# Low Back Exercises: Evidence for Improving Exercise Regimens

Despite the wide variety of exercises that are prescribed for the low back, the scientific foundation to justify their choice is not as complete as one may think, or expect. Thus, the clinician must often call upon "clinical opinion" when selecting exercise. Given that low back tissues may need stressing to enhance their health but too much loading can be detrimental, choosing the optimal exercise requires judgment based on clinical experience and scientific evidence. To assist in developing better exercise programs, this review documents some recent biomechanical evidence from my laboratory and from laboratories of other researchers that has been reported in various publications in an attempt to update clinicians on issues of low back exercise. Among the issues examined are mechanisms of injury; the relative importance of "strength" (ie, maximum force a muscle can produce during a single exertion to create joint torque), "flexibility," and "endurance"; and training to enhance stability. Finally, some specific exercises are described that have been shown to challenge muscle and enhance performance but that are performed in such a way as to minimize loading of the spine to reduce the risk of injury exacerbation. These exercises form a basic program for rehabilitation and maintenance of low back health. [McGill SM. Low back exercises: evidence for improving exercise regimens. *Phys Ther.* 1998;78:754–765.]

**Key Words:** *Exercise, Low back, Lumbar, Pain.*

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As a researcher who works closely with clinicians, I have grown to appreciate the challenges of clinical decision making. Collectively, we are all interested in evidence-based practice and outcomes. The intent of this review is to provide some of the latest research findings that may challenge some current popular thought. For example, we have all heard that sit-ups should be performed with bent knees or that a pelvic tilt should be emphasized when performing several types of low back exercise. An examination of the literature, however, will reveal that the scientific foundation on which many exercise notions are based is quite thin.[1] Instead, "clinical opinion" appears to prevail and often dominates the decision process. This observation is not intended to belittle the expertise developed from clinical practice (as I believe it is very important) but rather to emphasize that choosing an optimal exercise requires the blend of "experience" with "research." The professional challenge for us all is to make wise decisions by balancing research knowledge with clinical experience.

Low back and abdominal exercise regimens are performed for a variety of reasons, but mainly for rehabilitation of the low back, prevention of injury, and as a component of fitness programs. The objective of exercise is usually to stress both damaged tissue and healthy supporting tissues to foster tissue repair while avoiding further excessive loading, which can exacerbate an existing structural weakness. Certain types of low back injuries are characterized by very specific tissue damage and may require quite different exercise rehabilitation programs. For example, persons with a posteriorly herniated disk would do well to avoid full spinal flexion maneuvers, particularly with concomitant muscle activity, because this causes substantial compressive loading and this combination of posture and load appears in laboratory studies to herniate the annulus.[2,3] Yet, this posture is often unknowingly adopted by patients or consciously advocated by clinicians who routinely demand a full pelvic tilt. Another example involves the mechanically unstable spine, where stiffness may be decreased at one joint and which may be accompanied with muscles and a motor control system that are very "unfit." This combination can result in inappropriate muscle activation sequences when performing even relatively simple tasks such as bending over to pick up a pencil.[4] These motor control "errors" appear to compromise spinal stability and may lead to brief opportunities for the spine to buckle,[5] constituting a high risk of injury. To properly address this issue, the question must be asked: What are the stabilizers of the spine, and what is the safest way to train them?

The purpose of this article is to provide some guidance to assist therapists in developing better exercise programs, based on some recent biomechanical evidence from our laboratory and from laboratories of other researchers. In the next section, I describe the methods that have been used to evaluate the effects of exercises on the spine as well as muscles and ligaments associated with the back. This description is followed by a discussion of some mechanisms thought to cause injury. Some concepts for exercise development are then introduced and briefly critiqued, followed by suggestions for an exercise program that has been documented to challenge muscle and enhance performance but in a way as to minimize spinal loading and, therefore, the risk of injury or injury exacerbation.

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## Laboratory Methods to Evaluate Specific Exercises

The low back region is an extremely complex mechanical structure, and direct measurement of tissue loading in vivo is not feasible. The only tenable option for tissue load prediction is to utilize sophisticated modeling approaches. Once tissue loads in vivo have been estimated, they can be applied to spinal specimens in vitro to evaluate tolerance levels and injury mechanisms. Data from both approaches will be presented in this article. Descriptions of the actual methods will be kept brief, although the interested reader is urged to consult Cholewicki and McGill,[5] McGill,[6] McGill and Norman,[7] and Yingling et al[8] for more detail.

Over the last 15 years, our team has been developing a modeling approach that utilizes biological signals to assess muscle use and passive tissue loading.[5–7] The actual anatomical model is a detailed, 3-dimensional representation with over 90 laminae of muscle, approximately 13 representative ligaments at each lumbar joint, and nonlinear elastic disks, all of which deform under loading and under motion as the model mimics the motion of a real instrumented person. Three-dimensional spine kinematics coupled with individual passive tissue deformation relationships are used to quantify passive tissue loading throughout the full range of motion in flexion and extension, lateral bending, and axial twisting. During data collection from an individual, many channels of electromyographic (EMG) signals (usually 14) are placed over the torso musculature to obtain individual muscle load-time histories. The EMG signals are normalized and calibrated to the individual and then modulated (adjusted by several physiological parameters) by known relationships for instantaneous muscle length and the velocity of contraction. This appears to be the only method available that properly considers the co-contracting muscles and recognizes the individual differences and biological variability that people exhibit in muscle use, even between repeated trials by the same person. In this way, a "virtual spine" of a person is created, which moves and activates muscles in the same way as the subject performing a task or specific exercise. This method provides a "dynamic view" of the internal tissue loads together with insight into issues such as the selection and affect of specific exercise.

The major limitation of this approach has been the inaccessibility of the deeper muscles of the spine to measurement by EMG. Recently, McGill et al[9] and Juker et al[10] used EMG to document the activation of the deeper muscles (ie, psoas, quadratus lumborum, and 3 layers of the abdominal wall) using intramuscular electrodes during a wide variety of tasks to overcome this limitation and enable the data reported here.

Methods of actually applying loads to tissues of the spine in vitro are quite specialized, but provide insight into the injury process. Callaghan and McGill[11] attempted to mimic in vivo conditions for testing by developing an "artificial abdomen" in which to test specimens. Furthermore, in our laboratory, we have done most of our testing on the spines of pigs, which are somewhat similar in architecture to the spines of humans and sustain the same injuries but the tolerances need to be scaled up by approximately one third to match human tolerances. Although it can be argued that the pig spine differs from the human spine and is therefore a lower-grade substitute, it has the great advantage of providing groups of specimens that can be matched for age, genetic homogeneity, diet, activity levels, and so forth. These 2 approaches (in vitro and in vivo) were used in several studies reported in the next section.

## Low Back Injury Mechanisms as a Foundation for Designing Exercise Programs

I believe that understanding the mechanism of injury is very important for the formulation of exercise programs and the development of injury-avoidance strategies. The ultimate failure of a tissue (or injury) may result from cumulative trauma produced by repeated application of load, from a sustained load that is applied for a long duration, or from the single application of a very high magnitude of load. Furthermore, the posture of the spine at the time of loading determines which tissue will become irritated or fully injured. For more complete discussion of this important topic, the reader is referred to McGill.[1] Two mechanisms of injury are discussed next, as examples, to build a foundation for developing specific exercise programs.

### *The Old Issue of Stoop Lifting Versus Squat Lifting*

Lifting style has been a topic of debate for many years. For instance, there has been an emphasis in industry to recommend that workers bend their knees and not their back. Many workers prefer to stoop lift, which may be due to the long-recognized fact that there is an increased physiological cost in squatting.[12] Although there have been several attempts to evaluate the issue of stoop-lifting versus squat-lifting postures, these efforts were unable to uncover a clear biomechanical rationale for the promotion of either lifting posture. Perhaps the issue is much more complex. As the spine is flexed during lifting, muscles provide support and supply the torque necessary to maintain the posture. As the spine reaches full flexion, these support responsibilities are shifted from the muscles to the disks and ligamentous tissues.[13] However, the architecture of the lumbar extensor muscles (specifically, longissimus thoracis pars lumborum and iliocostalis lumborum pars lumborum) is also designed to provide resistance to anterior shearing force on the spine,[14] but ligamentous involvement eliminates the muscle's ability to do this. Furthermore, not only do the ligaments reduce the shear support from muscles, but they even add anterior shear to the spine due to their oblique orientation.[15] These shifts in shear loading associated with the fully flexed posture are quite dramatic and can easily cause excessive shear load.[1] In full flexion, not only is anterior shear loading higher, but the ligaments are also at risk of injury.

Adams and Dolan, in an excellent review,[2] suggest that the compressive tolerance of the spine is reduced in the final stages of full spinal flexion. The collective works of Adams and our own tissue work over the years have shown that the type of injury sustained by the intervertebral joint under compressive loading is a function of the posture at the time of loading. For example, if the spine is in a neutral position (or at least not fully flexed), failure will most likely occur to the end-plate. This failure may result in nuclear material squirting through the fractured end-plate and invading the cancellous bone of the vertebral body, or an edge fracture may occur as the fibers of the annulus apply tensile stresses on the end-plate and the vertebra due to their outward radial bulge.[1] Failure of the collagenous fibers of the annulus is rarely observed when the spine is in a neutral position. The collective works of Adams and Dolan[2] and Wilder et al[3] suggest that disk herniation, particularly posterior herniation characterized by annular failure and posterior protrusion of nuclear material, is associated with a fully flexed posture of the spine (which seems to be accelerated by vibration). Avoiding full lumbar flexion appears to provide protection from this type of injury.

The issue of whether to stoop or squat becomes much more complex when one considers the type of injury, the load distribution among the tissues, and the effect of spine posture on the failure tolerance of the spine. A case could be made that the important issue is not whether it is better to stoop lift or to squat lift but rather that emphasis could be placed on getting the load close to the body to reduce the subsequent joint loading and avoid a fully flexed spine. An argument could be made that when an object is too large to fit between the knees, a person should stoop to lift the object, flexing at the hips but maintaining the spine in a neutral position (not fully flexed or extended). There is relevance in this scenario for general exercise prescription and for designing work methods. Avoiding the end range of spinal motion solves a lot of ills—and reduces the risk of injury or reinjury.

### *Instability as a Cause of Injury*

Active motion in the joints of the lumbar spine about any axis is accomplished with large amounts of trunk muscle co-contraction.[16] Such coactivation patterns are counterproductive to generating the torque necessary to support applied loads in a way that minimizes the compressive load imposed on the spine. That is, the muscles are active in order to perform functions other than simply producing torque and movement. Muscle co-contraction is necessary for maintaining stability and preventing buckling of the spinal column.[5] The ligamentous spine (a cadaveric spine stripped of muscle) will fail (buckle) under compressive loading at about 20 N.[17] The spine can be likened to a flexible rod; under compressive loading, it will buckle if not stiffened with active muscle. If the rod (spine), however, has guidewires connected to it, like the rigging on a ship's mast, the rod ultimately experiences more compression but is able to bear a much higher compressive load as it stiffens and becomes more resistant to buckling.

A number of years ago, my colleague, Dr Jacek Cholewicki, and I studied the mechanics of the spines of power lifters while they lifted extremely heavy loads.[18] We used video fluoroscopy to view the lumbar spine and movement in the sagittal plane. Full flexion of each joint in the spine of each power lifter was measured by first asking the subject to flex at the waist and hang the upper body against gravity with no load in the hands. During their lifts, even though the subjects outwardly appeared to fully flex their spines, their spines were 2 to 3 degrees per lumbar joint from full flexion, thus explaining how they could lift magnificent loads without sustaining the type of injury that we suspected is linked with full flexion.[18] By chance, however, we recorded an injury occurring. This particular lifter dropped the weight and complained about pain. Measurements of the fluoroscopy videotape revealed a local instability. Specifically, the L3-4 joint temporarily approached the calibrated full flexion angle and then exceeded it by 0.5 degree while all other joints maintained their positions. To our knowledge, this was the first observation reported in the scientific literature documenting the presence of a local instability occurring at a single lumbar joint. Cholewicki proceeded to rigorously define lumbar stability mathematically[5] and then quantified levels of stability of the lumbar spine throughout a reasonably wide variety of loading tasks.

The spine appears to be most prone to failure due to instability when the loading demands are low and the major muscles are not activated to high levels, or when very high loads are experienced.[5] In the case of the power lifter,[18] the loading was extreme. Nonetheless, it appears that the chance of the motor control error, which results in a short and temporary reduction in activation to one of the intersegmental muscles, would cause rotation of just a single joint to a point where passive or other tissues become irritated or possibly injured. Cholewicki et al[19] found that sufficient stability is achieved by the spine, at least during upright unloaded tasks, by co-contracting the muscles of the abdominal wall to about 2% to 3% of maximal voluntary contraction (MVC). A patient who has lost normal joint stiffness due to injury, however, may require up to 6% MVC activation to maintain sufficient stability and avoid buckling. Gardner-Morse et al[20] have suggested that even higher values of muscle co-activation may be required, and the necessary muscle contraction level may present a challenge to the endurance capacity for some people's muscles. In addition, the very small intersegmental muscles (ie, the rotators and the intertransversarri muscles) may be of special interest. There is evidence to suggest that these muscles are rich in muscle spindles (at least 4 to 7 times more muscle spindles than in the multifidus muscles).[21] It would seem that these "intersegmental muscles" can produce small forces but in particular sense vertebral position via rich spindle densities—but are not functioning to produce functional force. Therefore, because of their minimal cross-sectional area, they act as position transducers for each lumbar joint to enable the motor control system to control overall lumbar posture and avoid injury. Once again, these findings are relevant to those responsible for injury management and the development of exercise programs, as spine stability and fitness of the motor control system appear to be important considerations.

## Toward Developing Scientifically Justified Low Back Rehabilitation Exercises—The Evidence

Choosing the best exercise, I believe, requires evidence about tissue loading and knowledge of how injuries occur to specific tissues.[10,22,23] Ideally, exercises that challenge muscle but that impose minimal joint loads should seem most attractive. Such exercises, however, may not always be best because they may produce a high relative rate of muscle loading compared with joint loading, although the joint load also may be excessive. Because there is no single exercise to challenge all flexor or extensor muscles simultaneously, several exercises are required to train all the muscles of the lumbar torso. In addition, the exercises that best suit an individual may depend on a number of variables such as the history of previous spinal injuries, the mechanism of the current injury, fitness level, training goals, and other factors specific to the individual. Depending on the purpose of the exercise program, however, several principles appear to apply. For example, I contend that an individual beginning a post-injury program should be advised to avoid loading the spine throughout the range of motion (at least for joint or soft tissue injuries), whereas a trained athlete may indeed achieve higher performance levels by doing so. The selection procedure of the exercises in this review was biased toward safety—minimizing spinal loading while presenting muscles with a sufficient load to lead to a training stimulus.

### *Sit-ups With Bent Knees?*

We have all been aware of the suggestion to perform sit-ups and other flexion exercises with the knees and hips flexed. An often-heard clinical belief is that this disables the psoas muscle or changes the line of action of the psoas muscle to reduce the compressive load on the low back, but recent data challenge this assumption. Recent data based on magnetic resonance imaging[24] demonstrated that the psoas muscle's line of action does not change due to lumbar or hip positioning (except at L5-S1) because the psoas muscle attaches to each vertebrae and "follows" the changing orientation of spine, not of the hip or knees. There is no doubt that the psoas muscle is shortened when the hip is flexed, modulating force production (we think force is reduced, although psoas muscle rest length remains unknown). But the question remains: Is there a reduction in load on the spine with the knees bent? Recently, I examined 12 young men with the laboratory technique described previously and observed no major difference in lumbar load as the result of bending the knees (average moment of 65 N·m with both straight legs and bent knees; compression: 3,230 N with straight legs, 3,410 N with bent knees; shear: 260 N with straight legs, 300 N with bent knees).[25] The psoas muscle, acting primarily as a hip flexor, must contribute to the production of hip flexion torque. The resultant compressive loads in excess of 3,000 N certainly raise questions of safety. This type of quantitative analysis raises the question: Is the issue of whether to perform sit-ups with bent knees or with straight legs as important as the issue of whether to perform sit-ups at all? In a subsequent section, I will contrast sit-ups with curl-ups.

### *The Pelvic Tilt*

Posterior pelvic tilts are routinely recommended by some therapists when prescribing certain exercises (as evidenced in many exercise and lifting manuals) although data supporting this recommendation are difficult to find. The pelvic tilt causes the spine to flex and preloads the annulus and posterior ligaments,[2] which appears to be associated with an increased risk of injury. A "neutral" spine (neutral lordosis; that is, neither hyperlordotic nor hypolordotic) achieves elastic equilibrium and minimizes passive tissue forces on the spine to reduce the risk of injury while the spine is under load from muscular contractions. I believe the correct general rule of thumb is to preserve the normal low back curve (similar to that of upright standing) or some modification of this posture that results in minimal pain. Because the posterior pelvic tilt preloads the spine, it would appear to be unwise to universally recommend the pelvic tilt during exercise that loads the spine.

### *Issues of Flexibility*

I contend that the emphasis to be placed on training for spinal flexibility depends on the individual's injury history (eg, type of injury, exercise goal). Despite the notion held by some people, there are few data to support a major emphasis on trunk flexibility to improve back health and to lessen the risk of injury. Some exercise programs that have included loading of the torso throughout the range of motion (in flexion and extension, lateral bending, or axial twisting) have had poorer outcomes,[26,27] and greater spinal mobility, in some cases, has been associated with low back trouble.[28,29] Furthermore, spinal flexibility has been shown to have little predictive value for future low back trouble.[28,30] The evidence I have presented in this article suggests that the end range of motion for specific injuries should be contraindicated. Some very successful rehabilitation programs appear to emphasize trunk stabilization through exercise with a neutral spine,[31] while emphasizing mobility at the hips and knees. Bridger et al[32] demonstrated mobility advantages for sitting and standing, and McGill and Norman[33] outlined advantages for lifting. Clearly, flexible hips and knees are required to adopt postures that conserve the low back.

For these reasons, I believe that torso flexibility exercises should be limited to unloaded flexion and extension (Fig. 1) for those individuals who are concerned with safety and not for those individuals who are interested in specific athletic performance. Flexibility of the spine may be more desirable in athletes who have never had a back injury. It would appear to be wise to cycle the spine through the full range of flexion and extension in a slow, smooth motion. This act results in less viscosity (and stiffness) in the spine,[34] reducing the passive stresses that otherwise would develop. Even though I argue that spinal flexibility may be de-emphasized, I contend that sufficient hip and knee flexibility is imperative to spare the spine excessive motion during the tasks of daily living. (Several ergonomics textbooks demonstrate work techniques to minimize loading and achieve joint conservation; McGill and Norman[33] have offered data and discussion toward this objective.) Hip and knee flexibility may be achieved through several movements that emphasize the maintenance of a neutral spine (therapists reading this article will have more expertise than I have on this topic).

### *Issues of Muscle Performance ("Strength" Versus "Endurance")*

Given the lack of consensus regarding operational definitions of "strength" and "endurance," we shall proceed with the term "strength" to refer to the maximum force a muscle can produce during a single exertion to create joint torque and with the term "endurance" to refer to the ability to maintain a force for a period of time. Muscle performance includes "strength" and "endurance," which in my opinion, must be recognized as distinctly different, especially for designing specific exercise programs. For example, it is well-documented that those persons with previous back injuries have lower muscle "strength,"[35] but very few studies (longitudinal) have linked reduced "strength" with the risk of a first-time low back injury. The few studies available suggest that "endurance" has a much greater prophylactic value than "strength."[36] Compromised "endurance" appears to be involved in many injuries that occur during submaximal tasks (eg, picking up a pencil). Furthermore, we are beginning to recognize the need for individuals with injured spines (who have lost some passive stiffness at a joint) to achieve sufficient stability with abdominal wall (external and internal oblique and transverse abdominis) muscle co-contraction up to activation levels of 6% MVC in upright postures[19] and probably higher when bending over. This example illustrates the challenge for

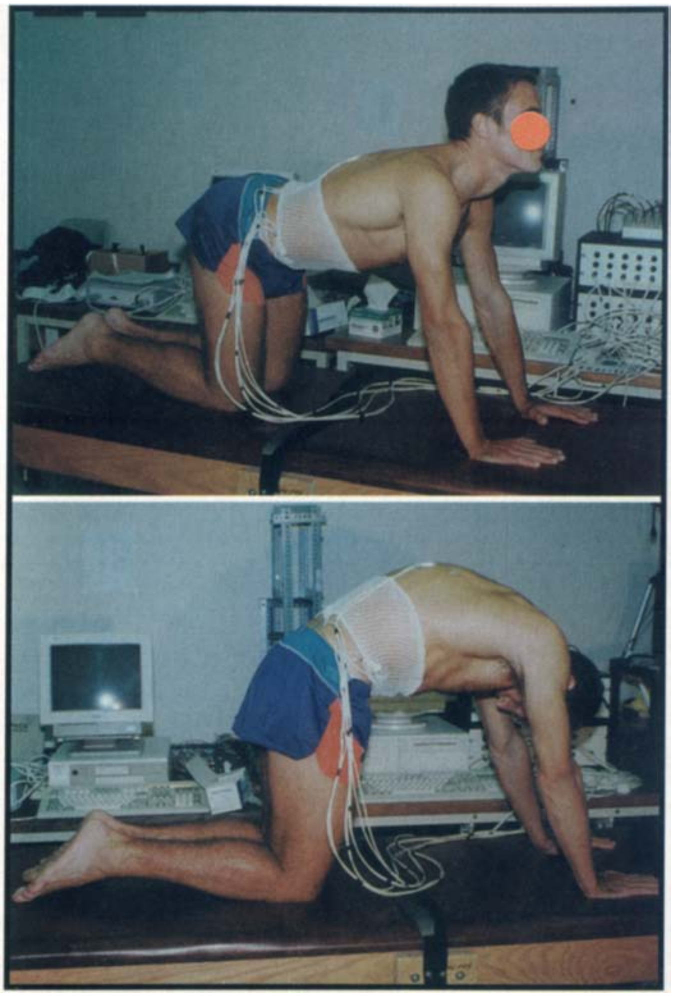

**Figure 1.**
The "cat stretch" is performed by slowly cycling through full spinal flexion (top panel) to full extension (bottom panel). Spinal mobility is emphasized rather than "pressing" at the end range of motion. This exercise provides motion for the spine, with very low loading of the intervertebral joints.

**Table 1.**
Low Back Moment, Muscle Activity, and Lumbar Compressive Load During Several Types of Abdominal Exercises[a]

| | | Muscle Activation | | |
|---|---|---|---|---|
| | Moment (N·m) | Rectus Abdominis Muscle (%MVC) | External Oblique Muscle (%MVC) | Compression (N) |
| Straight-leg sit-up | 148 | 121 | ~70 | 3,506 |
| Bent-knee sit-up | 154 | 103 | 70 | 3,350 |
| CSTF curl-up, feet anchored | 92 | 87 | 45 | 2,009 |
| CSTF curl-up, feet free | 81 | 67 | 38 | 1,991 |
| Quarter sit-up | 114 | 78 | 42 | 2,392 |
| Straight-leg raise | 102 | 57 | 35 | 2,525 |
| Bent-knee raise | 82 | 35 | 24 | 1,767 |
| Cross-knee curl-up | 112 | 89 | 67 | 2,964 |
| Hanging, straight leg | 107 | 112 | 90 | 2,805 |
| Hanging, bent knee | 84 | 78 | 64 | 3,313 |
| Isometric side support | 72 | 48 | 50 | 2,585 |

[a] Maximal voluntary contractions (MVCs) were isometric. Muscle activation values higher than 100% are often seen during other types of exercise. CSTF=Canadian Standardized Test of Fitness. (Reprinted with permission from Axler CT, McGill SM. Low back loads over a variety of abdominal exercises: searching for the safest abdominal challenge. *Med Sci Sports Exerc.* 1997;29:804–811.)

both the patient and the clinician to ensure a sufficient endurance profile to minimize the risk of further injury. The emphasis, I believe, should be placed on "endurance" and should precede strengthening exercise in a gradual, progressive exercise program (ie, longer-duration, lower-effort exercises).

### *Aerobic Exercise*

The mounting evidence supporting the role of aerobic exercise in reducing the incidence of low back injury[37] and in the treatment of patients with low back pain[38] is compelling. A recent investigation into loads sustained by the low back tissues during walking confirmed very low levels of supporting passive tissue load coupled with mild, but prolonged, activation of the supporting musculature.[39] Epidemiological evidence also sheds light on the effects of different types of aerobic exercise. Videman et al[40] examined age-related changes to the lumbar spines of over 1,500 elderly people as a function of lifelong activity level. Those subjects who were runners had no differences in spine changes, as measured from images obtained with magnetic resonance imaging, whereas weight lifters and soccer players were characterized as having more disk degeneration and bulges.

### *The Abdominal Muscles (Anterior and Lateral)*

There is no single abdominal exercise that challenges all of the abdominal muscles. Thus, the prescription of more than one exercise is required if the goal of treatment is to increase the force or endurance capacity of these muscles. Calibrated and normalized intramuscular and surface EMG evidence[10,25] suggests that the various types of curl-ups challenge mainly the rectus abdominis muscle, with the psoas and abdominal wall (internal and external oblique, transverse abdominis) muscle activity being low. Sit-ups (both straight-leg and bent-knee) are characterized by higher psoas muscle activity and higher low back compression, whereas leg raises cause even higher muscle activity and also spinal compression (Tab. 1).

Several relevant observations were made regarding abdominal exercises in our investigations. The challenge to the psoas muscle was lowest during curl-ups, followed by higher levels during horizontal isometric side support.[10] Bent-knee sit-ups were characterized by greater psoas muscle activity compared with straight-leg sit-ups.[10] The highest psoas muscle activity was observed during leg raises and hand-on-knee flexor isometric exertions.[10]

The "press-heels" sit-ups, which have been hypothesized to activate the hamstring muscles and neurally inhibit the psoas muscle,[41] actually increased psoas muscle activity.[10] Although there are several theories based on "neural inhibition" that are attractive to clinicians, this is an example where the "clinical opinion" and theory based on "neural inhibition" were untrue when substantiated with a direct measure of muscle activity (it is recognized that intramuscular measures of psoas muscle activity were previously unavailable). Rather, a more simple biomechanical explanation describes why the psoas muscle could not have been neurally inhibited. Activating the hamstring muscles increases hip extensor torque. More hip flexor torque, therefore, is required to maintain a net hip flexor torque to enable the sit-up, and the prime candidate to produce a hip flexor moment is the psoas muscle. Normalized EMG data are provided in Table 2 for comparative purposes. Some athletes intentionally train their psoas muscle and should find these data informative. People with low back injuries, however, must be more selective. The horizontal side support is one exercise that, although not often performed,

**Table 2.**
Electromyographic Activity Values ($\bar{X}\pm SD$) Normalized to 100% of Maximal Voluntary Contraction[a]

| Abdominal Task | Quadratus Lumborum Muscle | Muscle Channel Psoas 1 | Muscle Channel Psoas 2 | EO | IO | TA | RA | RF | ES |
|---|---|---|---|---|---|---|---|---|---|
| Straight-leg sit-up | | 15±12 | 24±7 | 44±9 | 15±15 | 11±9 | 48±18 | 16±10 | 4±3 |
| Bent-knee sit-up | 12±7 | 17±10 | 28±7 | 43±12 | 16±14 | 10±7 | 55±16 | 14±7 | 6±9 |
| Press-heel sit-up | | 28±23 | 34±18 | 51±14 | 22±14 | 20±13 | 51±20 | 15±12 | 4±3 |
| Bent-knee curl-up | 11±6 | 7±8 | 10±14 | 19±14 | 14±10 | 12±9 | 62±22 | 8±12 | 6±10 |
| Bent-knee leg raise | 12±6 | 24±15 | 25±8 | 22±7 | 8±9 | 7±6 | 32±20 | 8±5 | 6±8 |
| Straight leg raise | 9±2 | 35±20 | 33±8 | 26±9 | 9±8 | 6±4 | 37±24 | 23±12 | 7±11 |
| Isometric hand-to-knee, LH-RK | | 16±16 | 16±8 | 68±14 | 30±28 | 28±19 | 69±18 | 8±7 | 6±4 |
| Isometric hand-to-knee, RH-LK | | 56±28 | 58±16 | 53±12 | 48±23 | 44±18 | 74±25 | 42±29 | 5±4 |
| Cross curl-up, RS-across | 6±4 | 5±3 | 4±4 | 23±20 | 24±14 | 20±11 | 57±22 | 10±19 | 5±8 |
| Cross curl-up, LS-across | 6±4 | 5±3 | 5±5 | 24±17 | 21±16 | 15±13 | 58±24 | 12±24 | 5±8 |
| Isometric side support | 54±28 | 21±17 | 12±8 | 43±13 | 36±29 | 39±24 | 22±13 | 11±11 | 24±15 |
| Dynamic side support | | 26±18 | 13±5 | 44±16 | 42±24 | 44±33 | 41±20 | 9±7 | 29±17 |
| Push-up from feet | 4±1 | 24±19 | 12±5 | 29±12 | 10±14 | 9±9 | 29±10 | 10±7 | 3±4 |
| Push-up from knees | | 14±11 | 10±7 | 19±10 | 7±9 | 8±8 | 19±11 | 5±3 | 3±4 |

[a] Electromyographic channel: EO=external oblique muscle, IO=internal oblique muscle, TA=transverse abdominal muscle, RA=rectus abdominis muscle, RF=rectus femoris muscle, ES=erector spinae muscle. Psoas muscle, EO, IO, and TA channels are intramuscular electrodes; RA, RF, and ES channels are surface electrodes. LH=left hand, RH=right hand, LK=left knee, RK=right knee, LS=left side, RS=right side.

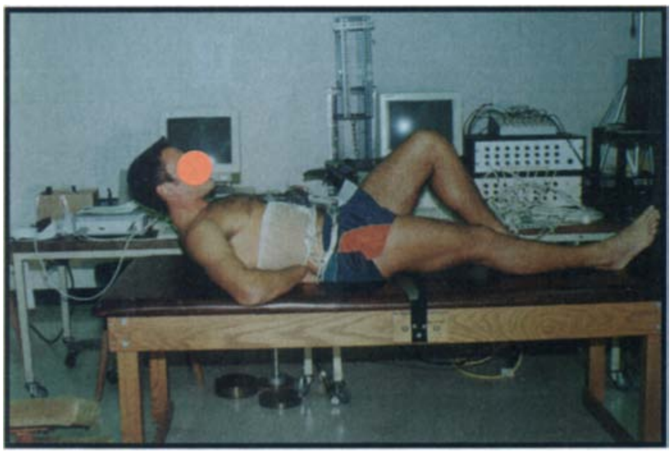

**Figure 2.**
The curl-up, where the head and shoulders are raised off the support surface, with the hands under the lumbar region, to help stabilize the pelvis and support the neutral spine. A variation is to bend only one knee while the straight leg assists in pelvic stabilization and preservation of a "neutral" lumbar curve.

appears to have merit because it challenges the lateral oblique muscles without high lumbar compressive loading. In addition, this exercise produces high levels of activity in the quadratus lumborum muscle, which experiments by McGill et al[42] have shown to be the most important stabilizer of the spine. Graded activity in the rectus abdominis muscle and in each of the components of the abdominal wall changes with each of these exercises, demonstrating that no single task is best for the collective "abdominals." Curl-ups excel at increasing the activity of the rectus abdominis muscle, but they produce relatively smaller oblique muscle activity.

In my view, a wise choice for abdominal exercises, in the early stages of training or rehabilitation, would consist of several variations of curl-ups for the rectus abdominis muscle (Fig. 2) and isometric horizontal side support, with the body supported by the knees and upper body supported by one elbow on the floor (Fig. 3), to challenge the abdominal wall in a way that imposes minimal compressive penalty to the spine. The level of challenge with the isometric horizontal side support can be increased by supporting the body with the feet rather than the knees.

### *Quadratus Lumborum Muscle and Spine Stabilization*

There are, in my opinion, several other clinically relevant findings from these 2 data sets.[10,42] Psoas muscle activity is really determined by hip flexion demands and is not linked with either lumbar sagittal moment or spinal compression demands.[10] I question the often-cited notion that the psoas muscle is a lumbar spine stabilizer.[42] Quadratus lumborum muscle activity is consistent with lumbar sagittal moment and compression demands, suggesting a larger role for that muscle in stabilization. When compression is applied to the spine, in an upright posture with no bending moments, the quadratus lumborum is the muscle whose activity most closely relates to the increasing need for stability, in fact, as much as any other muscle.[42] Psoas muscle activity is relatively high (greater than 25% MVC) during push-ups, suggesting that people with low back injuries may not want to do this exercise.[25] As mentioned, the horizontal side support appears to be a wise choice of exercise for training the quadratus lumborum muscle for enhancing stability of the spine.

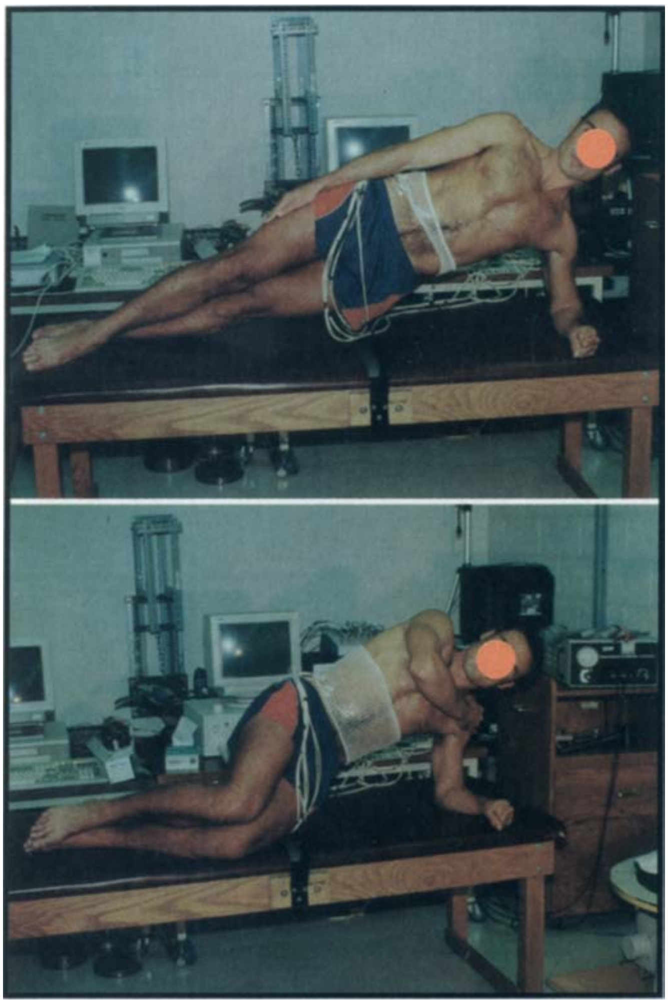

**Figure 3.**
The isometric horizontal side support. Supporting the lower body with the knees on the support surface (bottom panel) reduces the demand further for those individuals who are more concerned with safety, whereas supporting the body with the feet (top panel) increases the muscle challenge, but also the load on the spine.

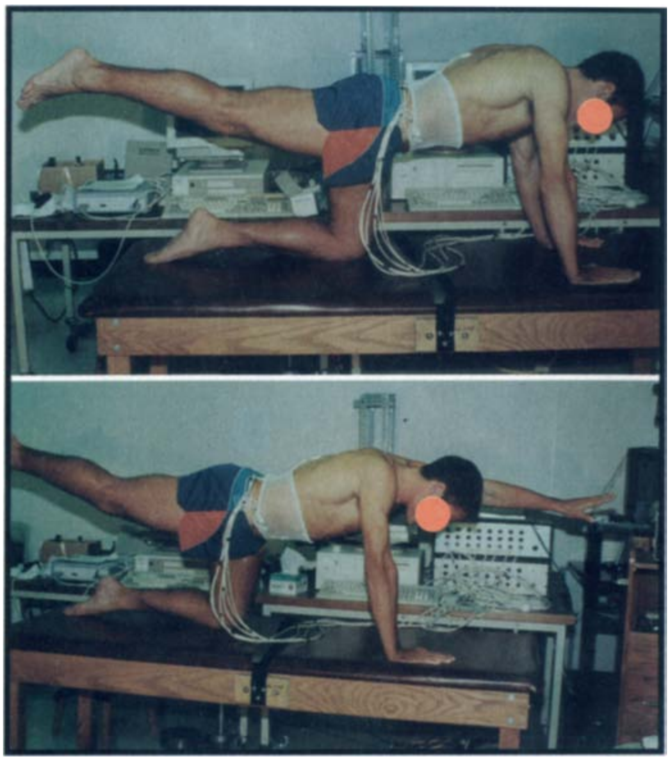

**Figure 4.**
(Top panel) Single-leg extension holds, while on the hands and knees, produces mild extensor muscle activity and lower spine compression (<2,500 N). (Bottom panel) Raising the contralateral arm increases extensor muscle activity, but also spine compression, to levels over 3,000 N.

### *The Back Extensors*

Most extensor exercises are characterized by high spinal loads, which result from externally applied compressive and shear forces (either from free weights or resistance machines). Callaghan et al[22] investigated methods of exercising the extensors with minimal spine loading. The single-leg extension hold, while on the hands and knees (Fig. 4), appears to create minimal external loads on the spine but produces an extensor moment (and small isometric twisting moments) that results in extensor muscle activity. Activity appears to be sufficiently high on one side of the extensors to facilitate training, but the total load on the spine is reduced because the contralateral extensors are producing lower forces (lumbar compression is less than 2,500 N). Switching legs results in training both left and right extensors (approximately 18% of MVC in the lumbar extensors of one side).[22] In total, 7 tasks were analyzed to facilitate comparison of various extensor tasks (Tab. 3).[22] Simultaneous leg extension with a contralateral arm raise increases the unilateral extensor muscle activity (approximately 27% MVC in the lumbar extensors of one side and 45% MVC in the thoracic extensors of the other side) but also increases lumbar compression to well over 3,000 N (Fig. 4). I believe the often-performed exercise of lying prone on the floor and raising the upper body and legs off the floor is contraindicated for anyone at risk of low back injury or reinjury (Fig. 5). In this task, the lumbar region must bear a high compressive load (approximately 4,000 N) as a result of the bilateral muscle activity. Furthermore, this high load is applied to a hyperextended spine. This load is transferred to the facets and can crush the interspinous ligament (noted as an injury mechanism[2]). Once again, these data are provided for the exercise professional who must design programs for a wide range of objectives.

### *The Beginner's Program*

In this article, I have endorsed the notion that each person's clinical picture should influence the design of his or her exercise program. With this notion in mind, the following suggestions form a basic program for clinicians to modify and revise according to their clinical impressions. I recommend that the program begin with the flexion and extension cycles (Fig. 1) to reduce joint

**Table 3.**
Muscle Activity Levels of 7 Low Back Electromyographic Channels (Shown for Only One Side of the Body Because Switching Limbs Produced a Mirror Image) for 13 Male Subjects Expressed as a Percentage of Maximal Voluntary Contraction and Compression Values ($\bar{X}$±SD)[a]

| Electromyographic Channel | Right Leg Extension | Left Leg Extension | Right Leg and Left Arm Elevation | Left Leg and Right Arm Elevation | Lying Prone Extending Legs and Head and Arms | Trunk Extended Over End of Bench |
|---|---|---|---|---|---|---|
| Right RA | 3.3±2.4 | 2.7±1.9 | 4.0±2.0 | 3.5±2.0 | 4.7±2.2 | 3.1±1.8 |
| Right EO | 8.4±4.9 | 4.9±1.5 | 16.2±6.0 | 5.2±2.3 | 4.3±2.5 | 3.7±1.7 |
| Right IO | 12.0±6.8 | 8.2±2.5 | 15.6±8.2 | 12.0±4.2 | 12.1±10.1 | 12.7±10.8 |
| Right LD | 8.1±5.4 | 5.8±3.5 | 12.0±4.2 | 12.5±6.2 | 11.2±4.3 | 6.5±4.0 |
| Right TES | 5.7±2.0 | 13.7±7.5 | 11.5±6.6 | 46.8±29.3 | 66.1±18.8 | 45.4±10.6 |
| Right LES | 19.7±9.1 | 11.7±4.9 | 28.4±10.2 | 19.4±11.0 | 59.2±11.7 | 57.8±8.5 |
| Right MF | 21.9±6.3 | 10.8±6.0 | 31.5±8.2 | 16.1±12.0 | 51.9±14.7 | 47.5±12.3 |
| Compression (kN) | 2.3±0.9 | 2.0±0.2 | 3.2±1.0 | 2.9±1.2 | 4.3±1.1 | 4.3±1.2 |

[a] Electromyographic channel: RA=rectus abdominis muscle, EO=external oblique muscle, IO=internal oblique muscle, LD=latissimus dorsi muscle, TES=thoracic erector spinae muscle, LES=lumbar erector spinae muscle, MF=multifidus muscle. (Adapted and reprinted with permission from the American Physical Therapy Association from Callaghan et al.[22])

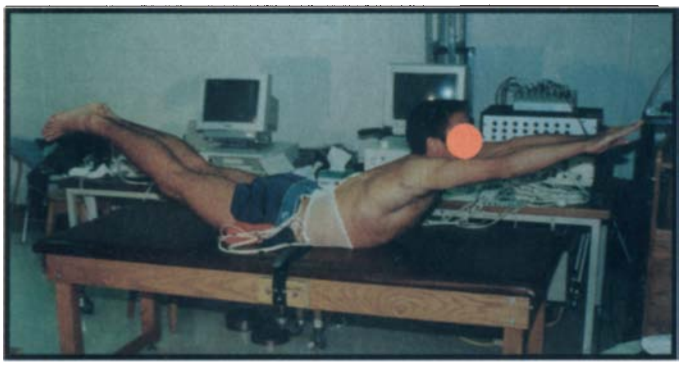

**Figure 5.**
This often-prescribed extensor exercise may be contraindicated for most individuals given the extended posture (and facet and annulus loading) and high spine compressive load of 4,000–6,000 N.

stiffness and relax elastic structures,[34] resulting in lower joint loads during subsequent movements. Because the spine is supported, these motions are conducted in an environment in which there is minimal loading of the spine. Then hip and knee mobility exercises should be conducted to facilitate spine-conserving postures. These exercises are followed by training specific muscles, beginning with anterior abdominal exercises while maintaining the spine in a neutral posture (Fig. 2), by lateral muscle exercises of side support for the quadratus lumborum and abdominal wall muscles (Fig. 3), and by the extensor muscle program (Fig. 4). Selection of the appropriate number of repetitions and holding times for each of these exercises is based on the clinician's judgment, because at present there are no data to guide selection for these variables.

## Notes for Designing Exercise

The following is a list of general caveats for designing low back exercise regimens, adapted from my contributions to the American College of Sports Medicine's *Resource Manual for Guidelines for Exercise Testing and Prescription*[43]:

1. Although there is a common belief among some "experts" that exercise sessions should be performed at least 3 times per week, there is some evidence that low back exercises are most beneficial when performed daily.[44]

2. The "no pain-no gain" axiom does not appear to apply when exercising the low back, particularly when applied to weight training, given the evidence of tissue damage associated with certain specific repeated movements.[1]

3. Although exercises designed for specific low back muscles have been described in this article, general exercise programs that include cardiovascular training (eg, walking) have been shown to be effective for rehabilitation of persons with LBP and for injury prevention.[38] The exercises shown in Figure 1 through 5 comprise only a component of a total program.

4. Diurnal variation in the fluid level of the intervertebral disks (disks are more hydrated early in the morning after rising from bed) changes the stresses on the disks throughout the day. It would be unwise to perform full-range spinal motions (bending) shortly after rising from bed.[2]

5. Exercises for the low back performed for maintenance of health need not emphasize "strength" with high-load, low-repetition tasks. More repetitions of less demanding exercises will assist in the enhancement of "endurance" and "strength." There is no

doubt that back injury can occur during activities with seemingly low-level demands (eg, picking up a pencil) and that the risk of injury from motor control error can occur. Although it appears that the likelihood of motor control errors, resulting in inappropriate muscle forces, increases with fatigue, there is also evidence to suggest that changes occur in passive tissue loading with repetitive lifting.[45] Because I believe evidence indicates that "endurance" has more protective value than "strength,"[36] "strength" gains should not be overemphasized at the expense of "endurance."

6. There is no such thing as an ideal set of exercises for all individuals. An individual's training objectives (eg, to reduce the risk of injury, to optimize general health and fitness, to maximize athletic performance) must be identified and the most appropriate exercises chosen. Although science, at present, cannot evaluate the optimal exercises for each situation, the combination of science and clinical experience can be utilized to enhance low back health.

7. Be patient and stick with the program. Increased function and pain reduction may not occur for 3 months in some persons.[46]

## Conclusion

The evidence and data presented in this review mostly pertain to isometric exercise. My colleagues and I are continuing to examine other types of exercises, including stabilizing exercises and exercises involving labile surfaces, and hope to provide further data and collaborate with clinicians to enhance clinical practice into the future.

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