[RESEARCH REPORT]

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Surface Electromyographic Analysis of the Low Back Muscles During Rehabilitation Exercises

Low back pain (LBP) is very prevalent in our society. It has been estimated that approximately 80% of the adult population has or will experience LBP in their lifetime.[62] During any 3-month period, about 25% of adults in the United States indicate that they experience LBP.[21] Eighty to ninety percent of patients with acute LBP seem to recover within 6 weeks, regardless of the treatment received.[62] In spite of this, there is about a 60% recurrence rate of LBP in patients within 1 year of the initial episode.[14] Some patients do not recover from the acute LBP episode and go on to have a chronic condition.

Exercise therapy is utilized extensively by physical therapists as an intervention for patients with LBP. Several literature reviews and guidelines for the treatment of LBP indicate that exercise therapy is an ineffective intervention for patients with acute LBP, but provides positive effects in treating patients with chronic LBP.[1,11,24,28,43,45,51,54,61] Even though there is lack of good evidence for exercise therapy for patients with acute LBP, there is some indication that all patients with either acute or chronic LBP may benefit from appropriate exercise programs.

• **STUDY DESIGN:** Prospective, single-group, repeated-measures design.

• **OBJECTIVE:** To analyze the longissimus thoracis and lumbar multifidi muscle activity with surface electromyography (EMG) during exercises used in back rehabilitation programs.

• **BACKGROUND:** Physical therapists use a variety of exercises when rehabilitating patients with low back pain (LBP). EMG analysis of exercises can provide a measure of muscle activation so a clinician can have a better idea about the effect the exercise may have on the muscle for stabilization, endurance, or strength training.

• **METHODS AND MEASURES:** Surface EMG analysis of the muscle activity of the longissimus thoracis and lumbar multifidi was carried out bilaterally on 3 different experimental groups while performing a variety of exercises commonly used in low back rehabilitation programs. Groups 1 and 2 each had 30 subjects and group 2 had 29 subjects, ranging in age from 21 to 35 years. All EMG data during exercises were normalized to percent of the maximum voluntary isometric contraction (MVIC).

• **RESULTS:** The lumbar multifidus and longissimus thoracis muscles were most active, with EMG amplitudes of greater than 92% ± 12% MVIC during prone lumbar extension to end range with resistance applied. Prone lumbar extension to neutral, resisted lumbar extension while sitting, and prone extension with the upper and lower extremities lifted (Superman exercise) produced EMG amplitudes ranging from a mean ± SD of 77% ± 13% to 82% ± 12% MVIC. Exercises that produced EMG amplitudes of less than 50% MVIC were bridging exercises, the side-bridge exercise, and upper and lower extremity raises in either the prone or quadruped positions.

• **CONCLUSION:** The findings from this study may be helpful for physical therapists in selecting exercises when progressing patients with LBP from low-intensity exercises to those that require more muscle activity. *J Orthop Sports Phys Ther 2008;38(12):736-745. doi:10.2519/jospt.2008.2865*

• **KEY WORDS:** *endurance, lumbar spine, stabilization, strength*

Several studies have demonstrated atrophy of the lumbar multifidus (LM) muscles with infiltration of fatty tissue in patients with chronic LBP,[6,12,18,33,38] and atrophy at the dysfunctional lumbar level in patients with unilateral acute LBP.[29,30] Hides et al[29] found that the LM muscle remained atrophied for at least a 10-week period when patients with acute LBP did not exercise, but recovered to normal size in patients who received a stabilization exercise program that stressed deep abdominal and isolated LM muscle contractions.[29]

There is no evidence that one exercise program is better than another for the rehabilitation of patients with LBP. Therefore, a wide variety of exercises have been utilized for progressive strengthening of the low back. Electromyography (EMG) provides a means by which the back muscle activation levels can be analyzed during exercises, which can assist a therapist in selecting appropriate exercises.

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McGill[48] and Kavcic et al[37] have provided the most extensive EMG data of the back muscles during a variety of low back exercises, while others have also performed EMG studies focusing more on specific exercises.[3-5,8,10,16,19,22,23,37,42,58] Some exercises have yet to be studied using EMG analysis.

Thus, the purpose of this study was to analyze the longissimus thoracis (LT) and LM muscle activity with surface EMG during a large variety of exercises often used in back rehabilitation programs.

TABLE 1 Exercises Performed in Group 1, Group 2, and Group 3

Group 1 Exercises (n = 30)	
1.	Prone trunk extension to end range with weight held against the chest at 10-RM intensity with the lower extremities stabilized (**FIGURE 2**)
2.	Prone trunk extension to neutral spine position at 10-RM intensity with the lower extremities stabilized
3.	Slow active sitting trunk extension against elastic tubing resistance with the pelvis mechanically stabilized (**FIGURE 3**)
4.	Slow active sitting trunk extension against elastic tubing resistance without the pelvis mechanically stabilized
5.	Maximum resistance to right hip extension to neutral in the quadruped position
6.	Maximum resistance to left hip extension to neutral in the quadruped position
7.	Maximum resistance to the right hamstring muscle with the knee flexed to 45°
8.	Maximum resistance to the left hamstring muscle with the knee flexed to 45°
9.	Left trunk side bending when lying on the right side with the lower extremities stabilized
10.	Right trunk side bending when lying on the left side with the lower extremities stabilized
Group 2 Exercises (n = 29)	
1.	Maximum resistance to prone trunk extension to end range with the lower extremities stabilized (**FIGURE 1**)
2.	Maximum resistance to prone trunk extension to neutral spine position with the lower extremities stabilized
3.	Sitting trunk extension with an isometric hold at end range against elastic tubing resistance with the pelvis mechanically stabilized
4.	Bridge to neutral spine position with knees extended and feet on a gymnastics ball (**FIGURE 7**)
5.	Active prone trunk extension to end range with the hips on a gymnastics ball and the feet on the floor (**FIGURE 5**)
6.	Bridge to neutral spine position (**FIGURE 8**)
7.	Prone trunk extension with upper and lower extremities lifted (Superman exercise) (**FIGURE 4**)
8.	Side-bridge to neutral spine position when lying on the left side (**FIGURE 12**)
9.	Maximum resistance to left trunk side bending when lying on the right side with the lower extremities stabilized (**FIGURE 10**)
10.	Maximum resistance to right trunk side bending when lying on the left side with the lower extremities stabilized
11.	Right upper and left lower extremity lifts with a neutral spine in a quadruped position (**FIGURE 11**)
12.	Bilateral lower extremity lifts to neutral spine position with the trunk supported on a gymnastics ball (**FIGURE 6**)
13.	Bridge to neutral spine position with the shoulders on a gymnastics ball and the feet on the floor (**FIGURE 9**)
Group 3 Exercises (n = 30)	
1.	Maximum resistance to prone trunk extension to end range with the lower extremities stabilized (**FIGURE 1**)
2.	Maximum resistance to prone trunk extension to neutral spine position with the lower extremities stabilized
3.	Slow active sitting trunk extension against elastic tubing resistance with the pelvis mechanically stabilized (**FIGURE 3**)
4.	Bridge to neutral spine position with knees extended and feet on a gymnastics ball (**FIGURE 7**)
5.	Maximum resistance to right hip extension to neutral in the quadruped position
6.	Bridge to neutral spine position (**FIGURE 8**)
7.	Maximum resistance to the right hamstring muscle with the knee flexed to 45°
8.	Side-bridge to neutral spine position when lying on the left side (**FIGURE 12**)
9.	Prone right upper and left lower extremity lifts (**FIGURE 13**)
10.	Abdominal hollow exercise in the quadruped position

Abbreviation: RM, repetition maximum.

METHODS

This study used a prospective, single-group, repeated-measures design to analyze the activation level of the LT and LM muscles during a variety of exercises used in rehabilitation of the lumbar spine. Three different groups of subjects were studied at different times, with some exercises being the same at more than 1 testing occasion.

Subjects

In group 1 there were 30 subjects (23 females, 7 males; mean ± SD height, 170 ± 6 cm; body mass, 64 ± 9 kg; age, 24 ± 4 years; age range, 23-31 years). Group 2 consisted of 29 subjects (12 females, 17 males; mean ± SD height, 175 ± 8 cm; body mass, 73 ± 10 kg; age, 27 ± 8 years; age range, 21-31 years). In group 3 there were 30 subjects (20 females, 10 males; mean ± SD height, 171 ± 7 cm; body mass, 68 ± 9 kg; age, 26 ± 7 years; age range, 22-35 years). All groups were similar in demographics, except for different ratios of males and females. All subjects were volunteers recruited from the University community. Subjects were accepted for the study if they were in good health, with no current back or lower extremity problems. Subjects were excluded if they had any previous back surgery. The rights of the subjects were protected. Participants signed an informed consent form approved by The University of South Dakota Institutional Review Board.

Procedures

Prior to electrode placement, each subject was familiarized to the procedures by being instructed in and practicing the muscle tests and exercises to be performed. When we were assured the subjects could correctly perform each muscle test or exercise, the sites for electrode placement were prepared by abrading the skin with fine sandpaper and cleansed with 70% isopropyl alcohol. Shaving excess hair was performed if necessary. Dual disposable silver/silver chloride surface recording electrodes (Noraxon USA, Inc, Scottsdale, AZ) were applied. Paper tape was also applied over the electrodes to minimize any

TABLE 2 EMG Signal Amplitudes of the Longissimus Thoracis and Lumbar Multifidus During Low Back Exercises That Symmetrically Activate the Back Muscles

Exercise	Longissimus Thoracis	Lumbar Multifidus
1. Maximum resistance to prone trunk extension at end range with the lower extremities stabilized (n = 59)	97 ± 7 (95-99)	98 ± 7 (96-100)
2. Prone trunk extension to end range at 10-RM intensity with a weight held against the chest with the lower extremities stabilized (n = 30)	92 ± 12 (88-96)	92 ± 14 (87-97)
3. Maximum resistance to prone trunk extension at neutral spine position with the lower extremities stabilized (n = 59)	82 ± 12 (79-85)	80 ± 12 (77-83)
4. Slow active sitting trunk extension against elastic tubing resistance with the pelvis stabilized (n = 60)	81 ± 15 (77-85)	78 ± 16 (74-82)
5. Prone trunk extension with upper and lower extremities lifted (Superman exercise) (n = 29)	81 ± 14 (76-86)	77 ± 13 (72-82)
6. Prone trunk extension to neutral spine position at 10-RM intensity with the lower extremities stabilized (n = 30)	68 ± 11 (64-72)	67 ± 13 (62-72)
7. Slow active sitting trunk extension against elastic tubing resistance without the pelvis stabilized (n = 30)	65 ± 18 (59-71)	62 ± 16 (56-68)
8. Sitting trunk extension with an isometric hold at end range, against elastic tubing resistance, with the pelvis mechanically stabilized (n = 29)	64 ± 17 (58-70)	62 ± 20 (55-69)
9. Active prone trunk extension to end range with the hips on a gymnastics ball and the feet on the floor (n = 29)	56 ± 18 (49-63)	50 ± 16 (44-56)
10. Bilateral lower extremity lifts to neutral from the prone position with the trunk resting over a gymnastics ball (n = 29)	54 ± 16 (48-60)	49 ± 14 (44-54)
11. Bridge to neutral spine position with knees extended and feet on a gymnastics ball (n = 59)	42 ± 13 (39-45)	44 ± 12 (41-47)
12. Bridge to neutral spine position (n = 59)	37 ± 12 (34-40)	39 ± 13 (36-42)
13. Bridge to neutral spine position, with the shoulders on a gymnastics ball and the feet on the floor (n = 29)	35 ± 13 (32-39)	38 ± 14 (35-41)
14. Abdominal hollow exercise in the quadruped position (n = 30)	6 ± 6 (4-8)	5 ± 2 (4-6)

Abbreviations: RM, repetition maximum.
** Values are expressed as mean ± SD percentage of maximum voluntary isometric contraction (MVIC) and 95% confidence interval in parentheses.*

movement of the electrodes during the exercises. EMG data were collected in all groups bilaterally from the LT and LM muscles and unilaterally from the right gluteus maximus (GM) and hamstring (HS) muscles in group 3.

Because surface EMG is subject to crosstalk between muscles,[21] we took the following steps to minimize its occurrence. Electrodes were positioned well within the borders of the muscles and were applied in parallel arrangement to the muscle fibers, with a center-to-center interelectrode distance of 20 mm. The skin impedance was accepted if less than 5000 Ω.[13] For the LT muscles, the electrodes were placed 4 cm lateral to the L1 spinous process and, for the LM muscles, the electrodes were placed 2 cm lateral to the lumbosacral junction.[4,5,16,19] For the GM muscle, the electrodes were placed in the center of the muscle belly between the lateral edge of the sacrum and the posterosuperior edge of the greater trochanter.[13] A general electrode placement was used for the entire HS muscle group and located in the center of the posterior thigh, midway between the gluteal fold and the popliteal line, on the posterior surface of the knee.[13] A reference electrode was placed over the right anterior superior iliac spine.

For normalization of the EMG data, a maximum voluntary isometric contraction (MVIC) was performed for each muscle and the EMG signal amplitude recorded. The test positions were consistent with those demonstrated in manual muscle testing books commonly used by physical therapists; but in the case of the back muscles, additional manual resistance was applied.[32,39] Manual pressure was gradually increased until maximum resistance was applied, and then held for 5 seconds. Each muscle test was repeated 3 times, with a 30-second rest between contractions. Proper electrode placement was also confirmed by observing the EMG amplitudes during the manual muscle tests.

The MVIC for the LM and LT muscles was performed with prone trunk extension to end range, with resistance applied at the upper thoracic area as the lower extremities were stabilized.[39] The MVIC for the GM muscle was performed in the prone position, with the knee flexed to 90° and the hip extended with resistance applied just above the knee.[32] The HS MVIC was performed in prone, with the knee flexed 45° and resistance applied just proximal to the ankle.[32]

The exercises performed by the 3 different groups are listed in **TABLE 1**. Resisted sitting extension was performed on a device fabricated by the first author. The exercises were performed in random order and held isometrically for 5 seconds during each repetition, except for active sitting extension, which was performed slowly over approximately a 2-second period. Rest periods of 30 seconds were allowed between repetitions of each exercise, and a 1-minute rest was given between the different exercises to help reduce the effects of fatigue. In group 1, each subject was retested after an 8-week low back strengthening program (data not presented here). The purpose of the exercise program was to determine if there was any change in the EMG levels after an exercise program. The exercise program consisted of 1 set of either prone extension or sitting extension exercises performed 2 times per week at a 10 rep-

TABLE 3 EMG Signal Amplitudes of the Longissimus Thoracis and Lumbar Multifidus Muscles During Low Back Exercises That Asymmetrically Activate the Back Muscles

	Longissimus Thoracis		Lumbar Multifidus	
Exercise	Left	Right	Left	Right
1. Maximum resistance to right trunk side bending when lying on the left side with the lower extremities stabilized (n = 29)	7 ± 4 (6-8)	58 ± 16 (52-64)	12 ± 6 (10-14)	39 ± 13 (34-44)
2. Maximum resistance to left trunk side bending when lying on the right side with the lower extremities stabilized (n = 29)	54 ± 13 (49-59)	9 ± 4 (8-10)	38 ± 12 (34-42)	13 ± 6 (11-15)
3. Active left trunk side bending when lying on the right side with the lower extremities stabilized (n = 30)	49 ± 16 (43-55)	7 ± 2 (6-8)	32 ± 11 (28-36)	14 ± 5 (12-16)
4. Active right trunk side bending when lying on the left side with the lower extremities stabilized (n = 30)	8 ± 3 (7-9)	48 ± 15 (43-53)	14 ± 6 (12-16)	33 ± 13 (28-38)
5. Maximum resistance to right hip extension to neutral in the quadruped position (n = 60)	43 ± 15 (39-47)	32 ± 11 (29-35)	39 ± 13 (36-42)	45 ± 12 (42-48)
6. Right upper and left lower extremity lifts with a neutral spine in the quadruped position (n = 29)	36 ± 12 (32-40)	35 ± 11 (31-39)	41 ± 12 (37-45)	29 ± 11 (25-33)
7. Side-bridge to neutral spine position when lying on the left side (n = 59)	39 ± 15 (35-43)	13 ± 9 (11-15)	35 ± 14 (31-39)	13 ± 10 (10-16)
8. Prone right upper and left lower extremity lifts (n = 30)	36 ± 14 (31-41)	49 ± 16 (43-55)	40 ± 11 (36-44)	45 ± 16 (39-51)
9. Maximum resistance to the right hamstring muscle with the knee flexed to 45° (n = 60)	28 ± 14 (25-31)	23 ± 12 (20-26)	28 ± 13 (25-31)	25 ± 13 (22-28)

* *Values are expressed as mean ± SD percentage of maximum voluntary isometric contraction (MVIC) and 95% confidence interval in parentheses.*

etition maximum (RM) intensity.

For group 1, interday reliability of the EMG recordings was evaluated for all subjects, and in groups 2 and 3 intraday reliability of the EMG recordings were tested by having several subjects repeat the exercise program.

EMG Analysis

An 8-channel EMG Noraxon Myosystem 1200 (Noraxon USA, Inc, Scottsdale, AZ) was used for data collection. Unit specifications include a differential input impedance of greater than 10 MΩ, a gain of 1000, and a common-mode rejection ratio of greater than 100 dB at 60 Hz. The EMG signals were band-pass filtered from 10 to 500 Hz using a first-order high-pass and fourth-order low-pass Butterworth filter. The Myosystem 1200 was interfaced with a computer with a 16-channel, 12-bit A/D card (Computer Boards, Inc, Middleboro, MA). The sampling rate was set at 2000 Hz per channel.

All data were stored on a personal computer and Myoresearch 2.02 software (Noraxon USA, Inc, Scottsdale, AZ) was used for data processing and analysis. During data collection, the raw EMG recordings were monitored.

The raw EMG data were full-wave rectified, processed using a root-mean-square algorithm and smoothed with a 20-millisecond moving window. The amplitude was calculated from a 2-second window centered about the peak activity of the muscles for each of the MVICs and exercises.

The maximum EMG signal amplitude during the MVIC of each muscle represented 100% muscle activity. The muscle activity recorded during the exercises was then expressed as a percentage of the MVIC.

Data Analysis

The SPSS Base 10.0 for Windows (SPSS Inc, Chicago, IL) computer program was used for data analysis. An intraclass correlation coefficient ($ICC_{3,1}$) was used to determine the same-day test-retest reliability of the EMG recordings.[53]

Each of the 3 groups performed some of the same exercises. The data from these exercises were pooled for these 3 groups due to the descriptive nature of the study, similar demographics of the groups, identical protocol and instrumentation, and similar results across groups. The data are presented in the tables as a mean ± SD percent of MVIC with a 95% confidence interval (CI). Statistical comparisons between the exercises were not performed due to pooling of group data on the tables. Given the lack of clinically and statistically significant differences between the muscle activity of the 2 sides of the back during symmetrical exercises, the right and left side data were also averaged so it could be more clearly displayed in a single table.

RESULTS

Reliability of EMG Recordings

Group 1 was tested and retested at 8 weeks. The intraclass correlation ($ICC_{3,1}$) of the EMG recordings for interday testing was 0.83 during the exercises. Intraday testing was performed for group 2. Twelve subjects repeated the 13 exercises a second time without changing the electrodes. For 6 of the exercises the ICC ranged from 0.90 to 0.98. For

TABLE 4 EMG Signal Amplitudes of the Right Gluteus Maximus and Right Hamstring Muscles During Exercises That Activate the Low Back Muscles*

Exercise	Right Gluteus Maximus	Right Hamstring
1. Maximum resistance to prone trunk extension to end range with the lower extremities stabilized (n = 59)	88 ± 15 (83-93)	82 ± 24 (73-91)
2. Maximum resistance to the right hamstring muscles with the knee flexed to 45° (n = 60)	28 ± 27 (18-38)	91 ± 14 (86-96)
3. Maximum resistance to right hip extension in the quadruped position (n = 60)	68 ± 23 (60-76)	67 ± 16 (61-73)
4. Maximum resistance to prone trunk extension at neutral spine position with the lower extremities stabilized (n = 59)	42 ± 15 (37-47)	47 ± 18 (41-53)
5. Bridge to neutral spine position (n = 59)	27 ± 13 (22-32)	35 ± 21 (27-43)
6. Bridge to neutral spine position with knees extended and feet on a gymnastics ball (n = 59)	20 ± 14 (15-25)	35 ± 14 (30-40)
7. Slow active sitting trunk extension with elastic tubing resistance with the pelvis mechanically stabilized (n = 60)	20 ± 10 (16-24)	22 ± 14 (17-27)

** Values are expressed as mean ± SD percentage of maximum voluntary isometric contraction (MVIC) and 95% confidence interval in parentheses.*

FIGURE 1. Maximally resisted end range lumbar extension.

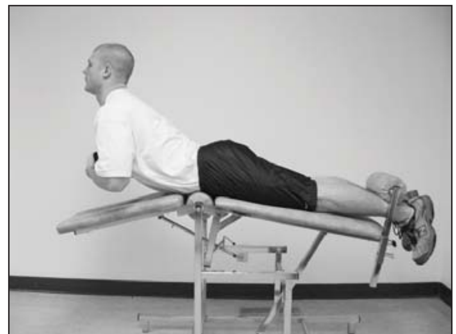

FIGURE 2. Prone trunk extension to end range with a weight held against the chest.

FIGURE 3. Resisted sitting lumbar extension with the pelvis mechanically stabilized.

the bridge, prone extension to end range, and prone extension to neutral spine position, ICCs ranged from 0.81 to 0.85. ICCs for the lower extremity lift over the ball, side-bridge, and sitting extension exercises ranged from 0.60 to 0.75. For group 3, 15 subjects repeated 3 exercises a second time after a 5-minute rest. ICCs were 0.93 for the bridge exercise, 0.92 for the right hip extension in the quadruped position, and 0.97 for the prone extension to end range.

EMG Data During the Exercises

The mean ± SD muscle activity, expressed as percent of MVIC during each exercise and the 95% confidence intervals (CI), is displayed in **TABLES 2 THROUGH 4. TABLE 2** presents the data from exercises activating the back muscles symmetrically, **TABLE 3** presents the data from exercises activating the back muscles asymmetrically, and **TABLE 4** presents data from exercises activating the GM and HS muscles.

The LT and LM muscles were activated very similarly during all the exercises, with no clear difference between them. When considering the symmetrical exercises (**TABLE 2**), prone lumbar hyperextension to end range with either maximum manual resistance (mean ± SD, 98% ± 7% MVIC) or resistance applied at 10-RM intensity (mean ± SD, 92% ± 12% MVIC) activated the LT and LM muscles the most (**FIGURES 1 AND 2**). Other exercises that required high levels of muscle activity were prone lumbar extension to the neutral position with maximum manual resistance, sitting extension against elastic tubing resistance (**FIGURE 3**), and the prone bilateral upper and lower extremity raises (mean ± SD, 77% ± 13% to 82% ± 12% MVIC) (**FIGURE 4**). A variety of exercises (exercises 6-10 on **TABLE 2**) that incorporated lumbar extension or lower extremity lifts over a gymnastics ball (**FIGURES 5 AND 6**) activated these muscles to more moderate levels (mean ± SD, 49% ± 14% to 68% ± 11% MVIC). Bridging exercises (**FIGURES 7-9**) activated these muscles to lower mean ± SD levels of 35% ± 13% to 44% ± 12% MVIC. The abdominal hollowing exercise developed very low mean ± SD levels of back muscle activity at 5% ± 2% to 6% ± 6% MVIC.

When considering asymmetrical exercises (**TABLE 3**), trunk side bending activated the LT and LM muscles to a mean ± SD level of 32% ± 11% to 58% ± 16% MVIC (**FIGURE 10**). There was the greatest difference in activation between the LT and LM muscles during this exercise compared to all other exercises. Other exercises commonly used in spinal rehabilitation, such as the quadruped or prone upper and lower extremity lifts and the side-bridge exercise (**FIGURES 11-13**), produced mean ± SD EMG signal amplitudes of 29% ± 11% to 45% ± 12% MVIC. Prone unilateral maximum manual resistance of the HS muscles produced mean ± SD EMG signal amplitudes in the back muscles ranging from 23% ± 12% to 28% ± 14% MVIC.

A back exercise that also highly activated the GM (mean ± SD, 88% ± 15% MVIC) and HS (mean ± SD, 82% ± 24% MVIC) muscles was prone extension to end range with maximum resistance. Bridging exercises (**FIGURES 7 AND 8**) activated these 2 muscles to mean ± SD levels ranging from 20% ± 14% to 35% ± 14% MVIC.

DISCUSSION

The purpose of this study was to analyze the activity level of the LT and LM muscles during exercises that are used by physical therapists during the rehabilitation of patients with LBP. These data can help guide physical therapists when progressing a patient from easier to more intense exercises.

When the surface EMG signal is rectified and smoothed, its amplitude is generally related positively to the amount of force produced by the muscle.[20] Investigators have reported both linear and nonlinear relationships between EMG signal amplitude and force production during isometric contractions.[2,7,47] Marras and Davis[47] found a strong linear relationship for the erector spinae, rectus abdominis, and external and internal oblique abdominis muscles during isometric flexion and extension exercises. Therefore, for the purpose of developing exercise programs, the EMG signal amplitude can provide a general guideline as to the intensity of the exercise.

Physical therapists tend to take different approaches when rehabilitating the muscles of the low back in patients, because there is no evidence in the literature that one exercise program is superior to another. The spinal stabilization exercise approach has become popular with many therapists. This approach stresses cocontraction of the deep abdominal and LM muscles during low-load exercises.[44,55] Using low-load stabilization exercises, Hides et al[29,31] have demonstrated hypertrophy of the LM in patients with acute LBP and also in active young patients with more chronic LBP, who initially had minor unilateral atrophy. Others have used these exercises for reducing disability and pain in patients with chronic LBP.[26,50]

More traditional strengthening programs have also been used successfully in improving patients with LBP.[9,27,34,36,40,41,46,49,56] When studying patients with recurrent LBP, 2 recent publications reported improvement in function and reduced pain with either general exercises for trunk muscle activation or with specific lumbar stabilization exercises.[9,40]

Because the LM and erector spinae muscles have a relatively high proportion of type I (slow-twitch) muscle fibers,[35,60] these muscles have fiber composition that makes them well suited for endurance or sustained contraction activities. Therefore, low-load or endurance exercises may be appropriate during any rehabilitation program and may lead to sufficient recovery for most patients with LBP. As reported above, some patient groups have demonstrated hypertrophy of the LM muscles with low-load stabilization exercises. It is thought that the LM muscle is inhibited in patients with LBP and the retraining of the muscle to contract may be of major importance during stabilization training. Danneels et al[17] studied the amount of muscle hypertrophy in the LM muscles with computed tomography imaging after a 10-week training in patients with chronic LBP. They compared 3 training groups. One group performed stabilization exercises, a second group performed stabilization and prone trunk extension exercises at 15 to 18 RM intensity, and the third group performed the same exercise program as the second group, with a 5-second isometric hold added at the end range of extension. The exercises were performed 3 times per week. The only group that demonstrated a significant increase in the cross-sectional area of the lumbar multifidus muscles was the group that performed back extensions at 15- to 18-RM intensity with a 5-second isometric hold at end range. Further research may provide more understanding about exercises that are best for developing hyper-

FIGURE 4. Lumbar extension with the upper and lower extremities maximally lifted.

FIGURE 5. Active lumbar extension to end range while supported on a gymnastics ball.

FIGURE 6. Bilateral lower extremity lifts to neutral spine position while supported on a gymnastics ball.

FIGURE 7. Bridge to a neutral spine position with the feet on a gymnastics ball.

FIGURE 8. Bridge exercise with the spine and hips in a neutral position.

FIGURE 9. Bridge to a neutral spine position with the shoulders on a gymnastics ball.

FIGURE 10. Maximally resisted trunk side bending.

FIGURE 11. Opposite upper and lower extremity lifts with neutral spine position in the quadruped position.

trophy of the LM muscles in patients with acute and chronic LBP.

In this present study, the LM and LT muscles were most active, with EMG amplitude levels of over 92% ± 14% MVIC, with lumbar extension to end range with resistance applied (**FIGURES 1 AND 2**). Other researchers have found EMG signal amplitude levels ranging from 80% to 84% MVIC in these muscles during active lumbar extension to end range.[3,16] Other exercises (**FIGURES 3 AND 4**) with active or resisted lumbar extension also produced fairly high levels of muscle activity in the back muscles. Therefore, these are the types of exercises required for more intense training of the back muscles.

McGill[48] has advised against utilizing the prone lumbar hyperextension in patients with LBP because of the high compressive load and shear forces on the spine. However, we feel that physical therapists need to make clinical judgments about each patient and, therefore, this exercise may be indicated in some cases. The lumbar paraspinal muscles can be progressively loaded during extension exercises by utilizing back exercise units that will tilt to different degrees.[25] As one progresses from a more upright position to a more horizontal position, the exercise becomes more intense for the back extensors. Once a patient can perform the exercise in the prone horizontal position, the patient can hold additional weight across the chest for further loading.

Sitting extension exercises performed with specialized equipment (**FIGURE 3**) are also a good way to strengthen the low back musculature, because the resistance can be progressively increased. It has been demonstrated that the exercise activates the low back muscles better if the pelvis is mechanically stabilized so that the extension movement comes from the spine rather than from the hip extensors.[52,57] In this present study there was about a 16% decrease in lumbar paraspinal muscle activity when the pelvis was not stabilized (**TABLE 2**).

Two other exercises commonly used in rehabilitation exercise programs are the quadruped or prone upper and lower extremity lifts (**FIGURES 11 AND 13**). These exercises performed actively without additional resistance produced EMG amplitudes in the LM and LT muscles ranging from 29% ± 11% to 45% ± 16% MVIC (**TABLE 3**). Others have recorded values ranging from about 20% to 50% MVIC for the erector spinae and 27% to 56% MVIC for the LM muscles during the quadruped exercise.[4,5,10,16,22,23,37,48,58] Because the EMG amplitude values are generally below 50% MVIC, these exercises would be regarded as more moderate-load exercises.

Side-bending exercises are thought to be excellent rehabilitation exercises because they produce cocontractions of the low back paraspinal, quadratus lumborum, and abdominal muscles. The 2 exercises analyzed in this study were side bending (**FIGURE 10**) and the side-bridge (**FIGURE 12**), which produced EMG signal amplitudes ranging from 32% ± 11% MVIC to 58% ± 16% MVIC in the low back muscles studied. Maximally resisted side bending produced the highest muscle activity. Others have found similar results for the paraspinal muscles during the side-bridge exercise,[23,48] as well as EMG signal amplitude levels of 54% MVIC in the quadratus lumborum[48] and up to 69% MVIC in the external oblique abdominis muscle.[23]

Three bridging exercises to the neutral spine position were evaluated. They were the bridge with the feet on a gymnastics ball and the knees extended (**FIGURE 7**), the supine bridge with the feet on the floor and the knees flexed (**FIGURE 8**), and a bridge with the shoulders on a gymnastics ball (**FIGURE 9**). For all 3 exercises the EMG signal amplitudes ranged from 35% ± 13% to 44% ± 12% MVIC in the LM and LT muscles. Others have demonstrated similar EMG amplitudes with the supine bridge exercise[5,23,37] and a bridge exercise with the feet on a ball.[8] These would be considered exercises of low to moderate intensity. Others have studied additional trunk stabilization exercises performed on gymnastic balls.[8,22]

A maximum contraction of the HS muscles at 45° of knee flexion in the

FIGURE 12. Side-bridge exercise to the neutral spine position.

FIGURE 13. Opposite upper and lower extremity lifts in the prone position.

prone position produced EMG signal amplitudes in the lumbar paraspinal muscles ranging from 23% ± 12% MVIC to 28% ± 14% MVIC (**TABLE 3**). Therefore, HS contractions can be used to initiate contraction of the paraspinal muscles and may be useful for teaching LM muscle contraction early in the rehabilitation process.

Leinonen et al[42] have shown that GM muscle activity is reduced in patients with LBP during standing flexion and extension of the trunk. Therefore, GM muscle function and strength should be considered during the rehabilitation of patients with LBP. In this study, maximally resisted lumbar extension at end range and maximally resisted neutral hip extension in the quadruped position produced EMG signal amplitudes above 68% ± 23% MVIC in the GM muscle. More specific strengthening exercises for the GM muscle should also be considered.

Limitations

Crosstalk may be a limitation when using surface electrodes. Stokes et al[59] have questioned the validity of using surface electrodes to monitor the activity of the LM muscles. They concluded that surface electrodes over the LM muscle pick up EMG signals from the LT muscle; but we believe their results should be interpreted with caution, because their spacing of the electrodes between the 2 muscles was much less than is usually used. Our electrode placements were consistent with those used by other researchers.[4,5,16,19] Arokoski et al[4] found a high correlation between the average intramuscular and surface activities of the normalized EMG signal of the LM muscle at the L2 and L5 levels, and Danneels et al[15] have demonstrated good reliability in the use of surface electrodes for the LM muscles. Additional research should be performed before a definite conclusion can be derived about the use of surface electrodes for the LM muscles. We feel even if there is some crosstalk between the 2 muscles, this study provides valuable information about the lumbar paraspinal muscle activity during various exercises.

In our study, the EMG signal was generally analyzed during isometric muscle contractions, except for the slow active sitting extension exercise. The results may have been different if dynamic muscle contractions were studied. However, isometric contractions of the trunk muscles are commonly performed during stabilization training of the spine.[44,55]

There is the potential that subjects did not generate a true MVIC of each muscle. This could be due to a lack of effort, or the muscle testing positions may not have been optimal for producing a maximum EMG signal. Optimal positions for producing a MVIC for each muscle group have not been clearly established. While interpretation of the absolute muscular effort expressed as a percent of MVIC may be affected by the MVIC testing, the within-subject design of this study provides a solid comparison of the relative difference in muscular effort among exercises.

There was generally a fairly wide variation in the muscle activity between individuals during the various exercises. This is possibly partially due to variation in muscle strength, which was not measured, among subjects. So, an exercise not requiring a maximum effort, such as lifting a body segment such as the trunk, may be easier for one subject and more difficult for another. The large SD for exercises simply reflects the difference in exercise intensity between subjects.

Finally, because these results were obtained by studying subjects without pathology, caution is warranted in extrapolating these findings to a patient population.

CONCLUSION

The findings from this study may be helpful to therapists when guiding a patient through a rehabilitation program for LBP, by first selecting exercises that produce low levels of muscle activity and then exercises that require progressively more muscle activation. Because there is quite a wide variation in muscle activation between subjects during any particular exercise, the program still needs to be individualized to take into consideration the patient's perception of exercise intensity. ◉

KEY POINTS

FINDINGS: Many exercises commonly used by physical therapists in LBP rehabilitation require low to moderate muscle activity of the LM and LT muscles. To increase the activity of these muscles during exercise, active or resisted lumbar extension is required. Resisted lumbar extension at end range tends to maximally activate these muscles.

IMPLICATIONS: Exercise intensity for the low back muscles can be incrementally increased during a rehabilitation program by changing exercises as patients improve.

CAUTION: Surface electrodes were used to record the EMG signal of the LM, therefore possibly also including signal from adjacent muscles.

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