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Avoiding Lumbar Spine Injury During Resistance Training

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summary

In this manuscript, the injury risk to the lumbar spine during common resistance exercises is discussed. Alternative, theoretically less risky exercises are presented.

Lumbar spine injury is extremely pervasive and can be extraordinarily debilitating. It has been estimated that up to 80% of adults eventually will develop some form of low back pain (12). In addition, it has been estimated that 10–15% of all sporting injuries involve the spine (21, 35–37). The compressive, shear, tensile, and torsional forces on the lumbar spine during resistance training may be sufficient to cause injury, especially if these forces are concentrated by virtue of the exerciser's mechanics. In this article we will review briefly the anatomy and pathologic mechanics of common lumbar spine injuries during weight training and discuss strategies for injury prevention. Our intent is not to provide an exhaustive review of lumbar spine pathologies, nor is it to enable strength and conditioning professionals to diagnose and to treat lumbar spine injuries. Instead, we hope to raise awareness of common resistance exercises that putatively are more likely to cause lumbar spine injury. In addi-

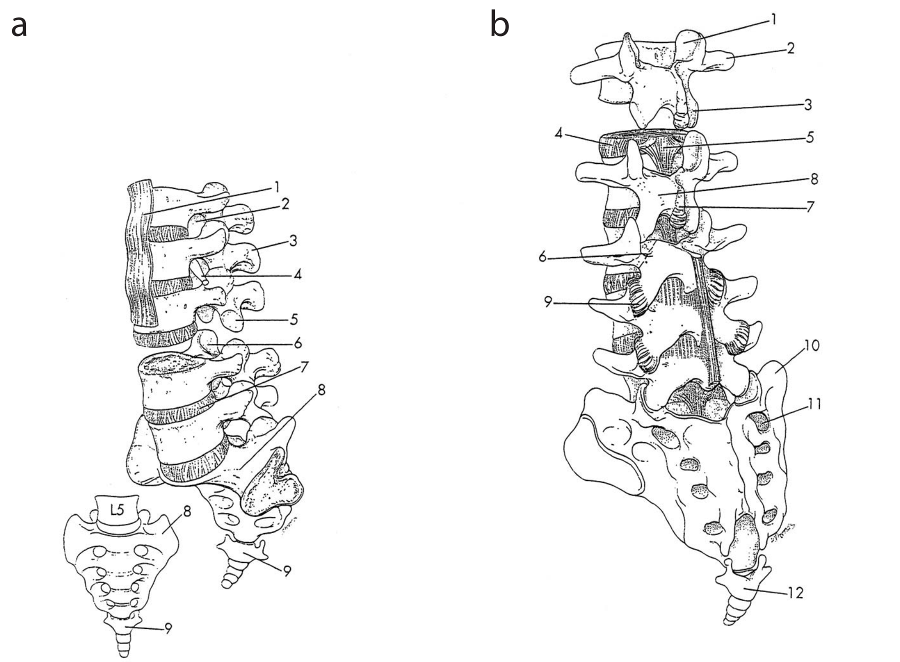

Figure 1. Anterior and posterior aspects of the lumbar spine. (a) anterior aspect of lumbosacral spine. 1, anterior longitudinal ligament; 2, intervertebral foramen; 3, spinous process; 4, spinal nerve; 5, inferior facet; 6, superior facet; 7, intervertebral disk; 8, sacrum; and 9, coccyx. (b) posterior aspect of lumbosacral spine. 1, superior facet; 2, transverse process; 3, inferior facet; 4, intervertebral disk; 5, posterior longitudinal ligament; 6, pars interarticularis; 7, spinous process; 8, lamina; 9, facet joint capsule; 10, sacral ala; 11, sacral foramina; and 12, coccyx. With permission from J.A. Nicholas and E.B. Hershman (29).

tion, we will discuss alternative, presumably less-risky, exercises. It is important to acknowledge that our advice is based on general biomechanical information and that biomechanical data are not available for all exercises that either directly or indirectly affect the lumbar spine. In spite of this, we believe that careful exercise selection and instruction based on knowledge of pathologic lumbar spine mechanics will reduce the incidence of lumbar spine injury.

Overview of Lumbar Spine Anatomy

The lumbar spine consists of 5 separate vertebrae, which increase in size from superior to inferior (Figure 1) (3). The lumbar vertebrae are the largest in the spinal column, enabling them to bear tremendous compressive loads. Between each pair of lumbar vertebrae is an intervertebral disc comprising a central nucleus pulposus, a series of fibrocartilaginous rings known as the annulus fibrosis, and a pair of cartilaginous end-plates at the disc/vertebral body interfaces. The nucleus pulposus acts like a gelatinous cushion that disperses spinal compressive forces to the annulus and end-plates. The annulus acts like a ligament, resisting shear (sliding), tensile (stretching), and torsional (rotational) forces imparted to the lumbar spine, while restraining the nucleus and connecting the vertebral bodies. The annulus fibrosis is thinner posteriorly than anteriorly in the lumbar spine. The vertebral end-plates, sandwiched between the disc and the vertebral body, permit diffusion of nutrient and waste material between the disc and vertebral body. The end-plates are thinnest and weakest in their centers adjacent to the nucleus pulposus (Figure 2) (3).

The bony posterior vertebral arch and vertebral body together form the neural arch, which envelops and protects the spinal cord (3). Small processes situated on each side of the arch articulate with adjacent vertebrae (Figure 1). These articulations are known as *zygoapophyseal*, or facet, joints. The portion of the neural arch located between the superior and inferior articular processes is known as the *pars interarticularis*. The pars interarticularis is a common site for a stress fracture in the posterior vertebral arch (9).

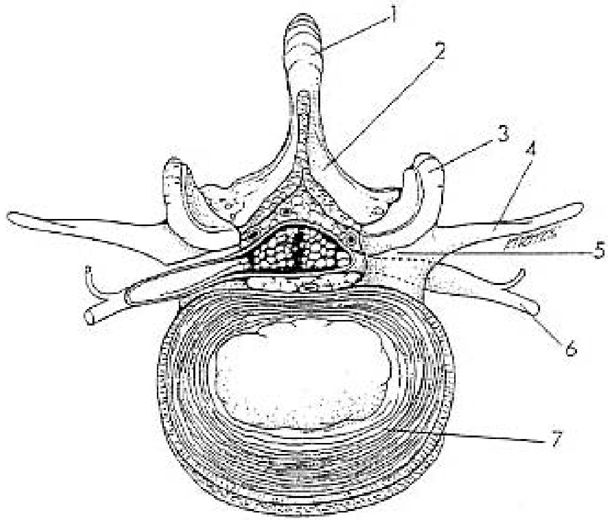

Figure 2. Axial section of the lumbar vertebrae. 1, spinous process; 2, lamina; 3, facet; 4, transverse process; 5, pedicle; 6, spinal nerve; and 7, intervertebral disk. With permission from J.A. Nicholas and E.B. Hershman (29).

The ligamentous restraints of lumbar spine movement are typically divided into anterior and posterior portions. These ligaments restrain spinal movements in all directions, but we will focus on their roles in limiting lumbar flexion and extension. The anterior longitudinal ligament becomes taut during the spine extension, whereas the posterior ligaments (posterior longitudinal ligament, ligamentum flavum, interspinous ligament, facet capsules, supraspinous ligaments) become taut during flexion (Figure 2) (3). The anterior longitudinal ligament is thicker and stronger anteriorly in the lumbar spine than in other regions of the spine; consequently, anterior ligamentous disruptions are rare. The posterior longitudinal ligament is considerably narrower and weaker than the anterior longitudinal ligament, but still provides support for the central posterior aspect of the intervertebral disc. The posterior lateral portions of the intervertebral disc, however, are not well protected by the posterior longitudinal ligament (3).

Kinesiology of the Lumbar Spine

Lumbar spine movement occurs in 6 directions, including left and right rotation in the transverse plane, around a vertical axis; left and right side bending (or lateral flexion) in the frontal plane, around an anterior/posterior axis; and forward bending (flexion) and backward bending (extension) in the sagittal plane, around a medial/lateral axis (3). We have chosen to focus our discussion of lumbar spine kinesiology on flexion and extension, because these are the primary movements in this region of the spine (28). All lumbar spine movements involve vertebral rolling (or tilting) and shearing (or sliding). During flexion, the superior vertebral segment rolls (or tilts) forward around a frontal plane axis, and it shears (or slides) forward, essentially along the transverse plane (3). The facets of the superior vertebral segments slide superiorly and anteriorly during flexion, while the posterior fibers of the annulus

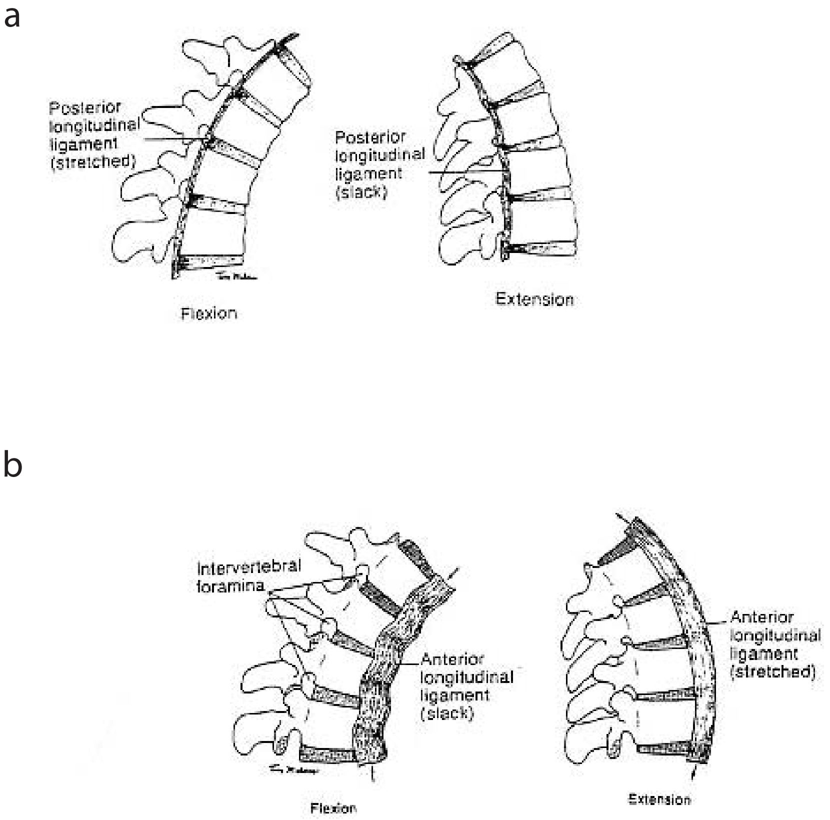

Figure 3. Flexion and extension of the lumbar spine. (a) posterior longitudinal ligament is stretched during forward flexion of the vertebral column and is slack and may be compressed during extension. (b) anterior longitudinal ligament is slack in forward flexion of the vertebral column and in extension of the vertebral column, the ligament is stretched. With permission from C.C. Norkin and P.K. Levangie (30).

pulposus and the posterior ligaments (ligamentum flavum, interspinous ligament, facet capsules, supraspinous ligaments, posterior longitudinal ligament) become taut. During lumbar spine extension, the superior vertebral segment tilts and shears backward, while the facets of the superior vertebral segments slide inferiorly due to the posterior rolling of the segments. The spinous processes approximate while the anterior annular fibers of the intervertebral disc and the anterior longitudinal ligament are stretched (Figure 3).

Several groups of muscles control movement of the lumbar spine and act to stiffen the spine, thereby providing resistance to injury. These include the abdominals (rectus abdominus, internal and external obliques, transversus abdominus), the erector spinae (iliocostalis, longissimus, spinalis), the deep intrinsic spinal muscles (multifidus, rotatores, semispinalis), and the quadratus lumborum (8, 11, 20). When these muscles are active, they function like guy wires to increase the stiffness (or rigidity) of the lumbar spine "mast" (8, 31). Some of these muscle groups, along with others (e.g., diaphragm, levator ani), also help to increase lumbar spine stiffness when they increase pressure in the abdominal cavity (10). As the stiffness of the spine increases, the spine becomes more stable, and presumably less vulnerable to injury (8). It is therefore imperative that the muscles that act to stiffen and to stabilize the spine have excellent strength and endurance. Advice on training these muscles is offered in the sections below.

Common Mechanisms of Lumbar Spine Injury During Resistance Training

Most lumbar spine injuries that occur during resistance training, fortunately, are thought to be simple muscle strains and/or ligament sprains (4, 34, 39). In one study of male Olympic weightlifters, nearly 75% of weightlifting-related back injuries were diagnosed as muscle strains (4). In our experience, muscle strains are often the result of improper exercise loads, improper rest intervals (i.e., fatigue), and/or improper lifting technique. Obviously, these factors can readily be adjusted with proper exercise guidance to reduce the risk of muscle strain.

Though muscle strains are often not serious injuries, injuries involving the intervertebral disc, pars interarticularis, or vertebral end-plate may have more serious consequences. As discussed above, the inherently weak posterior annulus fibrosis is under greater tensile stress during lumbar flexion (6, 13). Not surprisingly, most lumbar disc injuries occur when the spine is flexed (6, 13). Examples of resistance exercises that may involve full lumbar flexion include good mornings, dead lifts, rows, and sit-ups.

As mentioned previously, the posterior vertebral elements of the lumbar spine are compressed when the spine is extended. Repetitive, forceful end range of motion lumbar extension (e.g., during the end of a dead lift) or forceful shearing of the vertebrae can lead to compression injury of the facet joints and/or fatigue and failure of the pars interarticularis (9). Fracture of the pars interarticularis (known as a *spondylolysis*) may lead to forward slipping of the superior vertebrae on the inferior (known as a *spondylolisthesis*). In a sample of competitive weightlifters, 36% were found to have a spondylolysis on radiograph (27). Fortunately, fractures account for a small percentage of all weight-training injuries.

Another structure that may be injured with resistance training is the vertebral end-plate. With compressive loading (e.g., during a squat or leg press), the vertebral end-plate will fail before the intervertebral disc (24). Fissures in the end-plate lead to migration of the nucleus pulposus into the vertebral body, a loss of disc height, and an alteration of vertebral segment mechanics. End-plate fracture is always a potential risk during heavy compressive loading. It would be sensible to increase compressive loads gradually over time to encourage tissue adaptations that reduce the likelihood of injury.

Modifying Common Resistance Exercises to Reduce the Risk of Lumbar Spine Injury

As discussed above, the lumbar spine is more likely to be injured when loaded while flexed or extended. The posterior vertebral elements may be injured when the lumbar spine is loaded while fully extended, whereas the posterior intervertebral disc annulus appears to be most vulnerable when the spine is loaded while flexed. The corollary of this observation, then, would suggest that the structures of the lumbar spine are less likely to be damaged when the spine is in the middle of the available range of motion. The middle portion of the available range of motion has previously been described as the neutral range (15). The neutral range also has been purported to be advantageous for preventing injury and for enhancing athletic performance (16). Herring and Weinstein (16) suggest that the neutral range is close to the center of reaction and allows for quick movements into both flexion and extension. Because the neutral lumbar spine range appears to be relatively safe and may enhance athletic performance, it is sensible to perform strengthening and stretching exercises for the extremities with the lumbar spine in the neutral range. To help your clients find their neutral position, have them fully flex, then fully extend their lumbar spine in a supine position; the neutral range is midway between these two extremes.

Once a client is able to assume the neutral range, he or she should be challenged to maintain this range during resistance exercises. The strength and conditioning professional should develop the skill to identify when a client fails to maintain a neutral range and should provide verbal and/or tactile cueing until the neutral spinal range is adopted. For instance, the bench press is typically performed with the feet resting on the floor, which may place the hips in an extended position. If the hip flexors are short or inflexible, the lumbar spine will be forced to extend when the hips are extended, due to the attachment of the psoas muscle on the lumbar discs and vertebrae. If the lifter pushes through the legs and arches the lumbar spine to gain leverage during a bench press, lumbar spine extension will increase further, resulting in increased compressive loading of the posterior bony elements. The strength and conditioning professional should make appropriate adjustments to avoid excessive lumbar extension and adverse compressive loading of the posterior spinal structures. For example, improving extensibility of the hip flexors will reduce lumbar extension when the feet are placed on the floor. Alternatively, placing the feet on the bench throughout the lift reduces the tension on the psoas muscle. Exercises that repetitively load the posterior arch may overstress the weak pars interarticularis and result in a spondylolysis, or progress a spondylolysis into a spondylolisthesis (9). Clients with a spondylolysis or spondylolisthesis should be advised to avoid exercises that involve end range-of-motion lumbar extension.

The squat and the leg press are standard training exercises used to increase the strength of the entire lower-extremity kinetic chain, which can be problematic for those with back injuries. Proper form is essential to the correct execution of

Figure 4. Abnormal squat posture due to tight gastrocnemius/soleus complex.

Figure 5. Normal squat posture with block under heel.

Figure 6. Leg press with hips posteriorly rotated.

these exercises. One of the authors (R.M.) has rehabilitated several weightlifters following lumbar disc rupture occurring during the performance of the squat or leg press exercises. In all of these cases, the exercisers were injured when they executed the squat with a flexed lumbar spine. Excessive forward trunk flexion during the squat increases intradisc pressure and tensile loads on the posterior annulus (6, 13). A flexed posture during the squat also shifts the load anteriorly, relative to the lumbar spine (25). The effect of this load shift is a lengthening of the load's lever arm and an increase in the torque applied to the lumbar spine. Maintaining a neutral lumbar spine will help the exerciser keep the external load and the upper body directly over the hips and torso, and thus shorten the load's lever arm, decreasing the external torque on lumbar spine.

Clients who have difficulty maintaining a neutral lumbar spine during the squat may have greater success by using a self-spotting rack initially. A self-spotting rack should promote a more erect position during both the descent and ascent phases of the squat exercise. Clients with inflexible ankle plantar flexors (gastrocnemius/soleus/Achilles tendon complex) may flex their trunk to compensate for their inability to dorsiflex their ankles during the descent phase of the squat (Figure 4). In this case, placing a small wedge under the exerciser's heels will decrease the amount of dorsiflexion needed during that phase. This should improve the exerciser's ability to maintain a neutral lumbar spine position throughout the exercise (Figure 5), until the flexibility of their plantar flexors improves.

When performing the leg press, it is important that the exerciser maintain a neutral spine to modulate the lumbar spine injury risk. The strength and conditioning professional should be able to observe for excessive lumbar spine flexion during the beginning and end of the leg press exercise (Figure 6). The range of motion during the exercise may need to be limited, depending on the flexibility in the exerciser's hip extensors, to avoid full lumbar spine flexion.

As discussed above, the posterior annulus is vulnerable to injury when the spine is flexed. Individuals recovering from posterior intervertebral disc injury would be well advised to avoid lifts that involve lumbar flexion (e.g., good-mornings, stiff-legged dead lifts, bent-over rows). Exercisers with posterior intervertebral disc injury should maintain a neutral lumbar spine range to reduce tension on the posterior annulus. The importance of a proper warm-up and light stretching to reduce the risk of sprain or strain is familiar to most strength and conditioning specialists and therefore does not warrant further discussion.

Exercises to Reduce the Risk of Lumbar Spine Injury

Addressing strength deficits in the muscles that help stabilize the lumbar spine is a logical step toward reducing the risk of injury. In the authors' experience, the posterior spinal muscles (iliocostalis, longissimus, spinalis, multifidus, rotatores, semispinalis) are the most often neglected muscles in strength training routines. In a 5-year prospective study of the general population, individuals with low back pain were found to have a significantly lower ratio of trunk extensor to trunk flexor strength (20). This trunk extensor strength deficit proved to be the most sensitive predictor of future occurrence of low back pain; that is, individuals with relative weakness of the lumbar spine extensors were more likely to experience subsequent episodes of low back pain. In another study, extensor strength was significantly lower than flexor strength in patients recovering from spinal surgery (22). Several investigators have found that the multifidus muscle is particularly affected by back pain or injury (17, 18, 32). The multifidus has been found to atrophy quickly following back injury (17, 18), and to remain atrophied after back pain subsides (17).

Callaghan and colleagues found that single-leg extension in quadruped (i.e., hands and knees position) is a relatively safe exercise for the extensor muscles (5). This exercise also can be performed prone over an exercise ball. The exercise can be progressed to include simultaneous extension of the contralateral arm or by performing the movement from a prone position, lying with the spine in a neutral range (Figure 7). If tolerated, lumbar extension can be performed on a selectorized machine. When using a selectorized machine, the pelvis should be stabilized to limit substitution by the gluteals and hamstrings (14). Even such limited range-of-motion lumbar extension training should result in strength gains through a larger range of motion (14, 33).

Figure 7. Prone single-leg extension exercise.

Figure 8. Isometric horizontal side-support exercise.

Lateral stability of the lumbar spine appears to be largely attributable to the often-overlooked quadratus lumborum muscles (1, 25). Activity in the quadratus lumborum muscles has been found to increase significantly when the lumbar spine is loaded, suggesting that this muscle is important in stabilizing the lumbar spine (25). The isometric horizontal side-support exercise (Figure 8) has been shown to effectively challenge these muscles while imparting relatively low levels of spinal compression (2).

Many exercises have been suggested to enhance performance of the abdominal muscles in the interest of improving lumbar spine health. Training of the transversus abdominus muscle has been advocated in particular, because aberrant performance of this muscle has been found in patients with low back pain (19). Clients with a history of low back injury should utilize a regimen of abdominal exercises that create minimal lumbar spine compression and shear. Routine exercises such as the bent-knee sit-up involve high levels of spinal compression and may be contraindicated for certain clients (2, 23). Axler and McGill examined the safety of several abdominal exercises by comparing muscle activity with lumbar compressive loading (2). Four abdominal exercises were found to have a high ratio of muscle challenge to spine compression: the curl-up with feet unsupported, the curl-up with feet anchored, the dynamic cross-knee curl-up, and the hanging straight-leg raise. The curl-up exercise (feet free or fixed) had the highest ratio of muscle activity to lumbar spine compression, making this a relatively safe abdominal exercise. Several exercises were not recommended because they involve a high level of spinal compression. These were the supine bilateral straight-leg raise, bilateral bent-leg raise (supine and hanging), and isometric cross-knee curl-up (pushing against elevated knee) (2).

It is sensible to perform isolated strengthening exercises at the end of a workout for the muscles that support the lumbar spine. Exercising these muscles at the beginning of a workout will temporarily fatigue them and may impair dynamic spinal stabilization during the initial phase of the exercise session. High-repetition resistance exercise should be used with these muscles to promote greater endurance for lumbar spine stabilization.

In addition, muscle groups that help control pelvic position, hamstrings, quadriceps, iliopsoas, rectus femoris, gastrocnemius and soleus, and the associated hip rotators also should be strengthened if deficits are present (16). The lumbar spine requires a stable lower extremity and pelvic base of support to function effectively (21). Weakness in these muscle groups may require compensatory activity in the lumbar spinal muscles, predisposing the lumbar muscles to fatigue and an increased risk of injury.

The Use of Lifting Belts to Reduce Lumbar Spine Injury During Resistance Training

No article on lumbar spine injury during resistance training would be complete without a discussion of lifting belts. Although commonly used, there is no conclusive evidence that lifting belts are effective in preventing lumbar spine injury. However, lifting belts have been shown to increase intramuscular stiffness in the erector spinae muscles (26) and spinal stiffness in general (7). Whether or not increased erector spinae intramuscular stiffness increases spinal stiffness is unknown. Despite the increase in intramuscular stiffness, erector spinae electromyogram activity has been shown to decline when a lifting belt is worn (7, 38). It remains to be seen if the decline in erector spinae muscle activation is offset by the increase in muscular stiffness, thus increasing injury resistance during tasks that require an extensor moment, such as lifting from a flexed position (e.g., dead lift). We have observed many exercisers wearing belts during these lifts, with the intent of reducing spinal injury.

Although the extent to which a lifting belt can provide lumbar stabilization is unclear, a lifting belt does provide tactile biofeedback. This feedback may assist the lifter in making protective postural adjustments (e.g., maintaining a neutral lumbar spine) during a lift. We encourage strength and conditioning professionals to stay abreast of research in this area; future research may provide more definitive conclusions on the use of weightlifting belts to reduce lumbar spine injury risk during resistance training.

Conclusion

Strength and conditioning specialists need to be cognizant of factors that contribute to lumbar spine injury in order to formulate safe exercise regimens for their clients. Avoidance of lifting with a hyperextended or hyperflexed spine may reduce lumbar spine injuries during resistance training. Maintaining a neutral lumbar spine range allows forces borne on either the upper or lower portions of the body to be appropriately dispersed across the tissues of the lumbar spine. Performance of the trunk muscles that stabilize the lumbar spine should be improved to enhance dynamic stabilization of the spine during loading. When in doubt about the safety of a particular exercise for a client recovering from lumbar spine injury, consult with the appropriate health care provider. ♦

References

1. Andersson, E.A., L.E. Oddsson, H. Grundstrom, J. Nimsson, and A. Thorstensson. EMG activities of the quadratus lumborum and erector spinae muscles during flexion-relaxation and other motor tasks. *Clin. Biomech. (Bristol, Avon)*. 11:392–400. 1996.
2. Axler, C.T., and S.M. McGill. Low back loads over a variety of abdominal exercises: Searching for the safest abdominal challenge. *Med. Sci. Sports. Exerc*. 29:804–810. 1997.
3. Bogduk, N. *Clinical Anatomy of the Lumbar Spine and Sacrum.* (3rd ed.). New York: Churchill Livingston, 1997. pp. 5–13, 35, 58.
4. Calhoun, G., and A.C. Fry. Injury rates and profiles of elite competitive weightlifters. *J. Athl. Train*. 34:232–238. 1999.
5. Callaghan, J.P., J.L. Gunning, and S.M. McGill. The relationship between lumbar spine load and muscle

activity during extensor exercises. *Phys. Ther*. 78:8–18. 1998.

6. Callaghan, J.P., and S.M. McGill. Intervertebral disc herniation: Studies on a porcine model exposed to highly repetitive flexion/extension motion with compressive force. *Clin. Biomech. (Bristol, Avon).* 16(1):28–37. 2001.
7. Cholewicki, J., K. Juluru, A. Radebold, M.M. Panjabi, and S.M. McGill. Lumbar spine stability can be augmented with an abdominal belt and/or increased intra-abdominal pressure. *Eur. Spine. J*. 8:388–395. 1999.
8. Cholewicki, J., M.M. Panjabi, and A. Khachatryan. Stabilizing function of trunk flexor-extensor muscles around a neutral spine posture. *Spine*. 22:2207–2212. 1997.
9. Chosa E., Totoribe K., Tajima N. A biomechanical study of lumbar spondylolysis based on a three-dimensional finite element method. *J Orthop. Res*. 22(1):158–63. 2004.
10. Cresswell, A., P. Blake, and A. Thorstensson. The effect of an intra-abdominal muscle training program on intra-abdominal pressure. *Scand. J. Rehabil. Med*. 26:79–86. 1994.
11. Crisco, J.J., and M.M. Panjabi. The intersegmental and multisegmental muscles of the lumbar spine: A biomechanical model comparing lateral stabilizing potential. *Spine*. 16:793–799. 1991.
12. Frymoyer, J.W. Back pain and sciatica. *N. Engl. J. Med*. 318:291. 1988.
13. Gordon, S.J., K.H. Yang, P.J. Mayer, A.H. Mace Jr., V.L. Kish, and E.L. Radin. Mechanism of disc rupture. A preliminary report. *Spine*. 16(4):450–456. 1991.
14. Graves, J.E., D.C. Webb, M.L. Pollock, J. Matkozich, S.H. Leggett, D.M. Carpenter, D.N. Foster, and J. Cirulli. Pelvis stabilization during resistance training: Its effect on the development of lumbar extension strength. *Arch. Phys. Med. Rehabil*. 75:210–215. 1994.
15. Hart, D.L., T.J. Stobbe, and M. Jaraiedi. Effect of lumbar posture on lifting. *Spine*. 12:138–145. 1987.
16. Herring, S.A., and S.M. Weinstein. Assessment and nonsurgical management of athletic low back injury. In: *The Lower Extremity and Spine In Sports Medicine* (2nd ed.). J.A. Nicholas and E.B. Hershman, eds. St. Louis: Mosby Year Book, Inc., 1995. p. 1189.
17. Hides, J.A., C.A. Richardson, and G.A. Jull. Multifidis recovery is not appropriate after resolution of acute, first-episode low back pain. *Spine*. 21:2763–2769. 1996.
18. Hides, J.A., M.J. Stokes, M. Saide, G.A. Jull, and D.H. Cooper. Evidence of lumbar multifidus muscle wasting ipsilateral to symptoms in patients with acute/subacute low back pain. *Spine*. 19:165–172. 1994.
19. Hodges, P.W., and C.A. Richardson. Inefficient muscular stabilization of lumbar spine associated with low back pain. *Spine*. 21:2640–2650. 1996.
20. Lee, J., Y. Hoshino, K. Nakamura, and Y. Ooi. Trunk muscle imbalance as a risk factor of the incidence of low back pain. *J. Neuromusculoskeletal Syst*. 7:97–101. 1999.
21. Maxwell, C., and A. Spiegal. The rehabilitation of athletes following spinal injuries. In: *The Spine in Sports*. S.H. Hochschuler, ed. Philadelphia: Hanley and Belfus, 1990. pp. 281–292.
22. Mayer, T.G., H. Vanharanta, R.J. Gatchel, V. Mooney, D. Barnes, L. Judge, S. Smith, and A. Terry. Comparison of CT scan muscle measurements and isokinetic trunk strength in postoperative patients. *Spine* 14:33–36. 1989.
23. McGill, S.M. The mechanics of torso flexion: Sit-ups and standing dynamic flexion manoevres. *Clin. Biomech. (Bristol, Avon).* 10:184–192. 1995.
24. McGill, S.M. The biomechanics of low back injury: Implications on current practice in industry and the clinic. *J. Biomech*. 30:465–475. 1997.
25. McGill, S.M. Distribution of tissue loads in the low back during a variety of daily and rehabilitation tasks. *J. Rehabil. Res. Dev*. 34:448-458. 1997.
26. Miyamoto, K. N. Iinuma, M. Maeda, E. Wada, and K. Shimizu. Effects of abdominal belts on intra-muscular pressure, intra-muscular pressure in the erector spinae muscles and myoelectrical activities of trunk muscles. *Clin. Biomech. (Bristol, Avon).* 14:79–87. 1999.
27. Namey, T.C., and J.C. Carek. Power lifting, weight lifting and bodybuilding. In: *Sports Injuries: Mechanisms, Prevention, Treatment*. F.H. Fu and D.A. Stone, eds. Baltimore: Williams & Wilkins, 1994. pp. 515–529.
28. Ng, J.K., V. Kippers, C.A. Richardson, and M. Parnianpour. Range of motion and lordosis of the lumbar spine: Reliability of measurement and normative values. *Spine*. 26(1):53–60. 2001.
29. Nicholas, J.A., and E.B. Hershman, eds. *The Lower Extremity and Spine in Sports Medicine* (2nd ed.). St. Louis, MO: Mosby Year Book, Inc., 1995.
30. Norkin, C.C., and P.K. Levangie. *Joint Structure and Function: A Comprehensive Analysis* (2nd ed.). Philadelphia: F.A. Davis, 1992.
31. Panjabi, M. Symposium on the lumbar spine. *Orthop. Clin. North. Am*. 8:169–179. 1977.
32. Parkkola, R., U. Rytokoski, and M. Kormano. Magnetic resonance imaging of the discs and trunk muscles in patients with chronic low back pain and healthy control subjects. *Spine*. 18:830–836. 1993.
33. Pollock, M.L., S.H, Leggett, J.E. Graves, A. Jones, M. Fulton, and J. Cirulli. Effect of resistance training on lumbar extension strength. *Am. J. Sports Med*. 17:624–629. 1989.
34. Risser, W.L., J.M. Risser, and D. Preston. Weight-training injuries in adolescents. *Am. J. Dis. Child*. 144:1015–1017. 1990.
35. Spencer, C.W., and D.W. Jackson. Back injuries in the athlete. *Clin. Sports. Med*. 2:191–216. 1983.

36. Stinson, J.T. Spine problems in the athlete. *Md. Med. J.* 45:655–658. 1996.
37. Tall, R.L., and W. DeVault. Spinal injury in sport: Epidemiologic considerations. *Clin. Sports. Med.* 12:441–448. 1993.
38. Thomas, J.S., S.A. Lavender, D.M. Corcos, and G.B. Andersson. Effect of lifting belts on trunk muscle activation during a suddenly applied load. *Hum. Factors.* 41(4):670–676. 1999.
39. Zemper, E.D. Four-year study of weight room injuries in a national sample of college football teams. *Strength. Cond. J.* 12:32–33. 1990.

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