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Relationships Between Myoelectric Activity, Strength, and MRI of Lumbar Extensor Muscles in Back Pain Patients and Normal Subjects

Vert Mooney, Jennifer Gulick, Mark Perlman, David Levy, Robert Pozos, Scott Leggett, and Donald Resnick

University of California San Diego, La Jolla, California, U.S.A.

Summary: Eight normal individuals and eight patients with chronic back pain were evaluated. They undertook a treatment program lasting 8 weeks, with two exercise sessions each week. Myoelectric activity, lumbar extensor strength, and cross-sectional magnetic resonance imaging appearance of the lumbar paraspinal extensor muscles was assessed at the beginning and end of the program. Initial baseline and final extensor strength measurements were done isometrically at seven points through full range. Surface myoelectric activity was monitored during both flexion and extension exercise. Subsequently, electromyographic (EMG) signals were analyzed for mean frequency (MPF) and amplitude (RMS). An average functional improvement of 65% and reduction of pain complaint of 41% occurred in the eight patients with chronic low back pain. Extensor strength improved an average of 48% contrasted to 6% for the normal subjects. Four patients who showed severe fatty infiltration in the extensors had a decrease in the degree of infiltration and no change in muscle mass. Changes in fatty infiltration did not correlate with strength changes. The dynamic EMG changes documented a decrease in amplitude (RMS) and a smaller decrease in frequency (MPF) for the same resistance when used at the beginning and end of the program. Structural changes in the muscles are not always needed to achieve strength gains or symptomatic improvement. **Key Words:** Muscle—Low back pain—EMG—Muscle cross-sectional area.

This study explores factors related to extensor muscle status of the lumbar spine as determined by static testing, dynamic electromyograms (EMGs), and fatty infiltration appearance on magnetic resonance (MR) imaging, both before and after a specific strengthening program.

BACKGROUND

This study explores the relationships between the lumbar extensor muscles, electrical activity during dynamic exercise, and the relationship between apparent atrophy and electrical activity. This is a study of both normal subjects and patients with chronic back pain.

Study of the lumbar extensors was chosen because recent evidence indicates that when tested, the lumbar extensors are weaker than the flexors in individuals with chronic back pain (10,14,24). At one time it was thought that the flexor muscles were the more important muscles for strengthening in lifting activity. When tested, however, they are not really major factors in the lifting and lowering activity of the lumbar spine (17,22). When tested at various levels of resistance, the EMG amplitude of the abdominal muscles did not increase, whereas the extensor paraspinal EMG amplitude did increase parallel to the increasing resistance (22). Therefore, for the purpose of

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Address correspondence and reprint requests to Dr. V. Mooney, University of California San Diego, 4150 Regents Park Row, Suite 300, La Jolla, CA 92037, U.S.A.

this study, only the lumbar extensor muscles were monitored for the myoelectric activity.

It is appropriate to monitor the most active muscles in an effort to note the most significant change as related to strength. The relative activity of various lumbar extensor muscles has been demonstrated with a recent MR study (5). In this study, proton relaxation time was monitored directly after exercise in individuals with chronic back pain at various times after extensor exercise. The greatest signal intensities occurred in the multifidus musculature. The next most involved muscles by this technique were long erector spinae longissimus-iliocostalis, again corroborating the minimal role of the flexor muscles (they do not show any significant activity in this MR study). Based on these findings, it was decided to monitor the multifidus muscles at two levels.

In an effort to quantitate strength and exercise activity, it is necessary that a specific piece of equipment be available that could function not only as a measurement tool, but an exercise device (18). It is of course important that the dose of therapeutic exercise be standardized to allow comparison. Thus, the patients and subjects had their extensor strength and their exercise carried out on MedX equipment. This equipment does have the capacity to make appropriate isolation (Figs. 1 and 2). This is the customary equipment used in the treatment of chronic back pain patients at our center.

MATERIALS AND METHODS

Eight patients with chronic low back pain were evaluated by three tests: MR imaging, isometric strength, and EMGs. There were four men and four women (male age range, 48–63 years; female range, 45–64 years). All patients had radiographic evidence of degenerative disc disease and an average current pain duration of 4 months with a history of 2.5 recurrences. For comparison, eight normal subjects were similarly tested. To assure less variation and disc degeneration, these normal subjects were all male, with an average age of 35 years. The patients and normal subjects were placed into an exercise program. After initial isometric testing for baseline strength, each was placed into the MedX standard protocol for lumbar extensor strength (20). Initial resistance was set at 50% of maximum isometric torque. Once 20 repetitions could be achieved through full range with that weight, the resistance was increased 5%. The exercise program consisted of a workout session twice a week on the same MedX or back machine they were tested on for 8 weeks; thus, there were 16 specific strengthening sessions to the lumbar extensors. The training included both concentric and eccentric isolated lumbar extensor isotonic exercise. At the conclusion of the treatment program, isometric strength values were measured and compared with initial values. All patients filled out SF36 function questionnaires and quantified pain drawings at the beginning and end of treatment.

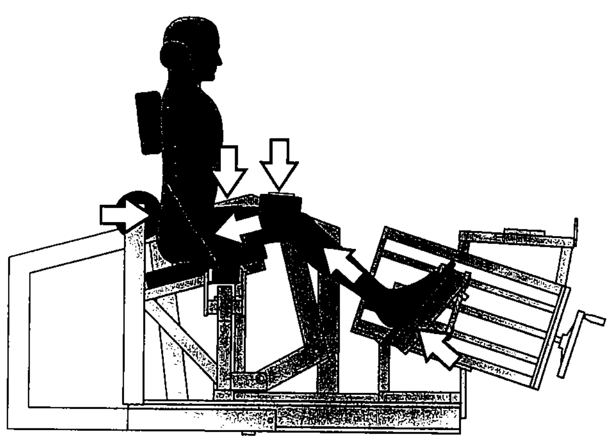

FIG. 1. The isolation technique used in MedX equipment. The pelvis is stabilized specifically for each individual. Lumbar extensors are isolated in their exercise isotonically, both in concentric and eccentric exercise. The torso is counterbalanced so that all movement against resistance is on the basis of muscle activity without the assistance of gravity.

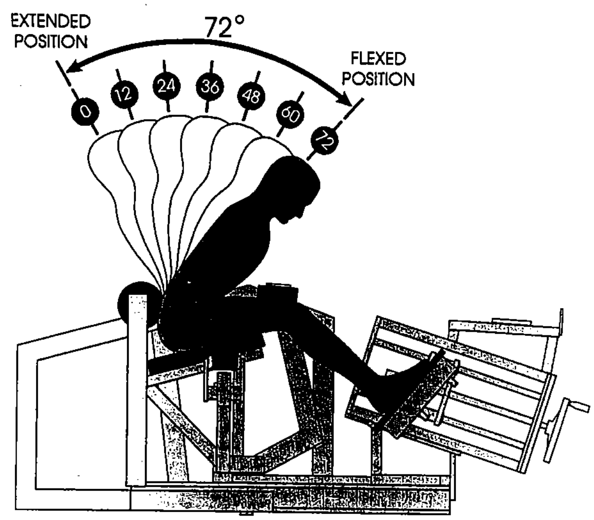

FIG. 2. This drawing documents the method of torque testing. Isometric strength is measured at various points in the total lumbar range. This range is isolated from the pelvis due to the restraint system.

Magnetic resonance studies were performed on each individual before starting and at the conclusion of their training program. The images obtained included axial as well as coronal sections that were T1 weighted [repetition time (TR) 700–900, echo time (TE) 12–25]. Coronal sections from the anterior border of the most anterior lumbar vertebral body to the junction of the thoracolumbar fascia and the subcutaneous fat were obtained. Axial views obtained were T1-weighted images (TR 500–600 and TE 17–25) from the endplate of L3 to the lower endplate of L5. The same imaging parameters were used ~8 weeks later following the MedX strengthening program when follow-up MRIs are done. Fatty infiltration within the lumbar paraspinal musculature was rated by two qualified musculoskeletal radiologists. They were not informed as to the category (patients or controls), nor phase of the exercise program (beginning or end). Each section was rated for fatty infiltration as normal, mild, moderate, or severe. This method was found to be comparable to the more quantitative approach of counting pixels on the basis of a small pilot study. None of the images had gadolinium enhancement.

EMGs were obtained using two sets of bipolar surface electrodes, located laterally 2 cm off of the midline, overlying the multifidus muscle at the level of the iliac crest at ~L4–L5 and at the upper lumbar spine, at ~L3–L4 4 cm below the thoracolumbar junction. The EMG recording equipment used was an ME3000 Professional Muscle Tester (Mega Electronics Ltd., Kuopio, Finland). The EMGs were recorded while the subjects and patients were undergoing a 2-min exercise routine during both flexion and extension or MedX. Each signal was sampled at 1,000 Hz and recorded for later downloading to a microcomputer via a fiberoptic link. The raw EMG was subsequently transferred to a Macintosh computer for statistical analysis. The raw signals were analyzed for root mean square (RMS) and mean power frequency (MPF). The slope percent change from starting point to end of exercise were calculated for RMS and MPF. All statistical analyses were performed on the Statview software package. An analysis of variance test was used to determine changes in isometric strength through the entire range within groups and then

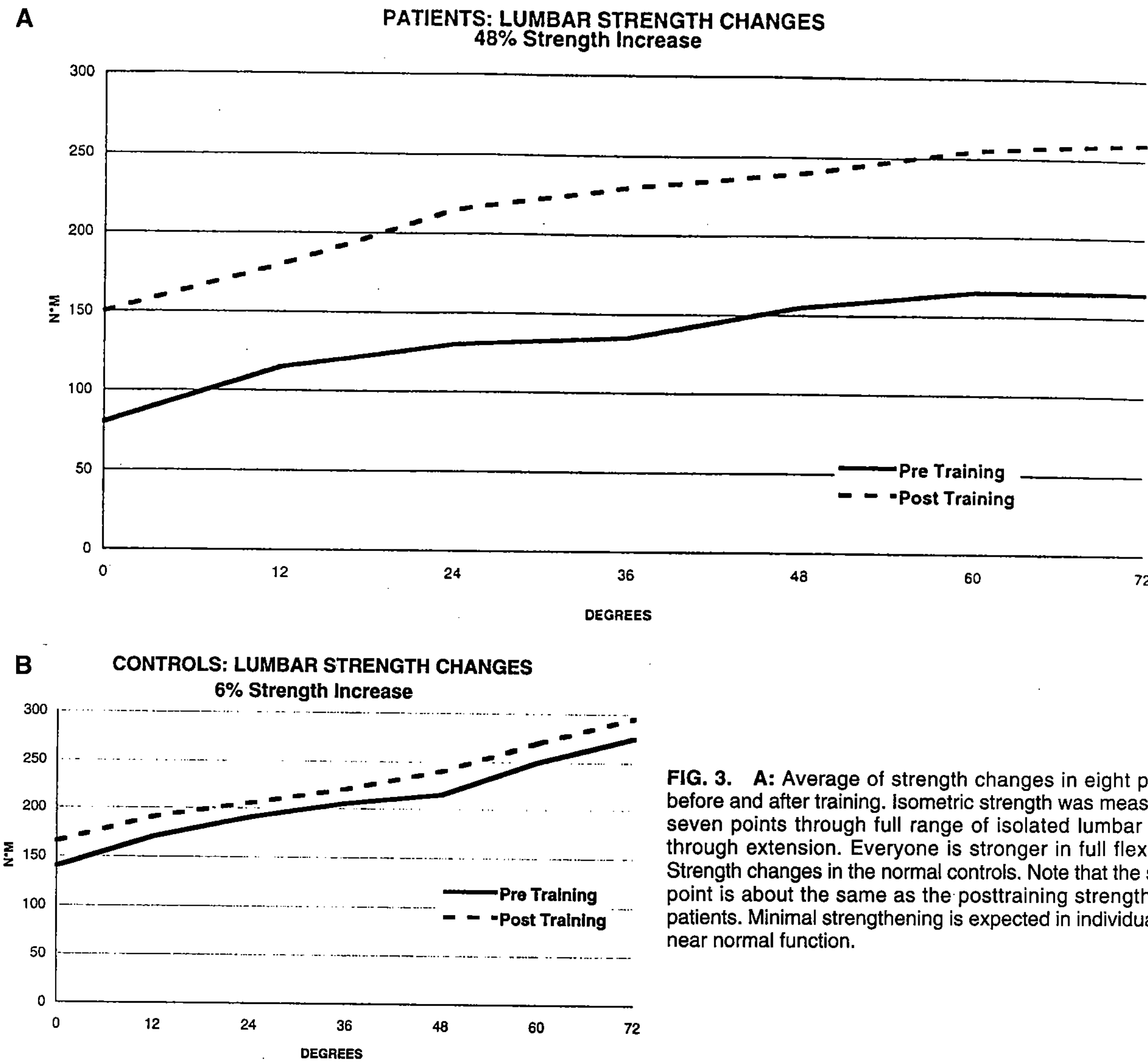

FIG. 3. **A:** Average of strength changes in eight patients before and after training. Isometric strength was measured at seven points through full range of isolated lumbar flexion through extension. Everyone is stronger in full flexion. **B:** Strength changes in the normal controls. Note that the starting point is about the same as the posttraining strength of the patients. Minimal strengthening is expected in individuals with near normal function.

comparatively. MRI changes were classified manually by a four classification system and analyzed by a simple *t* test. Studies were performed during the first exercise opportunity and at the conclusion of exercises 8 weeks (16 exercise episodes) after the initial evaluation.

MPF was determined with a fast Fourier transform and square window function on successive 1-s epochs with 0.5-s overlap. Each of four muscle groups was analyzed and the MPF for each epoch was plotted versus time. Because of the small variation in mean frequency with each contraction, a linear regression was performed on the data in their entirety rather than on individual peaks. The linear regression of MPF was plotted for each EMG signal. The initial value, intercept, the final value, end, and the slope of the MPF were analyzed.

RMS was also determined with a fast Fourier transform and square window function on successive 1-s epochs with 0.5-s overlap. RMS was plotted versus time, and various components of linear regressions of the peaks corresponding to each contraction were generated. The initial value, intercept, final value, and the slope of the RMS were analyzed.

RESULTS

At the end of the 8-week program, all patients reported improvement in function and reduction in pain. This was corroborated by the SF36 questionnaire, which documented functional improvements of 65% and reduction of pain complaint of 41%. In addition, the pain drawings improved an average of 81% by counting squares filled in on a clear plastic overlay. There was an average strength improvement of 48% for the eight patients (Fig. 3A). This is contrasted to an average of 6% strength improvement of the normal controls. It should be noted that the average deficit from normal strength for the patients was 40%, whereas the controls were at normal levels of strength, at the start of the exercise program (Fig. 3B and Fig. 4). Levels of normal strength for this age group have previously been determined by specific testing (7).

The MR studies documented that four of the five patients who had severe degenerative changes in the lumbar extensors, as defined by fatty infiltration, showed decrease in fatty infiltration after the 8-week, 16-episode training program. The other three patients had moderate changes noted in their MR scans at onset of exercise and showed no change in fatty infiltration at the conclusion of the exercise training program. There is apparently no correlation between the amount of strength gained and the degree of fatty infiltration. The numbers are too small to make a statistical evaluation. There is a relationship between age and the amount of fatty infiltration, as documented in Fig. 5. An example of changes in fatty infiltration is noted in Fig. 6A and B.

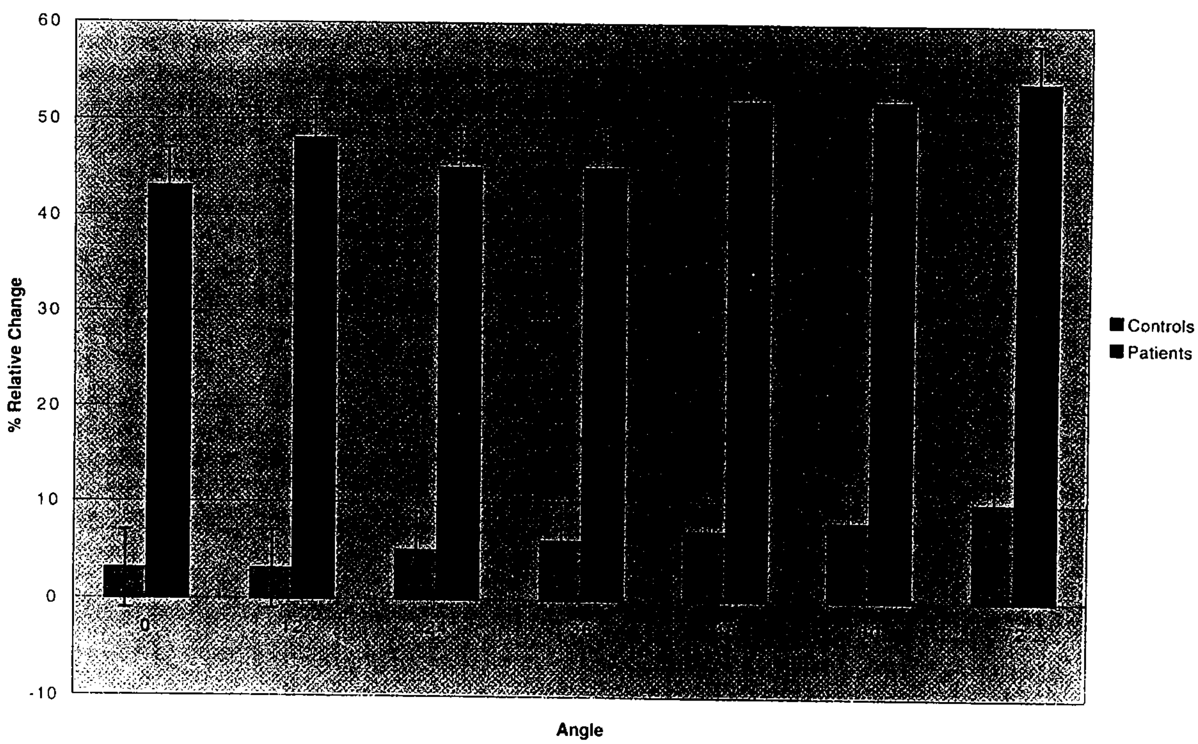

FIG. 4. This biograph combines the information from Fig. 3A and B demonstrating the relative percentage change, as well as the error bars of variation.

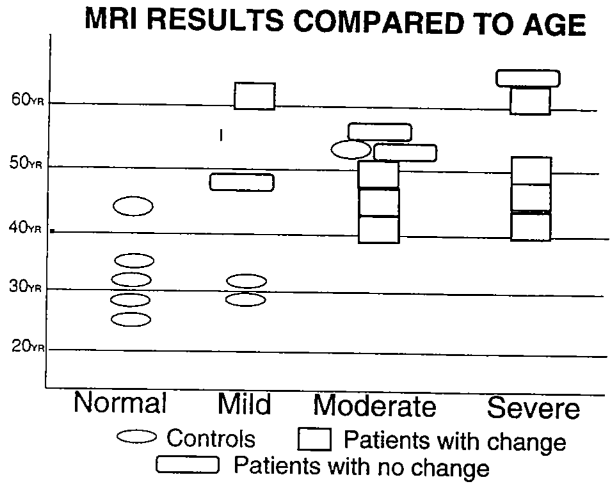

FIG. 5. Fatty infiltrations in the lumbar paraspinal extensor muscles vary both in age and with disease. Even though some of the patients had fatty infiltration, it did not change with an exercise program.

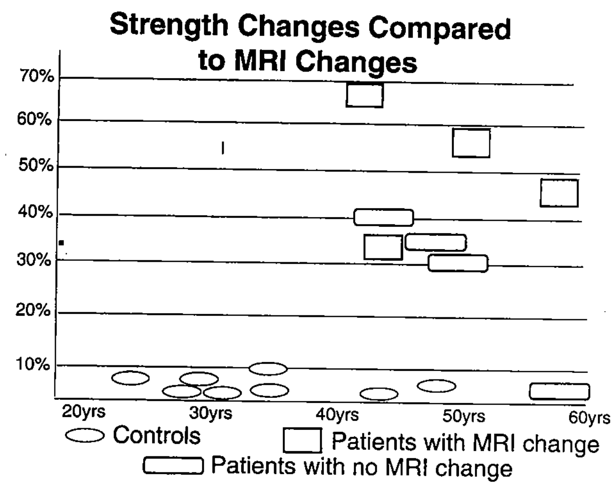

FIG. 7. In these eight patients, there seems to be a correlation with the severity of strength loss and the amount of change seen in lumbar extensor muscle fatty infiltration.

The three other patients had less severe degeneration, but did reveal a large increase in strength but no change in fatty infiltration (Fig. 7). No patients demonstrated a change

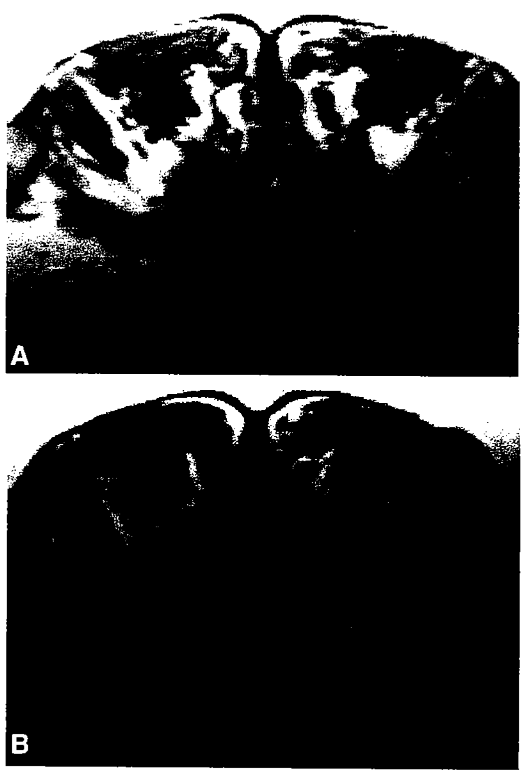

FIG. 6. **A:** The paraspinal lumbar extensors at L4–L5 in a 60-year-old woman before initiating exercise programs. Note the absence of fatty infiltration in the psoas muscles. None of the patients exhibited degeneration in the psoas or abdominals. **B:** Eight weeks later after sixteen exercise episodes and with an increase in 60% in strength, this same individual had a decrease in the amount of fatty infiltration (degeneration).

in muscle size. In all of the patients studied, there was considerably more fatty infiltration in the paraspinal extensor muscles than in any of the other muscles visualized by the MR axial view of the trunk.

The dynamic EMG studies (Fig. 8A and B) documented neuromotor control changes after the 8-week exercise program. In all patients, the amplitude increased as the resistance increased. A gradual and consistent decrease in frequency (compression of frequency spectrum) also always occurred. These two parameters were compared at the beginning of the exercise program and at the conclusion. When the initial resistance was used for the test resistance at the conclusion of the treatment program, the amplitude required to achieve the same work was less and did not increase during the exercise session, as had occurred during the initial exercise phase (Fig. 9).

The mean frequency consistently decreased during the initial exercise session. At the evaluation 8 weeks after the initiation of the exercise program during which the patients increased their resistance an average of 48%, the mean frequency did not diminish during exercise and remained about the same as the starting frequency. However, the starting frequency for the 8-week exercise program was consistently lower than the mean frequency computed at the beginning of the exercise program (Fig. 10).

DISCUSSION

The benefit reported by the patients from the specific isolated exercise training was the same as reported elsewhere (8,9,19,20). Because of the isolation of the lumbar extensors by MedX equipment, relatively infrequent exercise episodes are sufficient to stimulate the return in strength. The resistance offered is sufficient to create a training effect.

The individual starting resistance levels are dependent on the severity of the measured strength deficit. It has not been clear, however, whether the process of strengthening is on a structural basis or due to neuromotor changes.

This study clarifies some of these issues. Those individuals with severe degenerative changes, as reflected by a large amount of fatty infiltration, can demonstrate a retraining effect that is documented by their increase in strength and a decrease in fatty infiltration. This occurred in four of the subjects. A fifth subject, however, also had severe degenerative changes in the paraspinous muscles—especially the multifidus. Although he was in pain, he had only slightly deficient strength to start with, and only improved 6% in isometric strength during the 8-week period. Our findings are comparable to those of Alaranta et al. (1) and Parkola et al. (16), who noted an increased fatty infiltration in those individuals whose test results showed more weakness. These studies did not include follow-up studies to document changes in strength or MR fatty infiltration at the conclusion of a treatment program.

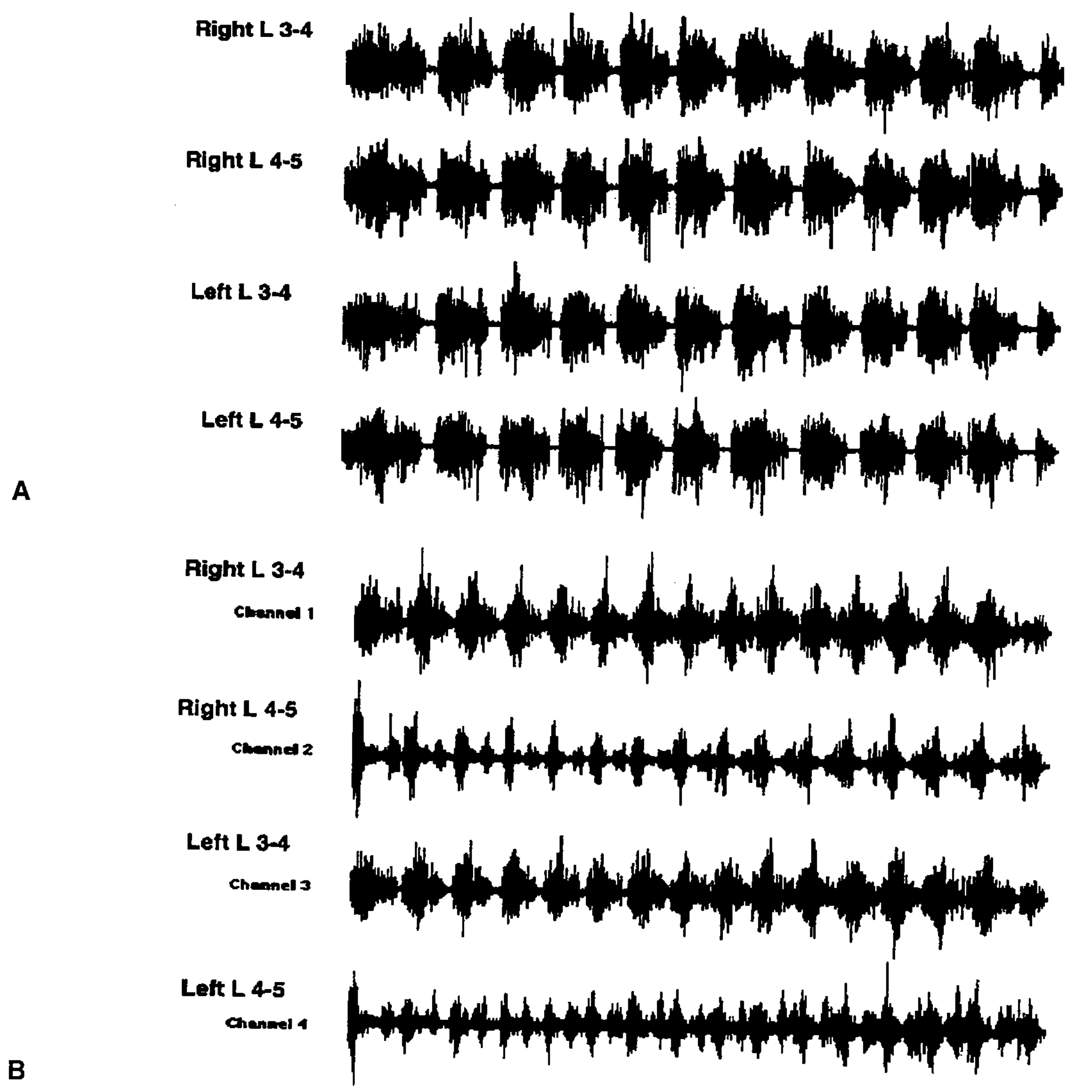

FIG. 8. A: Pretraining lumbar exercise dynamic electromyogram (EMG). Dynamic myoelectric signals recorded by surface electrodes at the L3–L4 level and the L4–L5 level on both the right and left. The peak of each burst of electrical activity represents the effort at full extension range. (This is the position of least mechanical efficiency for paraspinal lumbar extensors). The absence of electrical activity represents initiation of the next extension flexion cycle. These patterns point out that eccentric motor activity (the later phase of each bursts) requires less electrical activity for the same resistance as concentric function. B: Posttraining lumbar exercise dynamic EMG. Myoelectric activity is recorded for the same resistance as was used at the initiation of the training program. Eight weeks later, the training program has created the reorganization of effort so that L3–L4 is "working harder" than the L4–L5 level. The total amount of electrical activity seems to be less when compared with pretraining.

Those studies, like ours, however, did document that the size of the back muscles did not correlate with isometric extension strength. Also, like ours, the degree of fatty infiltration did not correlate with body weight. Their studies, like ours, also indicated that individuals can be quite comfortable and pain free with degenerative changes in the muscles as well as in the disc. In their studies, there was a higher incidence of disc degeneration in the patients with pain, although 48% of the normal subjects also had significant disc degeneration. We did not analyze our patient population for this in that all had degenerative disc changes. This was not seen in the younger pain-free subjects. This study also agrees with that of Mayer et al. (12), who noted that by computed tomography scan, extensor muscle atrophy was associated with muscle strength weakness.

Successful myoelectric recording with surface electrodes during dynamic exercise of the low back is relatively recent. This is largely due to the recent development of small high-competence preamplifiers located close to the muscle which reduces the electronic artifact during dynamic activity to allow analysis of the myoelectric signal. In clinical studies, especially when repeated studies are to be undertaken, surface electrodes are necessary. Most patients are unlikely to tolerate repeated EMG recording with needle electrodes.

A recent study by Robinson et al. (21) approached the problem in a way similar to that in our study. In their study, amplitude was evaluated during a fatiguing exercise, both in controls and in pain patients. The amount of amplitude in the chronic back pain patients was significantly less, but the fatiguing muscles demonstrated a decrease in amplitude. This is in direct distinction to our study wherein the amplitude (RMS) showed an increase in electrical signal as the patient progressed through an exercise program. However, in Robinson's study, the patients were not taken to complete fatigue, which may account for the difference. In addition, the Robinson et al. study did not have a before-and-after comparison. In our study, it is of interest that the amplitude did start at a lower level when the patient was tested after the exercise program was finished. This observation of less amplitude for the same resistance after training may be a definition of increasing muscle tone or better neuromotor control. It has been documented that increasing amplitude of the EMG does correlate with increased strength (15,25).

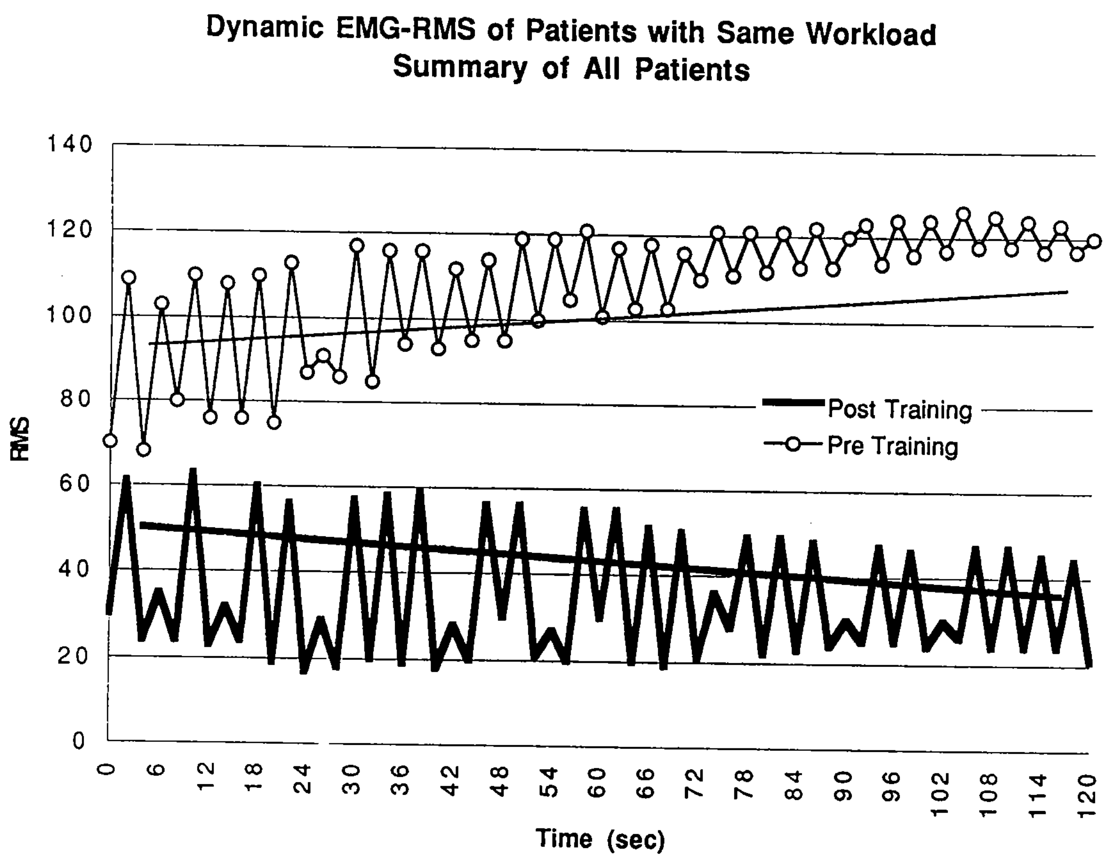

FIG. 9. The lower pattern starting at ~50 Hz represents the posttraining amplitude (root mean square) which for the same resistance as used at the initial exercise event presents a lower starting point. The training effect indicates that less amplitude is required to carry out the same work as was undertaken at the beginning.

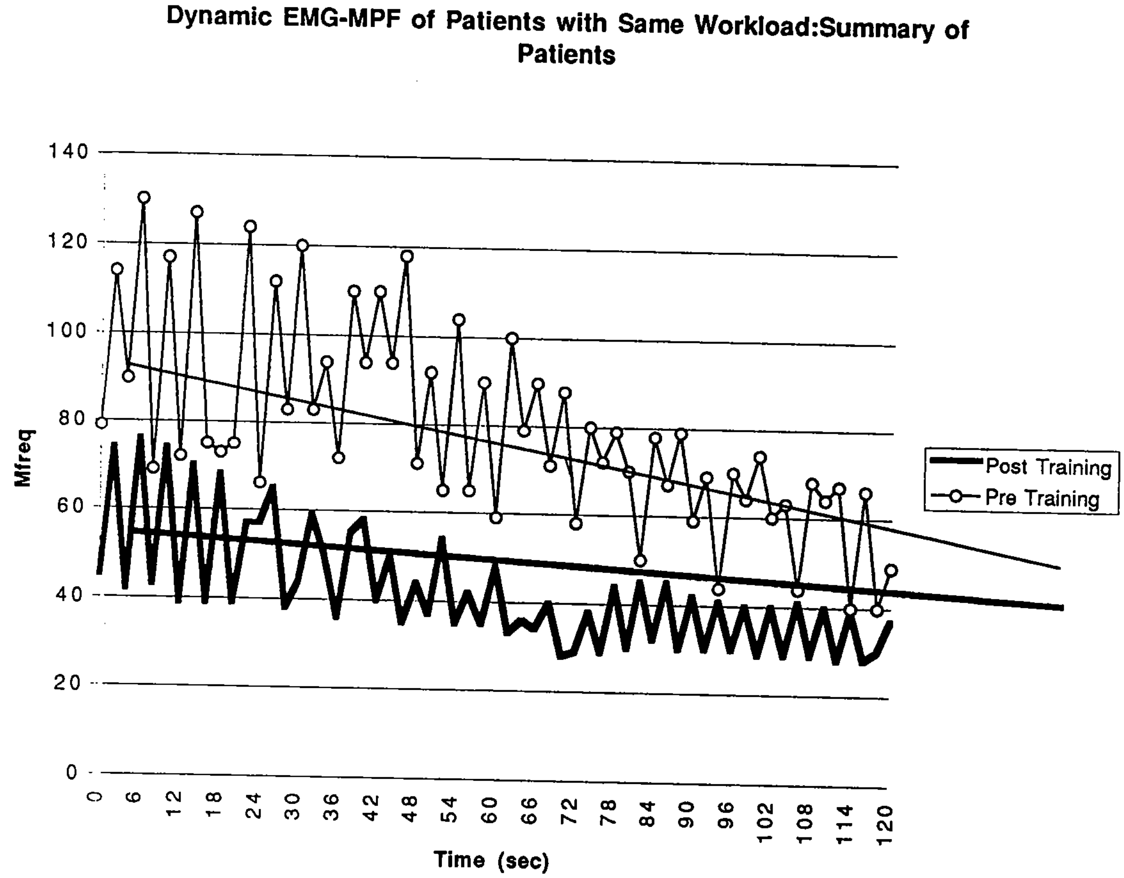

FIG. 10. The mean frequency of myoelectric activity gradually diminishes with increasing effort and fatigue. The posttraining frequency again starts at a lower frequency than initially was necessary, and the amount of decrease is significantly less compared with the initial effort. This suggests that these muscles fatigue less for the same resistance.

Cassisi et al. (3) measured the electrical activity of patients versus controls by monitoring myoelectric activity at various points in the range tested in an isometric mode. The controls had a greater amplitude than the patients. This study also isolated the lumbar spine, and tested at various points in the range. Thus, in this study, the amplitude was less in the far flexed position than in the extended position, which has less mechanical advantage. In the chronic low back pain patients, the increase in amplitude through the range of flexion into extension was far less than in normal individuals. This, again, confirms that low back pain patients are less able to stimulate muscle fibers, at least as reflected by myoelectric activity. No investigation as to the training effect was undertaken in this study. Cassisi et al. did suggest the use of myoelectric activity as an additional biofeedback tool in addition to the use of torque display while the individual is exercising. This study, as did others, combined a relationship between amplitude of electrical signal and torque production.

An alternative method of myoelectric analysis is to measure the frequency of the muscle activity. The frequency can be computed into a single number by computing the mean frequency of the electrical activity. Either mean or median frequency can be computed (13). It has been noted that with fatiguing activity, the frequency decreases (4). One explanation for this phenomenon was the buildup of hydrogen ions in an area of increased muscle activity. The pH change in the extracellular and intercellular fluid affects the depolarization of the muscle fiber membranes (11). The amount of decrease in myoelectric mean frequency was, therefore, a predictor of the severity of the fatigue or the potential for fatigue. Another explanation for the compression of spectrum of frequencies is diminished activity of fast-twitch muscle fibers during fatiguing activity (6).

In various studies, it has been documented that a more rapid rate of decline of the mean frequency is an excellent predictor as to individuals with low back pain and normals (2,23). These studies also did not make comparisons of myoelectric activity before and after training. All have noted a decline in the mean frequency on the occasion of strenuous exercise. The observation that there is less decline in the frequency when the muscle has been trained is a new observation. In addition, it is a new observation that a trained muscle has an initial frequency that is less than the frequency typical for that muscle when it is untrained.

CONCLUSION

Chronic low back pain patients have weaker lumbar extensor muscles than normal. Intense exercise, however, is quite effective in reversing this weakness, both from a torque-production standpoint as well as structural changes when the degeneration in the muscle is severe. The relatively rapid change of neuromotor control systems as reflected by the change in EMGs is remarkable, and shows that a very significant training effect on neuromotor organization can be created by a specific strenuous isolated exercise program in concentric and eccentric phases. Finally, atrophy as reflected by fatty infiltration involves the paraspinal muscle more than the trunk and psoas muscles.

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