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Spondylolysis in American Football Players: Etiology, Symptoms, and Implications for Strength and Conditioning Specialists

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ABSTRACT

SPONDYLOLYSIS IS A STRESS FRACTURE, TYPICALLY OCCURRING IN THE LUMBAR SPINE. IT IS THE LEADING CAUSE OF BACK PAIN IN ADOLESCENTS, WITH A HIGHER INCIDENCE IN ATHLETES THAN IN THE GENERAL POPULATION. AMERICAN FOOTBALL PLAYERS DEVELOP THE CONDITION AT A HIGHER RATE THAN MOST OTHER SPORTS, AND THE CONDITION CAN CAUSE SEVERAL MONTHS OF MISSED PLAYING TIME. THIS INCREASED INCIDENCE MAY BE DUE TO THE SPINE LOADING INHERENT IN FOOTBALL, BUT IS LIKELY EXACERBATED BY OTHER FACTORS. THIS ARTICLE DESCRIBES A SPONDYLOLYSIS, DISCUSSES THE POTENTIAL CAUSES, AND CONCLUDES WITH A SERIES OF EXERCISES INTENDED TO ADDRESS LIKELY RISK FACTORS.

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INTRODUCTION

Low-back pain (LBP) is a common complaint among adolescent athletes, affecting up to 36% annually (65). In this population one of the most common causes of LBP is a spondylolysis, which is a fracture of the pars interarticularis; an area on the posterior aspect of the vertebrae between the facet joints (87). Indeed, a frequently cited study by Micheli and Wood (59) demonstrated that 47 of 100 adolescent patients complaining of LBP had a spondylolysis. The purpose of this article is to describe a spondylolysis, discuss mechanisms of injury and predisposing factors as they relate to American football players, and then to detail specific activities which may help offset acquired anatomical alignments likely to play a role in the development of this condition.

DESCRIPTION OF SPONDYLOLYSIS

Anatomical discussions of the spine often subdivide it into anterior and posterior columns (31). The anterior column comprises the vertebral body, intervertebral disc, and associated anterior and posterior longitudinal ligaments. The posterior column is the focus of this article, and includes the pedicles, lamina, spinous and transverse processes, and the facet joints. The pedicles and lamina collectively form the neural arch. Between the facet joints is a narrow region of the neural arch called the pars interarticularis. A common defect in this region, typically described as a stress fracture and depicted in Figure 1, is spondylolysis. The term is

KEY WORDS:
pelvic stability; stress fracture; pars interarticularis

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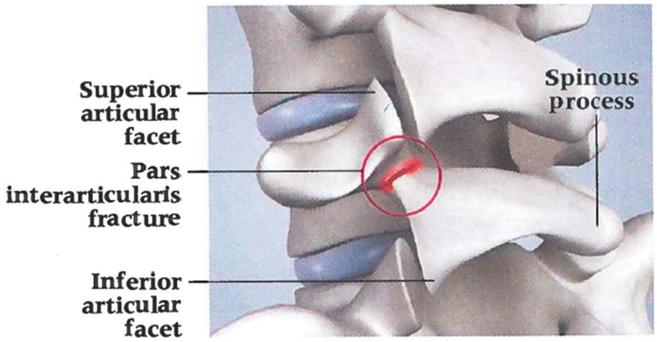

Figure 1. Spondylolysis. Used with permission from McGraw-Hill Education.

a combination of the Greek word "spondylos" which refers to a vertebrae and the suffix "lysis," which means to break down or decompose (17).

The pars interarticularis is the weakest part of the neural arch and particularly susceptible to injury in children and adolescents (17). Individuals who have not yet reached skeletal maturity have areas of growth cartilage and ossification centers in the spine, including one on each mammillary and transverse process (3). These areas are more susceptible to compression, torsion, and distraction than surrounding bones and have been called the "weakest links" in force transfer in the spine (58). The posterior column may not be fully ossified until the age of 25 (42). Nearly 90% of pars interarticularis defects occur in the fifth lumbar (L5) vertebra (80). The fourth lumbar vertebra (L4) is the next most commonly affected (38). The disproportionately high rate of spondylitic defects at L5 is primarily due to its interaction with the sacrum. The steep sagittal angulation of the sacrum causes anterior shear forces across the L5 neural arch (1). Combined with compressive loads on the pars interarticularis when the inferior facets of L4 contact it during full extension, L5 is likely to fail as a result of this "nutcracker" mechanism (11,72).

ETIOLOGY

Pelvic incidence is the sum of sacral slope and pelvic tilt, and individuals with a higher pelvic incidence are more likely to develop spondylolysis (50,64,70). Increased pelvic incidence correlates with increased lumbar lordosis, an abnormal anterior convexity of the lumbar spine, and results in increased compressive forces along the posterior column of the vertebrae (5). Although a variety of techniques have been used to measure lumbar lordosis, the most popular is Cobb's method, which is a measure of the angulation between the superior endplates of the first lumbar vertebrae and the sacrum (5). Using this measurement, mean values range between 54 and 60 degrees in the adolescent population, with some authors noting a report of pain with values above 60 degrees (5,49).

Increased lordosis is positively associated with spondylolysis (6,75). Some have pointed to changes in sacral slope as evidence of genetic inheritance (64), although this work was retrospective. A recent prospective study by Tallarico et al. (83) demonstrated changes in the sacrum after the fracture, indicating a potential anatomical alteration that formed as a result of the fracture. Regardless of whether changes in the sacrum occur before or after the fracture, sacral angulation is not a contributing factor which can be impacted through training. Other inherent anatomical characteristics have been implicated in the development of spondylolysis and spondylolisthesis including larger vertebral canals, abnormal orientation of the facet joints, and pelvic structure (15,35,53).

Although none of these anatomical variables can be impacted by training, of note to the strength and conditioning specialist is the role of pelvic tilt. An anterior tilt of the pelvis produces a hyperlordotic curvature of the lumbar spine, resulting in compression of the posterior aspects of the lumbar vertebrae (5,90). This anterior tilting can result from an imbalance in which spinal extensors are relatively stronger than spinal flexors (41). Although overdevelopment of the extensors can lead to compression of the posterior aspect of the lumbar vertebrae, it should be noted that some authors have pointed to lower extensor strength, relative to the flexors, as a risk factor for LBP (48).

Cyclic loading of the lumbar spine and L5 in particular has been implicated as a primary mechanism of injury for spondylolysis. Movements from full flexion to extension, repeated hyperextension, and repetitive trunk rotation are likely mechanisms (19,42,56). Given that children and adolescents tend to perform these movements frequently as part of their sport training when their neural arch has not completely ossified and their pars is relatively thin, it should come as no surprise that spondylolysis has been implicated as the most prominent cause of back pain in children and adolescents, particularly in athletes (16).

In addition to sport movements, The condition seems to be precipitated by the adolescent growth spurt when a rapid increase in bone growth leads to muscular tightness about the joints of the lumbar spine (4,31,55). Tightness of the iliopsoas and thoracolumbar fascia can both cause increased lumbar lordosis (18). Iliopsoas, in addition to causing a compressive load on the lumbar vertebrae, causes an anterior shear force owing to its course in front of the pubis on its way to the lesser trochanter of the femur (71). Weaknesses of the rectus abdominis (RA), internal and external obliques (EO) all of which flex the spine and produce a posterior pelvic tilt, have

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been suggested as contributors to increased lordosis (71,85). This is more likely in the presence of stiffness of the rectus femoris or tensor fasciae latae, both of which originate on the pelvis, insert onto the tibia, and can produce an anterior pelvic tilt resulting in lumbar lordosis (71,84). Similarly, iliopsoas can cause an anterior pelvic tilt, and tightness of the hip flexors has been associated with LBP (19,45). Stiffness or overdevelopment of the erector spinae group can also cause an anterior pelvic tilt (41). It has also been postulated that the latissimus dorsi, through its origin on the thoracolumbar fascia, can cause lumbar hyperextension and anterior pelvic tilt (71). This anterior tilting is resisted not only by the rectus abdominis and the obliques, but also by the hamstrings (71). The finding of tight hamstrings in patients with spondylolysis may well be due to the chronic stretch produced by an anteriorly tilted pelvis.

SPONDYLOLYSIS AND AMERICAN FOOTBALL

Epidemiological studies have shown an incidence of spondylolysis in the general adult population between 6 and 11% (25,38). In high-level athletes the incidence is slightly higher, observed in up to 14% of individuals in this population (69). In American football players, the incidence may be even higher with reports ranging from 15–21% of all players and some evidence that as many as 50% of linemen have spondylolysis (24,54,76,82). Iwamoto et al. (34) found radiographic abnormalities in the spines of 63% of high school and 60% of college football players, with the presence of spondylolysis as the most important predictor for back pain.

Football players have a higher likelihood of developing spondylolysis based on both the nature of the sport and the training typically employed before competition. Football linemen often start in a 3 or 4-point stance with 1 or 2 hands on the ground and the lumbar spine in a flexed position. At the snap of the ball, they move into a neutral or extended lumbar spine and engage players from the opposing team. At this point, there is an axial load on the spine with the athlete likely to be forced into hyperextension. Gatt et al. (26) noted that loading of the lumbar spine in collegiate linemen hitting a blocking sled exceeded loads previously demonstrated to cause pathologic changes to both the pars interarticularis and intervertebral disc. With college teams running 60–90 plays per game, the volume of loading, along with the magnitude, creates an increased risk of degenerative changes in the lumbar spine, particularly in linemen (27). Furthermore, it should be noted that football linemen also tend to be the largest players on the team, with one study on high school football linemen classifying 45% of them as being in the highest fifth percentile in age-specific body mass index (BMI) (46). This is significant because a high BMI has been correlated with increased lumbar lordosis (62).

In addition to the mechanical loading of the spine inherent to the game, most football players engage in preseason conditioning to prepare for their sport, and the most common activity used in that preparation is weight training (86). Contemporary weight-training programs for football typically include some combination of weightlifting variants such as power cleans, push jerks, or snatch squats, and powerlifting exercises such as squats and deadlifts. There is some evidence that weightlifters are at an increased risk of spondylolysis, with one report showing an incidence of just more than 30% (44). It should be noted that this study used data from before the elimination of the press which, when performed as a competitive lift, often involved significant hyperextension of the spine. Nonetheless, a more recent study by Yang et al. (89) found radiographic evidence of spondylolysis and spondylolisthesis in nearly 29% of weightlifters they examined. Additionally, Yang et al. found that weightlifters demonstrated increased lumbar lordosis relative to a control group and speculated that the altered posture might result from the role of the erector spinae group in resisting anterior shear forces during the lifts. Although not specific to spondylolysis, other works (13,68) have pointed to the low-back as the most frequently injured area in weightlifters. In a study of junior high and high school athletes injured in weight-training programs, 67% of the injuries were to the low back area (7). Similarly, a study of high school powerlifters in Michigan demonstrated that the low back was the most likely to sustain injuries, accounting for more than 50% of injuries (10). A 2011 study on elite powerlifters found that more than 40% of participants surveyed complained of back injuries (77).

SPONDYLOLYSIS SIGNS, SYMPTOMS, AND OUTCOMES

Athletes with spondylolysis typically present with LBP, described as a diffuse dull ache, and no known specific mechanism of injury (31). Resting and lying down typically decrease pain, whereas activity tends to increase it. The pain may radiate into the buttocks and posterior thigh and is exacerbated by lumbar hyperextension, particularly when combined with a single-leg stance (31). Muscular spasm of the spinal erectors is commonly noted, as is hamstring tightness (55). Neurologic symptoms, such as tingling or burning pain along a dermatome or lower extremity weakness are unusual. Spondylolysis is often bilateral and may predispose the athlete to the development of a spondylolisthesis, which is an anterior translation of the vertebrae relative to the next inferior vertebral segment (58).

Once a spondylolysis has been diagnosed, athletes typically respond well to conservative treatment (60). Surgery may be considered if pain does not resolve after 9–12 months of conservative treatment or if there has been a slippage (spondylolisthesis) of greater than 50% of the superior vertebral body over the inferior vertebrae (55). There is some controversy regarding the use of bracing with conservative treatment, with some authors advocating the use of a modified Boston brace to limit extension (57). The brace is worn 23

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hours per day for 3–4 months with weaning thereafter based on evidence of bony healing (31,55). Some authors have pointed out that the brace probably acts more to restrict activity than stabilize the spine and that bony healing has been shown with or without a brace (79). Whether or not bracing is used, rest is the primary component of all protocols. Athletes who stopped sport participation for at least 3 months were 16 times more likely to return to their previous level of play with no pain than those who did not rest as long (21). After this rest period, physical therapy is performed for 2–4 months with athletes eligible to return to play once they have demonstrated full pain-free range of motion (ROM), spinal awareness, appropriate sport-specific conditioning, and no pain while performing sport movements (79). In the authors' experience, the total return to play time is typically 5–7 months.

In addition to missed time, there is some evidence that LBP and injuries that are due to overuse can recur in up to 26% of males (81). This makes sense when one considers that LBP may lead to the development of decreased proprioception in the lumbar spine and altered lumbar muscle activation patterns (28,29). For athletes with prospects of playing at the highest levels, a recent study by Schroeder et al. (74) suggests that football players with a lumbar spine diagnosis, including spondylolysis or spondylolisthesis, were less likely to be drafted and had shorter playing careers in the National Football League (NFL) than matched controls. Brophy et al. (9) found that spondylolysis reduced the likelihood of running backs playing in the NFL and a trend toward fewer receivers with the diagnosis playing in the league. It should be noted that studies on spondylolysis in collegiate football players have not found the condition to adversely affect their playing careers (54,76).

POTENTIAL MITIGATION THROUGH STRENGTH AND CONDITIONING

As previously discussed, spondylitic fractures are a multifactorial condition. From the perspective of the strength and conditioning specialist, it should be noted that lumbar hyperlordosis is a key contributing factor, which can be caused by an anterior tilt of the pelvis. The strength and conditioning specialist may be able to play a role in decreasing the risk that a football player develops a spondylolysis by including activities which help mitigate anterior pelvic tilt. This could be accomplished by incorporating a combination of core endurance work, myofascial release, and static stretching. A recent study by Lee and McGill (47) demonstrated that isometric exercises were more effective at producing stiffness of the torso when compared with dynamic exercises over a 6-week training period. When one considers that spondylitic fractures are precipitated by cyclic flexion, extension, and rotation of the spine, isometric exercises seem to offer an additional benefit of increasing core endurance without adding spinal stresses at end-ranges of motion. Furthermore, Lee and McGill argue that low loads on the spine experienced during isometric exercises allow performance of the exercises almost daily. Given that there is a dose-response relationship between the volume of training and muscular endurance, it stands to reason that a higher total volume of work may confer additional protective benefits (67).

Myofascial release, in the form of foam rolling, has been demonstrated to acutely increase ROM in young adults and resistance-trained adolescent athletes (12,51,52,61,78). Although the exact mechanism for this increase in ROM is unknown, some have speculated that it might be due to a combination of decreased viscosity of the fascia, increased blood flow to the muscle, and decreased adhesions between layers of fascia (23,73). The increase in ROM seems to be greater when foam rolling is combined with static stretching (61,78). In addition to increased ROM, 2 studies have demonstrated positive effects on vertical jump height and muscular force (30,52), whereas another showed a reduction in perception of fatigue after foam rolling (32). Several studies failed to demonstrate enhancement of power, agility, or ROM (32,36). Although static stretching has been demonstrated to increase ROM, there is evidence that it decreases expression of muscular strength and power (8,66). Although a recent review article concluded that the detrimental effects of static stretching are largely limited to longer-duration stretches of more than 60 seconds, it seems prudent to incorporate foam rolling into the pre-exercise routine

Figure 2. Foam rolling for the rectus femoris. Should be performed with the knee both flexed and extended.

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as it has been shown to increase ROM without deleterious effects on muscular strength or power (23,40). Because there seems to be an additive effect between foam rolling and static stretching at increasing ROM, both may be combined in the postexercise routine (61,78). Moreover, foam rolling has been demonstrated to reduce muscle soreness and fatigue, making it a potentially useful recovery tool after exercise (51,73).

FOAM ROLLING

Based on research on the utility of foam rolling at acutely increasing ROM, the authors recommend foam rolling for 2–3 sets of 1 minute in duration for each of the following muscles/groups.

Rectus femoris. The athlete lies in a prone position with the foam roller in contact with the anterior thigh, supporting the body in push-up position with upper extremity. They are instructed to perform passes of the foam roller with the knee both extended and flexed (Figure 2).

Tensor fasciae latae. Although still in a prone position with the foam roller in contact with the superior-lateral anterior thigh and supporting the body in push-up position, the athlete performs passes with the hip both slightly flexed and extended.

Hamstrings. In a supine, seated position with the foam roller in contact with the posterior medial thigh, the athlete performs passes with the foam roller from the superior aspect of the thigh down to the knee. Once several passes have been made, the hip should be rotated to a neutral position for several more, and the athlete should finish by making passes along the posterior-lateral thigh (Figure 3).

Erector spinae. Remaining in a supine position, athletes should lie with arms across their chest, hips, and knees flexed, and the foam roller in contact with the middle of their back. The athlete should then perform passes of the foam roller with the spine in both flexion and extension (Figure 4).

Latissimus dorsi. Continuing in a supine position, athletes place their arms across their chest to put the muscle on tension, with their hips and knees flexed. Beginning with the foam roller in contact with the lower back at the thoracolumbar fascia, the athlete should work the roller superiorly and laterally on both sides. Passes are performed both in supine and side-lying positions with the arm abducted overhead to stretch the latissimus during the rolling maneuver (Figure 5).

Figure 3. Foam rolling for the hamstring group. Perform passes with the hip medially and laterally rotated, and with the hip in a neutral position.

ISOMETRIC STRENGTHENING

Based on the previously cited research on the efficacy of isometric strengthening to increase endurance of the trunk musculature, and a desire to minimize lumbar flexion-extension cycles during training, the authors recommend a program consisting of largely isometric exercises. As noted by Ayotte et al. (2),

Figure 4. Foam rolling for the erector spinae group. Should be performed with the spine both flexed and extended, and the roller should pass from the base of the neck down to the pelvis.

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Figure 5. Foam rolling for the latissimus dorsi. The upper arm can also be medially and laterally rotated to shorten or lengthen the muscle while rolling.

strength gains can be expected if a muscle contracts at 40% of maximum voluntary isometric contraction (MVIC) or higher.

Abdominal drawing-in maneuver. The athlete contracts the transverse abdominis by drawing the umbilicus in toward the spine. An athlete holds this contraction of the transverse abdominis while breathing. If athletes hold their breath to perform this maneuver, they are incorrectly using their diaphragm to perform the exercise. The athlete should be able to speak while performing this exercise, hold for 5–10 seconds, and repeat 20–30 times. A study by Oh et al. (63) demonstrated that the use of this maneuver was effective at inhibiting the activity of the erector spinae group, relative to the gluteus maximus (GM), which can play a role in producing a posterior tilt of the pelvis.

Back bridge. As demonstrated by Kalichman et al. (37,39), the lumbar lordosis is associated with decreased density of the lumbar multifidus (LM) muscle. This exercise is effective at increasing the size and strength of this muscle (88). Athletes start in a supine hook-lying position on the treatment table with their knees flexed to 90°, and their feet flat on the table. Athletes perform an abdominal drawing-in maneuver (ADIM) and then push through the heels to lift their hips into the air while maintaining a straight alignment of their knees, hips, and shoulders. Athletes hold this position for 5 seconds and then lower their backs and hips back to the starting position. An athlete performs 3 sets of 10 repetitions. Ekstrom et al. (20) demonstrated that this exercise achieved 44% MVIC for the multifidus and 40% MVIC for the GM when performed unilaterally. Yang et al. (89) demonstrated significant thickening of the LM after a 5-week program of unilateral back bridges performed 3 times weekly. Moreover, the work by Choi et al. (14) found that the addition of an elastic resistance around the knees during a bilateral back bridge increased the activity of GM by 21% of MVIC and resulted in a 20.5% decrease in pelvic tilt angle during the exercise (Figures 6 and 7).

Prone bridge (Plank). The athlete is prone on the ground and performs an ADIM, and then lifts the body off the ground supported through the elbows, forearms, and toes while continuing to maintain the drawn-in position. The athlete performs 3 sets of 30 seconds initially, and works up to sets for 45–60 seconds. Ekstrom et al. (20) found that this exercise elicited 43% MVIC for the RA, and 47% MVIC for the EO (Figure 8).

Side bridge. Athlete lies on their side, performs an ADIM, and lifts their body off the ground, using their elbow and ipsilateral foot as points of support. Athletes maintain an erect posture with their ankles, knees, and shoulders in a straight line. The athlete performs 3 sets of 30 seconds initially, and works up to 3 sets of 45–60 seconds. A

Figure 6. The back bridge performed with a band around the knees. The addition of an adducting force seems to increase recruitment of the gluteus maximus and decreases anterior tilt during the performance of this exercise.

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Figure 7. The unilateral back bridge. The gluteus maximus and the lumbar multifidus are activated to a greater extent when this exercise is performed using only 1 leg as a base of support.

program of side bridges performed 3 times weekly for 5 weeks produced significant thickening of the EO and was the most effective of the 4 different stabilization exercises at increasing the thickness of the transverse abdominis (88). In their EMG study, Ekstrom et al. (20) reported a mean activation of 69% of MVIC of EO in the side bridge and 74% MVIC for the gluteus medius (Figure 9).

Quadruped alternating extension. The athlete gets in quadruped position, with hands under the shoulders and knees under the hips (Figure 10). An athlete maintains a neutral spine and pelvis. The athlete performs an ADIM and extends an arm and their contralateral leg simultaneously. The athlete returns to the starting position and repeats with the other arm and leg. Compensatory movements, including pelvic rotation or a lateral lean with the torso, should be avoided. One repetition performed on each side equals one repetition total. An athlete performs 3 sets of 10 repetitions. This exercise has been shown to elicit 46% MVIC for the LM, 56% MVIC for the GM, and 42% MVIC for the gluteus medius (20) and was the most effective of the 4 stabilization exercises at increasing the thickness of the internal oblique (IO) (85).

Figure 8. The prone bridge.

Physioball roll out. The athlete starts in a kneeling position with hands flat on a physioball and performs an ADIM. Although maintaining a neutral pelvic position and flexion in the knees, the athlete allows the ball to roll forward. The shoulders will flex as the ball rolls up the forearm toward the elbow. With the shoulders in nearly full flexion, the athlete holds this contraction isometrically, and then extends the shoulders to return back to the starting position. The work by Escamilla et al. (22) has demonstrated that this exercise produces >45% MVIC in both the IO and EO, and 53% MVIC in the lower RA and 63% in the upper RA. This exercise is likely to be particularly useful for offensive linemen who must contract the RA and the obliques isometrically and eccentrically to avoid hyperextension of the lumbar spine while blocking an oncoming defender (Figure 11).

Prone hip extension on a physioball. The athlete starts in a push-up position with a physioball under the lower legs. Again, they will perform an ADIM and attempt to maintain a neutral pelvis throughout the exercise. Once this position has been achieved, the athlete will extend 1 leg at a time, holding for 1 second, and then alternate the legs. This pattern will be repeated 6–10 times with each leg to comprise 1 set. The athlete should perform 2–3 sets. As shown by Escamilla et al. (22), this exercise is effective in eliciting at least 40% MVIC from both the IO and EO, as well as the upper and lower RA. This exercise is useful in enhancing the player's ability to resist motions in the transverse and the sagittal plane (Figure 12).

STRETCHING

All static stretching should be performed after exercise or once athletes

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Figure 9. The side bridge exercise.

are warmed up. An athlete performs each stretch for 3 sets of 30 seconds on each side.

Iliopsoas. The athlete begins by placing one foot on an elevated platform, such as a bench or chair, and getting into the position of a lunge. They should then move their hips and lower extremity anteriorly, while countering the movement by extending the upper torso posteriorly. To increase the stretch, the athlete can reach the ipsilateral arm of the extended leg overhead and across the midline toward the support leg.

Piriformis. Athletes lie supine in a hook-lying position, cross 1 ankle over the opposite thigh, and pull their flexed knee to their chest. The athlete should maintain a neutral spine and avoid flexion of the lumbar spine during the stretch.

Latissimus dorsi. In the tall kneeling position, athletes place their hands on a physioball with their thumbs pointed toward the ceiling, externally rotated, and their elbows extended. Athletes gently lower their chest toward the ground while simultaneously rolling the ball away, flexing their shoulders until they feel a stretch at their shoulder blades. This stretch can be performed one arm at a time or both arms can be stretched simultaneously.

Figure 10. Quadruped alternating extension.

Rectus femoris. An athlete begins in the kneeling lunge position. The athlete contracts glute of the leg on which they are kneeling in order to stabilize the pelvis and avoid lumbar motion. The athlete then leans forward to extend the hip. If athletes want to make this stretch more aggressive, they can then flex their knee and pull their foot toward their hip. As discussed by Kolber and Fiebert (43), it is crucial that the athlete maintains neutral pelvic position during this stretch. As depicted in their work, this can be accomplished by having the athlete perform an ADIM before initiating the stretch and either placing the foot on a physioball or chair to emphasize knee flexion to stretch the rectus femoris without extending the hip.

Tensor fasciae latae. The athlete stands next to a wall and places the arm closest to the wall against it for support. An athlete then puts the leg closest to the wall behind the contralateral leg and leans the hips toward the wall. The athlete counters this movement by laterally flexing the trunk away from the wall.

Spinal erectors. The athlete is instructed to lie supine and pull 1 leg up with the knee flexed toward the chest. The athlete then applies an overpressure on the knee, further flexing the hip. A neutral spine should be maintained by attempting to keep the hip down on the surface, helping avoid flexion of the lumbar spine.

PRACTICAL APPLICATIONS

Spondylolysis has been observed to occur at a higher rate in high-level athletes than the general population. American football players, particularly offensive and defensive linemen,

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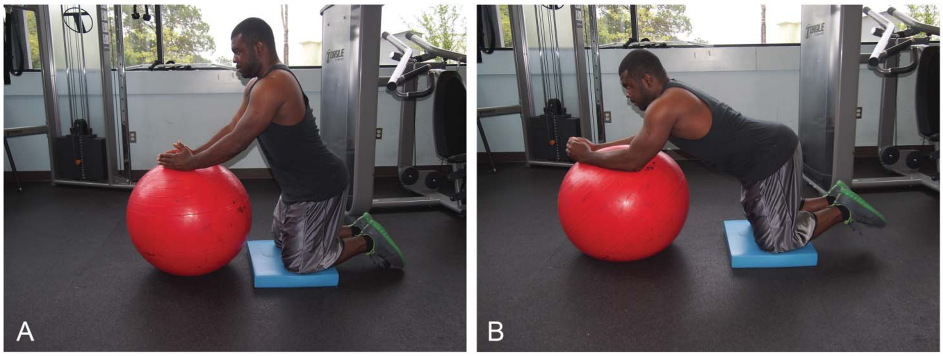

Figure 11. The physioball roll out. This exercise builds upon the prone bridge and requires maintenance of a neutral pelvic position while the upper extremities are in motion. A is the beginning and ending position of the movement. B is the position of isometric contraction of RA, EO, and IO. The athlete should stop rolling the ball forward once a neutral pelvis can no longer be maintained.

seem to have an even higher incidence of the condition than other athletes. In addition to pain and disability, the condition is likely to cause missed time for athletes and may reoccur. Although inherent characteristics of the athlete, such as sacral slope and vertebral configuration play important roles in the development of spondylolysis, hyperlordosis of the lumbar spine has also been correlated with the condition. By incorporating a combination of foam rolling, pelvic stabilization exercises, and static stretching, the strength and conditioning professional may be able to play a role in decreasing anterior tilt of the pelvis and hyperlordosis of the lumbar spine. As a result, athletes should have a decreased risk of developing spondylolysis. Although the time commitment of this program is not insubstantial, it is worth noting that a program consisting of pelvic stabilization exercises performed by Australian Rules football players resulted in increased player availability and a significant perception of benefit among players (33). Keeping players on the field is a primary goal of the strength and conditioning specialist and will lead to better outcomes for the players, the team, and the coach.

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Figure 12. Prone hip extension on a physioball. Another exercise building on the prone bridge. Successful performance requires minimizing lumbar rotation and isolated hip extension.

REFERENCES

1. Alexander MJ. Biomechanical aspects of lumbar injuries in athletes: A review. *Can J Appl Sport Sci* 10: 1–19, 1985.
2. Ayotte NW, Stetts DM, Keenan G, and Greenway EH. Electromyographical analysis of selected lower extremity muscles during

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five unilateral weight-bearing exercises. *J Orthop Sport Phys* 37: 48–55, 2007.

3. Baker BJ, Dupras TL, and Tocheri MW. *The Osteology of Infants and Children*. Vol. 81. College Station, TX: Texas A&M University Press, 2005.
4. Baranto A, Hellstrom M, Cederlund CG, Nyman R, and Sward L. Back pain and MRI changes in the thoraco-lumbar spine of top athletes in four different sports: A 15-year follow-up study. *Knee Surg Sports Traumatol Arthrosc* 17: 1125–1134, 2009.
5. Been E and Kalichman L. Lumbar lordosis. *Spine J* 14: 87–97, 2014.
6. Been E, Li L, Hunter DJ, and Kalichman L. Geometry of the vertebral bodies and the intervertebral discs in lumbar segments adjacent to spondylolysis and spondylolisthesis: A pilot study. *Eur Spine J* 20: 1159–1165, 2011.
7. Brady TA, Cahill BR, and Bodnar LM. Weight training-related injuries in the high school athlete. *Am J Sport Med* 10: 1–5, 1982.
8. Brandenburg JP. Duration of stretch does not influence the degree of force loss following static stretching. *J Sport Med Phys Fit* 46: 526–534, 2006.
9. Brophy RH, Lyman S, Chehab EL, Barnes RP, Rodeo SA, and Warren RF. Predictive value of prior injury on career in professional American football is affected by player position. *Am J Sport Med* 37: 768–775, 2009.
10. Brown EW and Kimball RG. Medical history associated with adolescent powerlifting. *Pediatrics* 72: 636–644, 1983.
11. Bugg WH, Lewis M, Juette A, Cahir JG, and Toms AP. Lumbar lordosis and pars interarticularis fractures. *Skeletal Radiol* 41: 817–822, 2012.
12. Bushell JE, Dawson SM, and Webster MM. Clinical relevance of foam rolling hip hip extension angle in a functional lunge position. *J Strength Cond Res* 29: 2397–2403, 2015.
13. Calhoon G and Fry AC. Injury rates and profiles of elite competitive weightlifters. *J Athl Train* 34: 232–238, 1999.
14. Choi SA, Cynn HS, Yi CH, Kwon OY, Yoon TL, Choi WJ, and Lee JH. Isometric hip abduction using a thera-band alters gluteus maximus muscle activity and the anterior pelvic tilt angle during bridging exercise. *J Electromyogr Kinesiol* 25: 310–315, 2015.
15. Cinotti G, Postacchini F, Fassari F, and Urso S. Predisposing factors in degenerative spondylolisthesis. *Int Orthop* 21: 337–342, 1997.
16. Cohen E and Stuecker RD. Magnetic resonance imaging in diagnosis and follow-up of impending spondylolysis in children and adolescents. *J Pediatr Orthop B* 14: 63–67, 2005.
17. Congeni J. Evaluating spondylolysis in adolescent athletes. *J Musculoskelet Med* 17: 123–129, 2000.
18. d'Hemecourt PA, Gerbino PG, and Micheli LJ. Back injuries in the young athlete. *Clin Sport Med* 19: 663–679, 2000.
19. Donatelli R, Dimond D, and Holland M. Sport-specific biomechanics of spinal injuries in the athlete. *Clin Sport Med* 31: 381–396, 2012.
20. Ekstrom RA, Donatelli RA, and Carp KC. Electromyographic analysis of core trunk, hip, and thigh muscles during 9 rehabilitation exercises. *J Orthop Sport Phys* 37: 754–762, 2007.
21. El Rassi G, Takemitsu M, Glutting J, and Shah SA. Effect of sports modification on clinical outcome in children and adolescent athletes with symptomatic lumbar spondylolysis. *Am J Phys Med Rehab* 92: 1070–1074, 2013.
22. Escamilla R, Lewis C, Bell D, Bramblet G, Daffron J, Lambert S, Pecson A, Imamura R, Paulos L, and Andrews J. Core muscle activation during Swiss ball and traditional abdominal exercises. *J Orthop Sport Phys* 40: 265–276, 2010.
23. Feldbauer CM, Smith BA, and Van Lunen B. The effects of self-myofascial release on flexibility of the lower extremity. *Int J Athl Ther Train* 20: 14–19, 2015.
24. Ferguson RJ, McMaster JH, and Stanitski CL. Low back pain in college football linemen. *Am J Sport Med* 2: 63–69, 1974.
25. Fredrickson BE, Baker D, McHolick WJ, Yuan HA, and Lubicky JP. The natural history of spondylolysis and spondylolisthesis. *J Bone Joint Surg Am* 66: 699–707, 1984.
26. Gatt CJ, Hosea TM, Palumbo RC, and Zawadsky JP. Impact loading of the lumbar spine during football blocking. *Am J Sport Med* 25: 317–321, 1997.
27. Gerbino PG and d'Hemecourt PA. Does football cause an increase in degenerative disease of the lumbar spine? *Curr Sport Med Rep* 1: 47–51, 2002.
28. Gill KP and Callaghan MJ. The measurement of lumbar proprioception in individuals with and without low back pain. *Spine* 23: 371–377, 1998.
29. Grabiner MD, Koh TJ, and Al Ghazawi A. Decoupling of bilateral paraspinal excitation in subjects with low back pain. *Spine* 17: 1219–1223, 1992.
30. Halperin I, Aboodarda SJ, Button DC, Andersen LL, and Behm DG. Roller massager improves range of motion of plantar flexor muscles without subsequent decreases in force parameters. *Int J Sport Phys Ther* 9: 92–102, 2014.
31. Haus BM and Micheli LJ. Back pain in the pediatric and adolescent athlete. *Clin Sport Med* 31: 423–440, 2012.
32. Healey KC, Hatfield DL, Blanpied P, Dorfman LR, and Riebe D. The effects of myofascial release with foam rolling on performance. *J Strength Cond Res* 28: 61–68, 2014.
33. Hides JA, Stanton W, Mendis MD, and Gildea J. Effect of stabilisation training on trunk muscle size, motor control, low back pain and player availability among elite Australian Rules football players. *Br J Sports Med* 45: 320, 2011.
34. Iwamoto J, Abe H, Tsukimura Y, and Wakano K. Relationship between radiographic abnormalities of lumbar spine and incidence of low back pain in high school and college football players. *Am J Sport Med* 32: 781–786, 2004.
35. Jackson RP, Phipps T, Hales C, and Surber J. Pelvic lordosis and alignment in spondylolisthesis. *Spine* 28: 151–160, 2003.
36. Jay K, Sundstrup E, Sondergaard SD, Behm D, Brandt M, Saervoll CA, Jakobsen MD, and Andersen LL. Specific and cross over effects of massage for muscle soreness: Randomized control trial. *Int J Sport Phys Ther* 9: 82–91, 2014.
37. Kalichman L, Hodges P, Li L, Guermazi A, and Hunter DJ. Changes in paraspinal muscles and their association with low back pain and spinal degeneration: CT study. *Eur Spine J* 19: 1136–1144, 2010.
38. Kalichman L, Kim DH, Li L, Guermazi A, Berkin V, and Hunter DJ. Spondylolysis and spondylolisthesis: Prevalence and association with low back pain in the adult community-based population. *Spine* 34: 199–205, 2009.
39. Kalichman L, Li L, Hunter DJ, and Been E. Association between computed tomography-evaluated lumbar lordosis and features of spinal degeneration, evaluated in the supine position. *Spine J* 11: 308–315, 2011.
40. Kay AD and Blazevich AJ. Effect of acute static stretch on maximal muscle performance: A systematic review. *Med Sci Sport Exer* 44: 154–164, 2012.

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41. Kim HJ, Chung S, Kim S, Shin H, Lee J, Kim S, and Song MY. Influences of trunk muscles on lumbar lordosis and sacral angle. *Eur Spine J* 15: 409–414, 2006.

42. Kim HJ and Green DW. Spondylolysis in the adolescent athlete. *Curr Opin Pediatr* 23: 68–72, 2011.

43. Kolber MJ and Fiebert IM. Addressing flexibility of the rectus femoris in the athlete with low back pain. *Strength Cond J* 27: 66–73, 2005.

44. Kotani PT, Ichikawa N, Wakabayashi W, Yoshii T, and Koshimune M. Studies of spondylolysis found among weight lifters. *Br J Sport Med* 6: 4–8, 1971.

45. Kujala U, Salminen J, Taimela S, Oksanen A, and Jaakkola L. Subject characteristics and low back pain in young athletes and nonathletes. *Med Sci Sport Exer* 24: 627–632, 1992.

46. Laurson KR and Eisenmann JC. The prevalence of overweight among high school football linemen. *J Am Med Assoc* 297: 363–364, 2007.

47. Lee BC and McGill SM. Effect of long-term isometric training on core/torso stiffness. *J Strength Cond Res* 29: 1515–1526, 2015.

48. Lee JH, Hoshino Y, Nakamura K, Kariya Y, Saita K, and Ito K. Trunk muscle weakness as a risk factor for low back pain. *Spine* 24: 54–57, 1999.

49. Lee JH and Yoo WG. Application of posterior pelvic tilt taping for the treatment of chronic low back pain with sacroiliac dysfunction and increased sacral horizontal angle. *Phys Ther Sport* 13: 279–285, 2012.

50. Legaye J, Duval-Beaupere G, Hecquet J, and Marty C. Pelvic incidence: The fundamental pelvic parameter for three-dimensional regulation of spinal sagittal curves. *Eur Spine J* 7: 99–103, 1998.

51. MacDonald GZ, Button DC, Drinkwater EJ, and Behm DG. Foam rolling as a recovery tool after an intense bout of physical activity. *Med Sci Sport Exer* 46: 131–142, 2014.

52. MacDonald GZ, Penney MD, Mullaley ME, Cuconato AL, Drake CD, Behm DG, and Button DC. An acute bout of self-myofascial release increases range of motion without a subsequent decrease in muscle activation or force. *J Strength Cond Res* 27: 812–821, 2013.

53. Masharawi Y. Lumbar shape characterization of the neural arch and vertebral body in spondylolysis. *Clin Anat* 25: 224–230, 2012.

54. McCarroll JR, Miller JM, and Ritter MA. Lumbar spondylolysis and spondylolisthesis in college football players. *Am J Sport Med* 14: 404–406, 1986.

55. McCleary MD and Congeni JA. Current concepts in the diagnosis and treatment of spondylolysis in young athletes. *Curr Sport Med Rep* 6: 62–66, 2007.

56. McGill SM. *Low Back Disorders: Evidence-Based Prevention and Rehabilitation*. Vol. 51. Champaign, IL: Human Kinetics, 2002. pp. 217.

57. McNeely ML, Torrance G, and Magee DJ. A systemic review of physiotherapy for spondylolysis and spondylolisthesis. *Man Ther* 8: 80–91, 2003.

58. Micheli L and Curtis C. Stress fractures in the spine and sacrum. *Clin Sport Med* 25: 75–88, 2005.

59. Micheli L and Wood R. Back pain in young athletes. *Arch Pediatr Adolesc Med* 149: 15–18, 1995.

60. Miller SF, Congeni JA, and Swanson K. Long-term functional and anatomical follow-up of early detected spondylolysis in young athletes. *Am J Sport Med* 32: 928–933, 2004.

61. Mohr AR, Long BC, and Goad CL. Effect of foam rolling and static stretching on passive hip-flexion range of motion. *J Sport Rehabil* 23: 296–299, 2014.

62. Murrie VL, Dixon AK, Hollingworth W, Wilson H, and Doyle TA. Lumbar lordosis: A study of patients with and without low back pain. *Clin Anat* 16: 144–147, 2003.

63. Oh JS, Cynn HS, Won JH, Kwon OY, and Yi CH. Effects of performing an abdominal drawing-in maneuver during prone hip extension exercises on hip and back extensor muscle activity and amount of anterior pelvic tilt. *J Orthop Sports Phys Ther* 37: 320–324, 2007.

64. Oh YM, Choi HA, and Eun JP. The comparison of sagittal spinopelvic parameters between young adult patients with L5 spondylolysis and age-matched control group. *J Korean Neurosurg Soc* 54: 207–210, 2013.

65. Olsen TL, Anderson RL, Dearwater SR, Kriska AM, Cauley JA, Aaron DJ, and LaPorte RE. The epidemiology of low back pain an in adolescent population. *Am J Public Health* 82: 606–608, 1992.

66. Pinto MD, Wilhelm EN, Tricoli V, Pinto RS, and Blazevich AJ. Differential effects of 30- vs. 60-second static muscle stretching on vertical jump performance. *J Strength Cond Res* 28: 3440–3446, 2014.

67. Radaelli R, Fleck SJ, Leite T, Leite RD, Pinto RS, Fernandes L, and Simao R. Dose-response of 1, 3, and 5 sets of resistance exercise on strength, local muscular endurance, and hypertrophy. *J Strength Cond Res* 29: 1349–1366, 2015.

68. Raske A and Norlin R. Injury incidence among elite weight and power lifters. *Am J Sport Med* 30: 248–256, 2002.

69. Rossi F and Dragoni S. The prevalence of spondylolysis and spondylolisthesis in symptomatic elite athletes: Radiographic findings. *Radiography* 7: 37–42, 2001.

70. Roussouly P, Gollogly S, Bertonnaud E, Labelle H, and Weidenbaum M. Sagittal alignment of the spine and pelvis in the presence of L5-S1 isthmic lysis and low-grade spondylolisthesis. *Spine* 31: 2484–2490, 2006.

71. Sahrmann S. *Diagnosis and Treatment of Movement Impairment Syndromes*. Vol. 31. St Louis, MO: Mosby, 2002. pp. 63–68, 136.

72. Sakai T, Sairyo K, Suzue N, Kosaka H, and Yasui N. Incidence and etiology of lumbar spondylolysis. *J Orthop Sci* 15: 281–288, 2010.

73. Schroeder AN and Best TM. Is self myofascial release an effective preexercise and recovery strategy? *Curr Sport Med Rep* 14: 200–208, 2015.

74. Schroeder GD, Lynch TS, Gibbs DB, LaBelle M, Patel AA, Savage JW, Hsu WK, and Nuber GW. Pre-existing lumbar spine diagnosis as a predictor of outcomes in National Football League athletes. *Am J Sport Med* 43: 972–978, 2015.

75. Schuller S, Charles YP, and Steib JP. Sagittal spinopelvic alignment and body mass index in patients with degenerative spondylolisthesis. *Eur Spine J* 20: 713–719, 2011.

76. Semon RL and Spengler D. Significance of lumbar spondylolysis in college football players. *Spine* 6: 172, 1981.

77. Siewe J, Rudat J, Rollinghoff M, Schlegel UH, Eysel P, and Michael JW. Injuries and overuse syndromes in powerlifting. *Int J Sport Med* 32: 703–711, 2011.

78. Skarabot J, Beardsley C, and Stirn I. Comparing the effects of self-myofascial release with static stretching on ankle range-of-motion in adolescent athletes. *Int J Sport Phys Ther* 10: 203–212, 2015.

79. Standaert CJ and Herring SA. Expert opinion and controversies in sports and musculoskeletal medicine: The diagnosis and treatment of spondylolysis in

Copyright © National Strength and Conditioning Association. Unauthorized reproduction of this article is prohibited.

adolescent athletes. *Arch Phys Med Rehab* 88: 537–540, 2007.

80. Sutton JH, Guin PD, and Theiss SM. Acute lumbar spondylolysis in intercollegiate athletes. *J Spinal Disord Tech* 25: 422–425, 2012.

81. Taimela S, Kujala UM, Salinen JJ, and Viljanen T. The prevalence of low back pain among children and adolescents: A nationwide cohort-based questionnaire survey in Finland. *Spine* 22: 1132–1136, 1997.

82. Tall RL and DeVault W. Spinal injury in sport: Epidemiologic considerations. *Clin Sport Med* 12: 441–446, 1993.

83. Tallarico RA, Fredrickson BE, Whitesides TE, and Lavelle WF. The association of sacral table angle measurements with spondylolytic and spondylolisthetic defects at the lumbosacral articulation: A radiographic analysis. *Spine Def* 3: 372–397, 2015.

84. Tateuchi H, Taniguchi M, Mori N, and Ichihashi N. Balance of hip and trunk muscle activity is associated with increased anterior pelvic tilt during prone hip extension. *J Electromyogr Kinesiol* 22: 391–397, 2012.

85. Waryasz GR. Exercise strategies to prevent the development of the anterior pelvic tilt: Implications for possible prevention of sports hernias and osteitis pubis. *Strength Cond J* 32: 56–65, 2010.

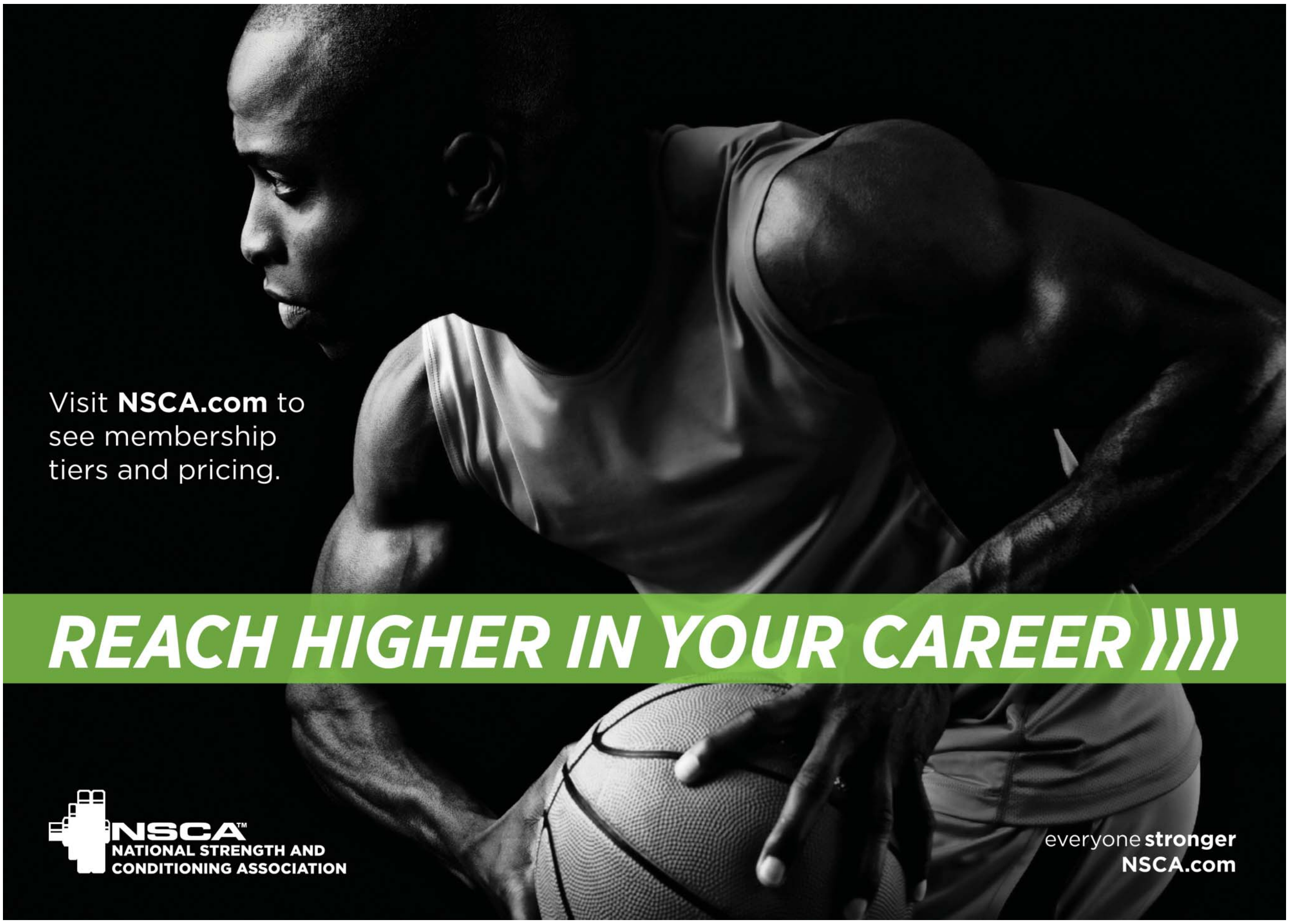
86. Wilkerson GB, Giles JL, and Seibel DK. Prediction of core and lower extremity strains and sprains in collegiate football players. *J Athl Train* 47: 264–272, 2012.

87. Wiltse LL, Widell EH, and Jackson DW. Fatigue fracture: The basic lesion in isthmic spondylolisthesis. *J Bone Joint Surg Am* 57: 17–22, 1975.

88. Yang HS, Lee YS, and Jin SA. Effect of evidence-based trunk stability exercises on the thickness of trunk muscles. *J Phys Ther Sci* 27: 473–475, 2015.

89. Yang JH, Barani R, Bhandarkar AW, Suh SW, Hong JY, and Modi HN. Changes in spinopelvic parameters of elite weightlifters. *Clin J Sport Med* 24: 343–350, 2014.

90. Youdas JW, Garrett TR, Egan KS, and Therneau TM. Lumbar lordosis and pelvic inclination in adults with chronic low back pain. *Phys Ther* 80: 261–275, 2000.



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