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Evaluation of Specific Stabilizing Exercise in the Treatment of Chronic Low Back Pain With Radiologic Diagnosis of Spondylolysis or Spondylolisthesis

[Clinical Studies - Diagnosis]

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Outline

Graphics

Abstract^

Study Design. A randomized, controlled trial, test-retest design, with a 3-, 6-, and 30-month postal questionnaire follow-up.

Objective. To determine the efficacy of a specific exercise intervention in the treatment of patients with chronic low back pain and a radiologic diagnosis of spondylolysis or spondylolisthesis.

Summary of Background Data. A recent focus in the physiotherapy management of patients with back pain has been the specific training of muscles surrounding the spine (deep abdominal muscles and lumbar multifidus), considered to provide dynamic stability and fine control to the lumbar spine. In no study have researchers evaluated the efficacy of this intervention in a population with chronic low back pain where the anatomic stability of the spine was compromised.

Methods. Forty-four patients with this condition were assigned randomly to two treatment groups. The first group underwent a 10-week specific exercise treatment program involving the specific training of the deep abdominal muscles, with co-activation of the lumbar multifidus proximal to the pars defects. The activation of these muscles was incorporated into previously aggravating static postures and functional tasks. The control group underwent treatment as directed by their treating practitioner.

Results. After intervention, the specific exercise group showed a statistically significant reduction in pain intensity and functional disability levels, which was maintained at a 30-month follow-up. The control group showed no significant change in these parameters after intervention or at follow-up.

Summary. A "specific exercise" treatment approach appears more effective than other commonly prescribed conservative treatment programs in patients with chronically symptomatic spondylolysis or spondylolisthesis.

Lumbar instability is considered to be a significant factor in patients with chronic low back pain (CLBP).[15] However, there is considerable debate as to what exactly constitutes spinal instability.[46] Panjabi [46] redefined spinal instability in terms of a region of laxity around the neutral resting position of a spinal segment called the "neutral zone." This neutral zone is shown to be larger with intersegmental injury and intervertebral disc degeneration [30,38,45] and smaller with simulated muscle forces across a motion segment.[9,30,45,62] In this way, the size of the neutral zone is considered to be an important measure of spinal stability. It is influenced by the interaction between what Panjabi [46] described as the passive, active, and neural control systems: The passive system constituting the vertebrae, intervertebral discs, zygapophyseal joints, and ligaments; the active system constituting the muscles and tendons surrounding and acting on the spinal column; and the neural system comprising the nerves and central nervous system, which direct and control the active system in providing dynamic stability.[46] Panjabi [46] then defined spinal instability as a significant decrease in the capacity of the stabilizing systems of the spine to maintain intervertebral neutral zones within physiologic limits, so there is no major deformity, neurologic deficit, or incapacitating pain.

One of the limitations in the clinical diagnosis of lumbar instability lies in the difficulty to detect accurately abnormal or excessive intersegmental motion, because conventional radiologic testing is often reported to be insensitive and unreliable.[12,47] Traditionally, the radiologic diagnosis of spondylolisthesis, in patients with CLBP attributable to these findings, has been considered to be one of the most obvious manifestations of lumbar instability,[17,40,47] with a number of studies reporting increased translational and rotational motion occurring segmentally in the presence of this condition and also with spondylolysis.[15,16,31,37,39,64]

A wide range of conservative interventions has been advocated for the treatment of this condition when it is chronically symptomatic. These interventions include orthotic bracing, flexion exercises, abdominal trunk curls, hamstring stretching, pelvic tilt exercises, and general aerobic exercise such as swimming and walking.[4,7,21,23,58] However, few clinical trials have evaluated the effectiveness of these different conservative measures for this clinical problem that may result in surgical fusion.[22,40]

A recent focus in the physiotherapy management of patients with CLBP has been the specific training of muscles surrounding the lumbar spine whose primary role is considered to be the provision of dynamic stability and segmental control to the spine.[48] These are the deep abdominal muscles (internal oblique [IO] and transversus abdominis [TA]) and the lumbar multifidus (LM). The importance of LM muscle regarding its potential to provide dynamic control to the motion segment in its neutral zone is now well acknowledged.[19,30,45,62] The deep abdominals, in particular the TA, are primarily involved in the maintenance of intraabdominal pressure, while imparting tension to the lumbar vertebrae through the thoracolumbar fascia.[9-11,61] It is considered that the role of the deep abdominal muscles acting in co-contraction with the LM is to provide a stiffening effect on the lumbar spine through its attachment to the thoracolumbar fascia, in conjunction with an increase in intraabdominal pressure.[2] In addition, there is increasing evidence that these muscles are preferentially affected in the presence of low back pain (LBP),[25,26] CLBP,[6,28,29,51] and lumbar instability.[32,56,57]

Richardson and Jull [48] proposed that the specific submaximal training of these "stability" muscles of the lumbar spine and the integration of this training into functional tasks decrease both pain and functional disability in those suffering from mechanical LBP. Clinically, this approach appears particularly effective where the segmental stability of the lumbar spine has been compromised. Until this time, no study had evaluated the benefit of specifically training these muscles in patients with CLBP, where the segmental stability of the lumbar spine has been compromised. On this basis, it was hypothesized that, where the integrity of the passive stabilizing structures of the lumbar spine has been compromised, such as in chronically symptomatic spondylolysis and spondylolisthesis, the neuromuscular system may play an important role in providing dynamic stability to the segment.

Methods^

The aim of the current study was to evaluate the effectiveness of specific "stabilizing" exercises in the treatment of patients with CLBP whose symptoms were considered attributable, based on radiologic diagnosis, to spondylolysis or spondylolisthesis. These exercises were directed primarily at the deep abdominal muscles, with co-activation of the LM proximal to the pars defect.

Patients. Ethical approval for the study was granted by the Human Ethics Review Committee of Curtin University of Technology, Western Australia. Criteria for inclusion in the study was restricted to 44 patients of either gender between the ages of 16 and 49 whose LBP symptoms (with or without pain extension into the lower limbs) were recurrent and had persisted longer than 3 months with no sign of abating. The patients were selected on the basis of their symptoms and clinical presentation being considered attributable to the radiologic diagnosis of isthmica spondylolysis or spondylolisthesis by their treating medical specialist.[41] The radiologic diagnosis of isthmica spondylolysis or spondylolisthesis was determined by a consultant radiologist after oblique and lateral view radiographs or reverse-gantry-view computed tomography scanning of the lumbar spine. The grade of defect was determined from lateral view radiographs using the method described by Meyerding.[36] The grades of spondylolisthesis for patients in both groups are outlined in Table 1.

Table 1. Subject Characteristics Upon Entry to the Study

Patients were excluded from entry to the trial if they had: a clinical presentation considered not attributable to the presence of the spondylolysis or spondylolisthesis by the treating medical specialist; a diagnosed psychologic illness; difficulty understanding English, precluding them from answering the questionnaires; undergone spinal surgery; or a diagnosed inflammatory joint disease or displayed overt neurologic signs (sensory or motor paralysis). Patients were withdrawn from the study if they withdrew their consent, showed a lack of cooperation and motivation to carry out the intervention (indicated by less than 50% compliance as measured by the patient compliance form), or showed any persistent exacerbation of their symptoms. Patients were recruited from general and specialist medical practices, pain management clinics, and physiotherapy practices in the Perth metropolitan area.

Study Design. A randomized, controlled clinical trial, test-retest design with two treatment groups and a blind investigator was used. At entry to the trial, patients signed an informed consent form and then undertook the testing procedure (described later), performed by an independent investigator blind to group allocation. After completion of the initial testing, the patients were assigned randomly to either the specific exercise group (SEG) or a control group (CG). Randomization was performed independently. Cards numbering from 1 to 44 were shuffled in a container and, in a blinded manner, alternately placed into either the SEG or CG. In this way, 22 cards were allocated randomly to either group. During the following 4-month period, as patients were recruited, they were allocated to either group concordantly. The intervention period was 10 weeks. At the completion of the intervention period, patients were again tested by the same investigator, blind to group allocation. Subjects were then reassessed by postal questionnaire for a 3-, 6-, and 30-month follow-up. The 30-month follow-up questionnaire also required subjects to report whether they had received treatment or regularly took medication for their LBP during the previous 12 months.

Forty-two patients completed the trial. One CG patient failed to return for retesting, and one SEG patient was excluded because of failure to comply with the exercise intervention, as defined by a subject compliance sheet. Two SEG patients were lost at the 30-month follow-up. One could not be contacted because of a change in address. The other SEG patient underwent spinal fusion surgery for spondylolisthesis 18 months after the intervention period and therefore was excluded from the 30-month follow-up. One CG patient was lost at the 3-month follow-up because of a change in address, another was lost at 6 months because of an interstate move, with no contact address given. Three other patients were lost at the 30-month follow-up because they were unable to be contacted due to changes in address. One patient also was excluded from the CG at the 30-month follow-up because of undergoing the specific exercise intervention 18 months earlier. The group characteristics at entry to the trial are described in Table 1.

Measures. Before measures were carried out, each patient's height and weight was assessed and a brief history was taken, noting age, mode of onset of symptoms, duration of symptoms, and treatment history. All measures used were validated previously and shown to have acceptable reliability. These were:

1. **Pain measures:** The short form McGill pain questionnaire was used to assess each patient's average symptoms during the previous 2 weeks. This questionnaire includes: (a) a visual analogue pain scale, (b) a pain descriptor scale, and (c) a pain body chart. This was shown to be sufficiently sensitive to demonstrate differences due to treatment at statistical levels.[35] Average weekly medication intake also was reported.
2. **Functional measures:** The Oswestry disability questionnaire was used to give a percentage score that indicated each patient's level of functional disability. This questionnaire is used widely to monitor treatment affect with regard to changes in the functional mobility of patients with CLBP and is sufficiently sensitive to monitor these changes.[14,59]
3. **Lumbar spine and hip sagittal range of movement in standing:** This was measured using a Cybex Electronic digital inclinometer (Cybex, Ronkonkoma, NY). The repeat-ability of the inclinometer for measuring lumbar curvature in the population with CLBP has been established and validated against lumbar spine radiographs.[1,33,54] The testing procedure was standardized (as described by Williams et al [63]) to ensure its reproducibility, and was performed as described by Mayer et al.[33] The upper inclinometer reading (T12) represented the gross spinal motion, and the pelvic inclinometer reading (line bisecting the posterior superior iliac spines) measured the pelvic or hip motion. The true lumbar motion was obtained from a subtraction of the pelvic motion from the gross motion, expressed in angular degrees of flexion and extension.[1]
4. **Abdominal muscle recruitment patterns:** For the purpose of this study, surface electromyography

analysis of the IO and rectus abdominis muscles was performed during the abdominal drawing in maneuver.[49] This maneuver has been found in the healthy muscles to activate the deep abdominal muscles with minimal activity of the rectus abdominis.[43,60] In the population with CLBP, an inability to isolate the activation of IO relative to rectus abdominis has been reported.[43] The methods and results of this aspect of the trial have been reported separately.[42]

Intervention. The SEG underwent a 10-week treatment program directed on a weekly basis by one of four manipulative physiotherapists who practice in different parts of the Perth metropolitan area. All therapists had significant experience and expertise in the specific exercise approach to treatment of the low back region. The treatment approach given was standardized such that all therapists followed the guidelines as follows:

The intervention involved patients being taught exercises designed to:

1. Train the specific contraction of the deep abdominal muscles, without substitution from large torque producing muscles such as rectus abdominis and external oblique, using the abdominal drawing in maneuver.[48]
2. Train the specific contraction of deep abdominal muscles with co-activation of LM proximal to the pars defect, as described by Richardson and Jull.[48]

The holding time for these exercises was increased gradually, in conjunction with a pressure biofeedback monitor, to the point where patients were able to perform 10 contractions with 10-second holds. It was stressed that these exercises are precise isometric contractions involving low levels of maximum voluntary contraction, to ensure that subtle patterns of muscular substitution were prevented.[48]

Once an accurate and sustained contraction of these muscles was achieved, the exercises were progressed by applying low load on the muscles by means of adding leverage through the limbs. Subjects were required to perform the exercises at home on a daily basis. The exercise program was designed to take approximately 10-15 minutes. Subjects also completed a daily exercise sheet to monitor their compliance.

Once accurate activation of the co-contraction patterns (1 and 2) was achieved without synergistic substitution, they were incorporated immediately into functional holding postures and activities known to previously aggravate the subjects symptoms. Subjects were encouraged to activate these muscles regularly during daily activities, particularly in situations where they anticipated or experienced pain or felt unstable. This aimed to enhance the dynamic stability of the lumbar spine in a functionally specific manner for each individual. In a practical sense, if the subject complained of the onset of symptoms in sustained positions such as sitting and standing, they were trained to perform a gentle sustained co-contraction in these positions throughout the day. If, however, the complaint was an arc of pain during lumbar flexion, co-contraction was initiated during this movement pattern. The same was the case for twisting of the spine and extension activities. Once appropriate activation was trained during dynamic movement tasks, this pattern was incorporated into light aerobic activity such as walking and previously aggravating activities of daily living, at the speed the activity demanded.

The CG underwent treatment throughout a 10-week period, directed by each patient's medical practitioner. This consisted of all but one of the patients carrying out regular weekly general exercise (such as swimming [10], walking [7], and gym work [2]). Eight of the patients regularly attended other treatment providers, which involved supervised exercise programs and the application of local pain-relieving methods such as heat, massage, and ultrasound. Nine of the subjects also reported performing trunk curl exercises on a regular basis (several times a week), as directed by their treating practitioner.

Data Management^

1. Repeated measures analysis of variance were performed:
A. on the baseline data, to assess for group differences at entry to the trial.
B. to assess change within each group after the intervention period.
C. on the change scores (the difference between the follow-up score and the baseline score for each individual) of each measure, to assess differences between the two groups after the intervention period.
2. A two-way repeated measures analysis of variance was carried out on the questionnaire data, to assess differences within and between the groups after the intervention and at the 3-, 6-, and 30-month follow-up. If statistical significance was achieved, contrasts were performed, using mean comparisons to determine where the change occurred.
The level for statistical significance was set at the 95% confidence limit. Statistical analysis was performed using Super-Anova software package (Abacus Concepts, Berkeley, CA) for Macintosh.

Results^

Statistical analysis revealed no statistically significant differences between the groups on entry to the trial. Analysis of differences within each group after the intervention period revealed significant differences in the SEG after the intervention period, with a decrease in pain intensity ($F_{(1,20)} = 75.5$, $P < 0.0001$) and pain descriptor scores ($F_{(1,20)} = 35.8$, $P < 0.0001$), and a reduction in functional disability levels ($F_{(1,20)} = 49.1$, $P < 0.0001$) (Table 2). With regard to weekly medication intake, nine SEG patients reported regularly taking analgesic or anti-inflammatory medication on a weekly basis before intervention, whereas only two subjects reported doing so afterward. Two SEG patients also reported regular use of transcutaneous nerve stimulation for pain relief before the intervention, but not afterward. The CG, however, had no significant difference, on the basis of pain intensity scores and functional disability levels after the intervention period. A statistically significant, but clinically insignificant, reduction in pain descriptor scores ($F_{(1,20)} = 5.3$, $P = 0.0316$) was detected in the CG (Table 2). With regard to weekly medication intake, nine CG patients reported regularly taking medication before intervention, and nine reported still taking them afterward.

Table 2. Means, Standard Deviations, and Within and Between Group Differences for the Control Group and Specific Exercise Group Following the Intervention Period

When differences between the groups were analyzed based on the degree of change in each group after intervention, a statistically significant difference was seen, reflecting reductions in pain intensity ($F_{(1,20)} = 55.5$, $P < 0.0001$), pain descriptor scores ($F_{(1,20)} = 8.1$, $P = 0.0088$), and functional disability ($F_{(1,20)} = 34$, $P < 0.0001$) in the SEG when compared with the CG (Table 2, Figures 1-3).

Figure 1. Visual Analogue Scale pain intensity scores for the control group and specific exercise group after intervention and at long-term follow-up (means and standard deviations).

Figure 2. Pain descriptor scores for the control group and specific exercise group after intervention and at long-term follow-up (means and standard deviations).

Figure 3. Oswestry functional disability scores for the control group and specific exercise group after intervention and at follow-up (means and standard deviations).

With regard to the lumbar spine sagittal mobility, no significant change was detected within or between the groups after intervention. However, the SEG showed significant increases in hip flexion ($F_{(1,20)} = 6.2$, $P = 0.0215$) and extension mobility ($F_{(1,20)} = 6.8$, $P = 0.0165$) after the intervention period, whereas no significant change was seen on this basis in the CG. Evaluation for group differences based on change scores revealed a significant increase in hip flexion mobility ($F_{(1,20)} = 9.2$, $P = 0.0066$) in the SEG after intervention when compared with the CG (Table 2).

Analysis of the follow-up data revealed significant differences between the SEG and CG on the basis of pain intensity ($F_{(1,32)} = 14.4$, $P = 0.0006$), with an interaction effect occurring ($F_{(1,32)} = 14.6$, $P = 0.0001$) (Table 3, Figure 1). Contrasts performed on the mean comparisons revealed that the significant reduction in pain intensity in the SEG, after the intervention, was maintained at the 30-month follow-up, where no significant change occurred in the CG during the follow-up period (Table 3, Figure 1). Analysis of group differences on the basis of the pain descriptor scores revealed significant differences between the SEG and CG ($F_{(1,32)} = 6.1$, $P = 0.0187$, with an interaction effect occurring ($F_{(1,32)} = 14.6$, $P = 0.0045$) (Table 3, Figure 2). Contrasts performed on the mean comparisons revealed that the significant reduction in pain descriptor scores in the SEG, after the intervention, was maintained at the 3- and 6-month follow-up, but increased slightly at the 30-month follow-up. No significant change occurred in the CG during the follow-up period. Analysis of the Oswestry functional disability scores revealed significant differences between the SEG and CG ($F_{(1.32)} = 4.2$, $P = 0.0481$), with an interaction effect occurring ($F_{(1,32)} = 8.01$, $P = 0.0001$). Contrasts carried out on the mean comparisons revealed that the significant reduction in functional disability in the SEG, after the intervention, was maintained at the 30-month follow-up. Again, no significant change occurred in the CG during the follow-up period (Table 3, Figure 3). At the 30-month follow-up, two CG patients reported receiving treatment and three reported taking medication on a regular basis for their LBP during the previous 12 months. Of the CG patients, nine reported receiving regular treatment and eight reported taking medication on a regular basis for their LBP during the same period.

Table 3. Means, Standard Deviations (SD), and Within and Between Group Differences for the Control Group and Specific Exercise Group Following the Intervention Period and at Follow-Up

Discussion^

The results of this study support the initial hypothesis that specific exercise training of the "stability" muscles of the trunk is effective in reducing pain and functional disability in patients with chronically symptomatic spondylolysis and spondylolisthesis. Analysis of the pain and functional disability change score data in the SEG revealed that there was no difference in treatment outcome for patients with spondylolysis compared with those with spondylolisthesis. This treatment approach was more effective than other conservative treatment approaches carried out by the CG, which mainly involved general exercise programs. These findings support the Panjabi's [46] hypothesis that the stability of the lumbar spine is dependent not solely on the basic morphology of the spine, but also the correct functioning of the neuromuscular system. Therefore, if the basic morphology of the lumbar spine is compromised, as in the case with symptomatic spondylolysis and spondylolisthesis, the neuromuscular system may be trained to compensate, to provide dynamic stability to the spine during the demands of daily living.

The recent research of Gardner-Morse et al [18] lends support to Panjabi's hypothesis, revealing that a reduction of motion segment stiffness of as little as 10% can compromise the stability of the spine. They concluded that factors such as pathologic reduction in motion segment stiffness, as well as poor neuromuscular control of the spinal musculature and reduction of muscle stiffness, could result in a state of spinal instability. Consistent with these findings, Cholewicke and McGill [8] reported that lumbar stability is maintained *in vivo* by increasing the activity (stiffness) of the lumbar segmental muscles, and highlighted the importance of motor control to coordinate muscle recruitment between large trunk muscles and small intrinsic muscles during functional activities, to ensure stability is maintained.

The concept of different trunk muscles playing differing roles in the provision of dynamic stability to the spine was proposed by Bergmark.[5] He hypothesized the presence of two muscle systems in the maintenance of spinal stability. The global muscle system consists of large, torque-producing muscles that act on the trunk and spine without being directly attached to it. These muscles include the rectus abdominis, external oblique, and the thoracic part of lumbar iliocostalis, and they provide general trunk stabilization, but they are not capable of having a direct segmental influence on the spine. The local muscle system consists of muscles that directly attach to the lumbar vertebrae and are responsible for providing segmental stability and directly controlling the lumbar segments. By definition, the LM, TA, and posterior fibers of the IO form part of this local muscle system.

The TA, IO, and LM are muscles known to be tonically active during upright postures and during active spinal movements,[9,44,60,65] with the TA capable of tonic activity irrespective of trunk position, direction of movement, or loading of the spine.[9] Recent research indicates that the TA is also the first trunk muscle to become activated before movement initiation [27,28] or perturbation,[10] and is the primary muscle involved in the initiation and maintenance of intraabdominal pressure.[9,11] The TA and the posterior fibers of the IO also have a direct potential stabilizing role on the lumbar spine by way of their attachment to the lumbar spine through the thoracolumbar fascia.[61] Of the back extensor muscles, the LM is considered to have the greatest potential to provide dynamic control to the motion segment, particularly in its neutral zone.[19,30,34,45,62] The co-contraction of the deep abdominal muscles with the LM has the potential to provide a dynamic corset for the lumbar spine, enhancing its segmental stability during functional tasks and the maintenance of neutral spinal postures, irrespective of position of the spine.[2]

Research investigating changes to the neuromuscular system in the presence of CLBP and lumbar instability indicates that it is the local muscle system that is particularly vulnerable to dysfunction. Several studies have highlighted the presence of specific dysfunction in the LM [6,25,26,32,51,52,55-57] and, more recently, the deep abdominal muscles [28,29] in the population with CLBP. Such changes appear to result in altered patterns of synergistic control or coordination between trunk muscles.[13,20,28,43] These findings support those of clinicians who report the presence of altered patterns of motor control between trunk synergists, such that global system muscles have a tendency to substitute or dominate over the impaired function of local system muscles in the population with CLBP.[43,48,50] It could be argued that the presence of an "unstable" spondylolysis or spondylolisthesis, coupled with this form of dysfunction in the neuromuscular system, could render the motion segment doubly vulnerable during functional tasks.

Specific exercises directed at the local muscle system have been advocated by physiotherapists as an effective means of treating CLBP conditions by enhancing the dynamic stability of the lumbar spine.[48] Recently, Hides et al [24] carried out a randomized controlled trial in a group of subjects after their first episode of acute LBP who displayed a segmental loss of LM at the symptomatic level, detected by ultrasonography. Intervention group patients were treated with specific exercises similar to that carried out in this trial, while CG subjects received medical treatment. At a 1-year follow-up, patients in the SEG reported a significant reduction in pain recurrence when compared with control subjects. Other researchers reported positive effects from specific exercise in the treatment of patients with CLBP, but not during randomized controlled conditions.[32,53] This study is the first randomized controlled trial to evaluate this form of exercise intervention in the CLBP population when the stability of the spine has been compromised.

The specific exercise approach used in this trial is very different to general exercise approaches commonly advocated in the rehabilitation of patients with CLBP. This approach aims, in the early stages, to specifically train the isometric co-contraction of the deep abdominal muscles and LM proximal to the pars defect, with minimal co-activation of global system muscles. These co-contractions involve a high level of specificity and patient compliance and low levels of maximal voluntary contraction. In all of the SEG patients, an isolated pattern of activation of the deep abdominals and co-activation with LM was reported to be very difficult to achieve because of dominant substitution of other trunk synergists such as rectus abdominis, external oblique, the long back extensors, and difficulty controlling breathing. It was reported that, during the trial, several subjects took as long as 4 or 5 weeks of specific training before an accurate pattern of co-contraction could be achieved. The greater the effort or higher the level of voluntary contraction to the motor task, the more likely the patients were to alter the motor pattern by activating other muscles. Low load was only introduced through the limbs when the patients could isolate the contraction and hold it 10 times for 10 seconds.

Once this pattern of co-contraction was achieved, it was immediately incorporated into dynamic tasks or static holding postures, as determined by the subject's complaint. Subjects were encouraged to perform the contractions many times throughout the day, particularly in situations where they experienced or anticipated pain or felt "unstable." This was deemed essential to reinforce engram motor programming, such that the patterns of co-contraction would eventually occur automatically, without need for conscious control during activities and habitual postures of daily living.[53] Only once was this pattern of muscle co-contraction isolated or did many of the subjects report a reduction in symptoms when able to integrate it into static postures (such as sitting, standing and sustained flexion), functional activities (such as bending, twisting, and lifting), and aerobic activities (such as walking, swimming, or running). This ability to control pain reported by many subjects when performing the muscle co-contraction appeared to act as a powerful biofeedback to reinforce the integration of this muscle control into functional tasks.

This form of specific training at low levels of activation supports the recent findings of Cholewicke and McGill [8]-that only low levels of maximal voluntary contraction of the segmental muscles are required to ensure the stability of the spine *in vivo.* It is also consistent with assertions that motor learning and control are not simply a process of strength training, but depend on patterning and inhibition of motor neurons, with the acquisition of skills occurring through selective inhibition of unnecessary muscular activity, as well as the activation of additional motor units.[3,13]

The range of spinal motion in both groups remained unchanged after the intervention period. The majority of subjects had full spinal mobility but complained of through-range movement pain, or pain in neutral-sustained postures rather than end-of-range symptoms. In addition, it was commonly reported that, in the SEG, the addition of the specific muscle co-contraction significantly diminished or abolished symptoms in many subjects during these previously painful movements and postures. It could be argued that these observations lend support to the Panjabi's [46] view that lumbar instability is a condition that influences active neutral zones more than the total range of spinal motion.

Arguably, the most significant finding of this study was the sustained reduction in symptoms and functional disability levels in the SEG at the 3-, 6-, and 30-month follow-ups. In addition, at the 30-month follow-up, SEG patients reported a reduced need for medication and medical treatment during the preceding 12 months, compared with patients in the CG. Many of the SEG patients, at follow-up, reported that they no longer needed to perform the formal exercises they had been taught, but simply continued to co-activate the muscles during functional activities of daily living. One reason for this maintained improvement may lie in the findings of the surface electromyography data that provided evidence of both a conscious and subconscious change in the pattern of activation of the abdominal muscles, with an increase in the levels of activation of the IO relative to the rectus abdominis in the SEG.[42] The findings of this study support the view that a change in the motor program had occurred in the SEG after the intervention, such that the automatic pattern of recruitment of the abdominals to stabilize the spine during a motor task incorporated higher levels of deep abdominal muscle activity. This appears to represent an enhanced ability, in those in the SEG, to stabilize dynamically their spine during functional tasks. A challenge for future research will be to further investigate the potential of this form of exercise intervention to alter automatic patterns of muscle recruitment within the trunk musculature in pain populations. However, the lack of change in the CG during the 30-month period indicates that the natural outcome for this chronically symptomatic population using other forms of conservative intervention is not positive. Further research is needed to assess the efficacy of this form of intervention in other CLBP populations where the anatomic stability of the lumbar spine has been compromised.

Conclusion^

The findings of this trial support the view that the functional integration of specific exercises directed at the deep abdominals and LM muscles are effective in reducing pain and functional disability in patients with chronically symptomatic spondylolysis or spondylolisthesis. This supports Panjabi's [46] hypothesis, that spinal stability is dependent on an interplay between the passive, active, and neural control systems. Accordingly, where the stability of the basic morphology of the lumbar spine is compromised (such as with symptomatic spondylolysis or spondylolisthesis), specific training of the muscles considered to provide dynamic stability to the lumbar spine may act to maintain the neutral zones of the motion segment within more normal limits during functional activity. In addition, the results of this study indicate that a "specific exercise" treatment approach directed at specific muscles is more effective than other conservative treatment approaches commonly used in patients with this condition. This intervention may provide a significant and viable alternative treatment approach in a patient population where such pathology is commonly treated with surgical fusion. Finally, this treatment approach may also have implications for the wider LBP population when "instability" of the lumbar spine is suspected.

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