-education has a dual genesis in the diffusion of motor impulses.
RESULTS

There was no statistically significant difference in the subjects’ age, height, weight, and strength of the TA between the two groups (Table I). The torque of the TA in the ST group increased to 109.4±12.1%, 115.3±16.1%, and 116.4±16.2% after two, four, and six weeks of stimulation, respectively. The SH group showed a similar increase of 105.1±7.8%, 108.3±7.8%, and 103.0±6.5%. Both increases were statistically significant. In comparing the two groups the ST group’s increase was significant at the beginning of the six-week period (Fig. 1). The work capacity of the TA in the ST group significantly increased to 114.2±16.2%, 118.2±33.0%, and 116.2±23.0% after two, four, and six weeks, respectively. The SH group showed an increase of 101.6±10.6%, 112.2±12.5%, and 108.0±12.4%, of which the values after four and six weeks were significant. In comparing the two groups the ST group’s increase in work capacity was significant after two weeks (Fig. 2). The coefficient of fatigue of the TA showed no statistical significance when comparing the rate of increase in the torque for each group and for each week period in both groups (Fig. 3).

The torque of the unstimulated TA in the ST group increased to 105.5±6.4%, 108.0±7.7%, and 104.3±7.5% after two, four, and six weeks, respectively, of which the values at the end of the two- and four-week periods were significant. The SH group, however, showed a non-significant increase of 97.3±9.7%, 101.8±9.6%, and 98.5±11.1%. The comparison between the two groups showed that the torque value at the end of the two-week period was significant (Fig. 4).

Intensity of the EMS varied from subject to subject according to the individual’s threshold of pain and dural change in pain tolerance. There was, however, no significant difference in the amount of intensity tolerated by the two groups.

DISCUSSION

Although the types of muscles and/or conditions for EMS vary, many researchers have reported methods of muscle strengthening by means of EMS to be effective: a minimal increase of 6% obtained by Singer (8) and a maximum increase of 44% obtained by Selloowitz (9) as summarized by Lloyd (10). These reports, however, do not mention the state of the muscle. Studies on the state of muscles include the experiments by Summers et al. on the cat’s soleus muscle in a stretched position (11), and by Ferguson on the rabbit’s TA immobilized with tension (12), as well as Thomson’s similar animal experiment (13), all of which were effective in producing hypertrophy of the muscle. Furthermore, our experiment resulted in an increase of 32% of the wet weight of a rat’s soleus muscle which was maintained in a stretched position (7). The author therefore assumed that it might be possible to stimulate electrically a muscle in the stretched position so as to increase the power production effectively, and at the same time to ascertain the effect upon cross-education.

According to the animal experiment by Williams et al., electrical stimulation combined with stretch for a period as short as four days on fast contracting muscle showed that reprogramming of the synthesis of fiber-type-specific contractile proteins could be achieved (14).

Application of the EMS to the TA increased the force production in both the ST and SH groups, the result being the same as that reported by the other researchers (8), though the ST group’s increase was significantly larger at the end of the six-week period. This fact suggests that trophic activity is at work from the muscle to the nerve. The increase in power production in the stretched position is, therefore, thought to have been brought about by the addition of contractile activity produced by EMS on the metabolic activity mentioned above (15).

The fact that the ST group had a significant gain in power production in their unstimulated TA after two- and four-week periods suggests the presence of a cross-educational effect. Moritani considered cross-education to be neurological (16). Stromberg investigated the effect upon the contralateral side in exercise therapy for the upper limb and reported especially the fact that the grip strength increased to 150% after one month compared with the control group (17). He thus stated that this phenomenon could be explained by contralateral motoneurone excitability, involvement of synergic movement, or the psychological effect of training. Hellebrandt et al. have argued that the effect of cross-education is brought about not by the training period but by the training intensity, and that the cross-education has a dual genesis in the diffusion of motor impulses.
REFERENCES


Address for enquiries:
Katsushika Tachino, MD, PhD
Division of Physical Therapy
School of Health Sciences
The University of Kamazawa
1-80, Kodakumato 5
Kamazawa 921
Japan

ABSTRACT: A general population of 928 men and women aged 30, 45, 50, and 60 years participated in a health survey with emphasis on low back trouble (LBT). All 135 variables were analyzed to identify possible indicators for first-time experience and recurrence or persistence of LBT during a one-year follow-up. Stepwise logistic regression analyses were carried out to identify the most informative combination of indicators for prediction of LBT. For men, a high risk for recurrence or persistence of LBT was associated with frequent LBT in the past, worsening of the LBT since onset, sciatica and living alone. For women corresponding risk indicators were: recency of the last LBT episode, waking up during night because of LBT, aggravation of LBT often lasting, rumbling of "the stomach" and smoking. The strongest risk indicators for first-time experience of LBT were egocentric pain, daily smoking and low isometric endurance of the back muscles. In addition, hospitalizations for whatever cause and a long distance from home to work showed predictive power for first-time LBT among gainfully employed participants. The results indicate that persons either recovering or first-time LBT had more health problems and probably lived under a higher psycho-social pressure than those without LBT in the follow-up year.

Key words: low-back trouble, epidemiology, prospective study, risk indicators, general population, first-time occurrence, recurrence.

Low back pain, or rather low back trouble (LBT) affects 70-80% of all people in the industrialized world at some time during their lives (24, 27). In addition to the subjective discomfort, LBT results in considerable expense, for instance to medical services (30, 41) and in sickness benefits (1, 11, 32).

Despite the appreciable size of this problem, only little is known about risk indicators for LBT and this emphasizes the importance of epidemiological studies, in particular those which employ a longitudinal design. The aim of the present study has thus been through a prospective design to identify risk indicators for recurrence or persistence and for first-time experience of LBT among questionnaire items on medical (including low back), social and occupational history and among physical measurements relating to the lower back. Multivariate analyses are used to trace the jointly significant indicators among the many individually informative ones.

POPULATION AND METHODS

Of all 30-, 40-, 50- and 60-year-old inhabitants in the Municipality of Glæsterg (a suburb of Copenhagen, Denmark) invited to a free general health survey, 82% (449 men and 479 women) participated (3, 8).

The following information was gained from questionnaires: 51 items concerning LBT (4, 5, 6, 8); 25 variables relating to the history of health, symptoms and diseases, notably cardiovascular, pulmonary, gastrointestinal and urological problems together with general health and contacts with health services; 6 variables on tea, coffee, alcohol and smoking habits; 24 on occupational conditions; and also 13 social and leisure variables (10). One of the authors carried out a physical examination relating to the lower back, comprising anthropometric measurements, flexibility/elasticity measurements of the back and hamstrings, as well as tests for trunk muscle strength and endurance (7).

Twelve months after the examination, 99% of the population examined (442 men and 478 women) completed a follow-up postal questionnaire focused specifically on LBT in the intervening period (3, 8).

Definition of LBT

In all questionnaires, LBT questions were phrased as follows: "Have you ever/within the last 12 months had pain or other trouble with the lower part of your back?" The reproducibility of the history of LBT thus obtained has been found to be satisfactory (9).

Diagnostic value

The predictive value for recurrence or persistence (jointed termed recurrence) or first-time experience of LBT in the follow-up year of the above-mentioned parameters was evaluated. This was done by comparing the answers for those with LBT previously and during the follow-up year with those without LBT previously but during follow-up (Table 1). A corresponding set of comparisons was made between those who had their first experience of LBT in the follow-up year with those who had had LBT either previously or not during the follow-up year (Table I).