Core and Back Rehabilitation for High-speed Rotation Sports: Highlight on Lacrosse

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Abstract
Lacrosse is a fast-paced game that incorporates elements from multiple sports, such as soccer, basketball, baseball, tennis, and hockey. The sport involves rapid changes of direction, endurance, sprinting, physical contact, rotational movement, passing, and shooting. Passing and shooting are further complicated by having a weighted object (ball) at the end of a long moment arm (crosse) which places increased stress on the body segments. Thus, it is important to properly prepare for sport participation by improving strength, endurance, and dynamic stability of the postural and core stability muscles. Because high mechanical loads are experienced during play, (re)establishment of symmetric strength and flexibility is essential for rehabilitation and injury prevention. This article will focus on the musculoskeletal demands placed on the body in lacrosse, the importance of core strength and dynamic stability to prevent injury, and the elements of both prehabilitation and rehabilitation programs to properly prepare the athlete for participation.

Introduction

In 2016, national lacrosse participation reached an all-time high of 825,000 players in organized teams, a number up 255% over a 15-year span (1). Growth continued in all levels of play that year from 2.2% in youth to 54.2% at the professional level for men and women (1). Establishment of postcollegiate clubs and adult leagues also is rising in the United States. At the international level, global participation continues to expand to nations on several continents. Lacrosse is a fast-paced game involving running, rapid change of direction, dodging, physical contact, passing, and shooting. Complexities of the game include strategizing, dual-attention tasking and fast decision making. Lacrosse athletes must perform precise movements under unique physical demands, whereby they are often running or playing in unbalanced conditions while under physical contact pressure. The culmination of these game factors amplifies the risk for several types of musculoskeletal pain and injury, particularly when the stakes are higher in competition (2).

Despite the rapid growth of the sport, research and development of appropriate prerehabilitation and rehabilitation training strategies has lagged behind. However, emerging and consistent evidence is showing the relevance of superficial and deep core and back muscles to the sport motions similar to those produced in lacrosse (3–5) and possible factors related to injury risk in lacrosse players (6). The major superficial muscles of the core include the latissimus dorsi, trapezius, rhomboids, and external obliques rectus abdominis. The main deep core muscles include erector spinae, multifidus, quadratus lumborum, psoas, internal abdominal oblique, and transverse abdominis. Proximal muscles that support the pelvis include the gluteus (medius, maximus), piriformis, and gemellus. A relationship between trunk muscle activity and lower-extremity movement exists, such that poor core stability may contribute to injury and core training may reduce this injury risk (7). The rationale of the phrase, "proximal stability for distal mobility"(8), is that a stable core can efficiently respond to or anticipate changing sport conditions, which is believed to reduce injury risk and improve performance (9). Core stability involves the lumbopelvic hip complex and diaphragm and is defined as the ability to maintain the spine in its normal physiological limits with varying perturbations (7). Because dynamic stability is continually challenged during lacrosse, and players must shoot, pass, or catch in awkward positions through defenders, it is of utmost importance to strengthen the core. Additionally, body contact, or checking, is permitted in boys' and men's lacrosse, while no body contact is permitted in girls' and women's lacrosse. Here, we will provide the most recent evidence of the potential risk for injury and the necessity of core and back strengthening that pertain to lacrosse performance optimization and injury prevention.

Noncontact Injury Patterns That Relate to Core Strength Deficiencies

Risk factors for pain or injury include intrinsic factors (body mechanics, age, sex, joint hypermobility, skill level)

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and extrinsic factors (game rules, protective equipment use, position plated, and game vs. practice) (10). Checking and unintentional contact (hits from stick, ball, or another player) contributes to a variety of acute injuries, such as fracture, contusions, sprains, and concussions (2,11,12). The noncontact mechanisms of injury that require prehabilitation and rehabilitation to minimize the threat from an underdeveloped neuromotor system are most relevant here. Compiled estimates indicate that 18.1% of all injuries fall in this category across the age spectrum in boys (13). Of all reported injuries in collegiate men's lacrosse, 29.6% and 40% were categorized as "noncontact injuries" that occurred during games and practice, respectively (14). Injuries can include overuse, sprain, and strain. Girls and women tend to have relatively more injuries in the lower extremity than boys and men, particularly in the knee and ankle (10,15). Among boys and men, common noncontact injury sites during practice and competition include knee sprain, ankle sprains, and leg strains (upper leg, hip/groin). The frequency at which noncontact and overuse injuries occur jumps from 6.3% in U9/U11 boys to 23.3% in U13/U15, indicating a critical age in which strengthening may help offset this injury risk (13). Interestingly, the injury frequency for these same mechanisms is 30.4% in U9/U11 girls and 25% in U13/U15 (16), supporting that young girls may be a target population who may benefit from core and other strengthening. Even game officials are at risk for injury. Recently, U.S. Lacrosse officials have been provided a core exercise toolkit to help them reduce discomfort postgame and reduce injury risk (17).

Mechanical Stressors of Key Lacrosse Motions

Three of the sports skills in lacrosse that have been studied include shooting, running, and jump landings. Offensive and defensive players participate in all of these motions to a varying degree, and with different crosse characteristics. For example, most midfielders run relatively more while carrying shorter, lighter crosses compared with most defensemen who may run less, but wield longer poles or hold heavier goalie sticks. Hence, there is wide variation in the mechanical stress among different player positions with different combination of stick lengths, weights and field coverage during play. For all positions, crisp and fast ball movement is required for successful passing, clearing, or scoring.

Throwing and shooting

Different types of shots and methods of shooting the ball exist (18). There are numerous game situations in which players must adjust their shot motion, such as dodging defensemen, shooting on the run (18), and the position of the goalie in the goal. Every shot, however, requires coordinated transfer of energy from the lower body to the upper body for maximal power and ball velocity. There are common underlying motion patterns that require coordination, power, and movement accuracy for successful play. Compared with other throwing sports like baseball and cricket that require 70 to 110 maximal throws per game, lacrosse players perform an extensive volume of slower velocity passes and fewer maximal-velocity shooting to score. During practices, our conservative estimates indicate that high school players throw the ball more than 200 times per session in warm-ups, drills, and scrimmages. The accumulated volume of throwing may increase stress on key anatomic areas of rotation such as the lumbar spine or shoulder. Recent estimates indicate that 11.0% (13) of players incur injuries while shooting, indicating that there is a need to better prepare players for this motion.

Vincent et al. (19) described the overhand lacrosse shooting motion and Macaulay et al. provided additional insight on the overhand, sidearm, and underhand shot (20). Outdoor lacrosse players predominantly take shots on the run, after a series of small steps or coming to a stop. These start-and-stop change of direction motions are similar to other sports like basketball. Indoor players typically use one-step shooting. Skilled players can shoot equally well from both sides. Irrespective of shot type, similar events occur in the shooting motion which require strong core muscles. As a shot is initiated, similar to that of a golf swing or a baseball pitch, the peak rotational velocities should occur earliest for the pelvis, followed by the torso and then shoulder during the shot or throw (19,21,22). The back and abdominal muscles must engage to initiate the throw, create a stable base of support during thoracic rotation, and decelerate the trunk during follow-through. An important note is that players who shoot at very high speeds may be at greater risk for reporting chronic low back pain; we found that Major League Lacrosse players, especially midfielders, show motion features that increase mechanical stress at the lumbar spine and sacroiliac joint (23). Wasser et al. (24) also found that onset of mild low back pain among high school and collegiate players corresponded to a 23.9% reduction in trunk maximal angular velocity, and in the incremental change in angular velocity from pelvis to trunk (87 degrees$\cdot$s^{-1} vs 151 degrees$\cdot$s^{-1}, respectively). Ball velocity was 12.7 km$\cdot$h^{-1} less in players with back pain. Rehabilitation training plans should emphasize core strengthening to foster improved sequencing of throwing motion and bracing of the lumbopelvic complex to maintain shooting performance and prevent injury.

In our laboratory, we found that among young lacrosse players, pelvic and torso maximal angular velocities during shooting occurred 11% to 19% later in the throw cycle compared with more experienced players, thereby reducing ball speed and increasing stress loads on more distal body segments (23). Altered timing of the sequence of segment rotations could contribute to relatively high shoulder or elbow forces and subsequent injury compared to collegiate and professional players (19). Rehabilitation maneuvers that recruit core muscles during complex motions may be helpful in enhancing activation of these muscles earlier in the throwing or shooting motion.

Running with a crosse

Running alone requires core and back strength for optimal body posture, pelvic anterior tilt, and hip-knee kinematics. The back and abdominal musculature is activated and increased with progressively greater running intensity (4). Dysfunction of the deep core musculature during running contributes to mechanical stress transfer to the spine and improper muscle coordination and compensatory movements (3). Holding a crosse while running causes asymmetric systemic loading, particularly when carrying it single-handedly. While both compressive and shear forces act at the spine during running, asymmetric loading from the crosse may amplify these forces, especially if the core strength is inadequate. During run-to-cut or pivoting maneuvers, cocontraction of lumbar extensor muscles and inadequate trunk flexion may contribute to stiffer landings and increased risk for anterior cruciate ligament (ACL) injury (9). Epidemiologic data show that 17.8% of youth male players younger than 15 years become injured while running, chasing a ball, passing, or receiving a pass (13). Observational data from the men's World Lacrosse Championships indicated that change of direction and/or speed were the most common noncontact injury mechanisms, with 50.7% of injuries occurring in the lower extremity (ankle most commonly injured joint) (25). Among collegiate female players, severe knee ligament injuries (ACL) occur frequently (26). A potential mechanism contributing to this is that when running with a two-handed hold on a lacrosse stick, the knee valgus moment during stance increases in women by an average of 1.7% of body weight × height (27).

In situations where players are unable to use one arm for balance and must carry the stick with both arms, control of the trunk must be achieved by abdominal and lumbar muscles (27). If these core muscles are insufficiently strong to provide stability in running, the center of mass shifts laterally and increases the knee valgus moment. Higher proximal neuromuscular control, defined as more overall gluteal and trunk muscle activity during front swing phase and backswing phase (when airborne), also can protect against hamstring injuries during sprinting (28). In offensive or defensive sprint bursts, this protection for lacrosse players is important. Moreover, running stability is important for offensive players who must resist and run against defenders who are attempting to dislodge the ball or push the players away from scoring range.

Jump landings

Jump landings can occur when players must jump up to catch a high pass or a clear, or to block a shot or pass. Appropriate technique is required to minimize the risk for severe knee injuries when landing (29). During competition and practice scenarios, jump landings do not typically replicate those in the laboratory setting. First, players carry crosses, which could produce adverse biomechanics in the lower extremity and increase hip adduction. Second, players may land single-legged after jumping vertically to catching a pass. Third, players may run to catch a clear from the goalie, jump up and land after the run. Controlled trunk position and deceleration during landing is dependent in part on adequate core strength and muscle activation to support the pelvis, hips, and lower-extremity position. Lower-body injuries are related to excessive motion at the trunk. For example, lateral trunk flexion and knee abduction angles are larger in athletes who incur knee injuries (30). This excessive motion supports the need for strong and fatigue-resistant muscles that buttress the abdomen, back, and pelvis to prevent excess motion in the distal body segments. When the core or back strength is inadequate, there is instability in the jump landing motion. A primary target for injury is the knee. Injury and athlete exposure data show that ACL injury rates are higher in female than male high school and collegiate players (rate 3.16 to 0.93 in females vs. 1.3 and 1.14 in males per 10,000 athletic exposures) (31). Balance training, neuromuscular exercise, and plyometrics may be used to modulate knee angulation and trunk positioning upon landing (32). The individual components of rehabilitation programs (plyometrics, strengthening, core) reduce the risk for ACL injury by 61% to 68% (30).

Core and Back Strengthening for Injury Prevention in Lacrosse

Systematic reviews of best evidence of injury prevention training programs specific to lacrosse do not yet exist; however, several reviews and intervention studies (7,30,32–36) provide methods used in athletes from other sports that can be directly applied to lacrosse. With respect to the sport-specific variation in shooting motion, running with a crosse and jump landings, we propose that combinations of training program components may be the most beneficial for lacrosse athletes compared with programs that focus on one type injury prevention alone. The Osteoarthritis Action Alliance consensus opinion paper describes that among the best practices of injury prevention programs for ACL and lower-extremity injuries are strengthening, proximal control maneuvers, and minimal-to-no extra equipment (33). Proximal control through core strengthening has been shown to be vital in reducing the risk of injuries (37), and athletes with core muscle weakness demonstrate elevated risks of knee joint injuries and groin strain (30,37). Studies show that there is protective value of each different rehabilitation component in a training program (*e.g.*, balance training, plyometrics) (35) against noncontact injuries, such as ACL. When activated appropriately and synergistically, deep and superficial core muscles collectively maintain posture, create an abdominal brace to support the spine, and increase pelvic stability.

Goals of lacrosse rehabilitation programs should be to improve movement safety by fostering dynamic movement control in the three planes of motion, increasing movement velocity and power, and optimizing coordination and motion sequencing. These programs can be used for injury prevention (prehabilitation) and for postinjury rehabilitation. Thus, exercises should target increased coordination, strength, and stability of the core stabilizing muscles. Programs can progress over time by varying exercise intensity through changing surface stability (foam pads, wobble boards, BOSU balls). Hip and torso strength and coordination should be established in conjunction with removal of lateral balance, postural stability, and single-legged strength deficits. Neuromuscular challenges that promote proper correction of body position with perturbation are critical to simulate the real experience of lacrosse.

Table 1 provides an overview of the categories of exercises that can be a valuable part of lacrosse core and back rehabilitation training programs. Note that many of these exercises can provide more benefits than core and back strengthening alone. As exercises become more complex, additional musculature is required to maintain balance or postural control. This complexity of movement is of direct importance in lacrosse, as athletes are often doing more than just a simple task of a jump landing, or a throw or running. Increasing exercise complexity and providing variety of exercises prepares the athlete for rapid movement

Table.
Core and back stability exercises for lacrosse players.

Category	Sample Exercises	Increasing Complexity
Planks	Standard plank	Forearm plank, TRX plank, walking plank, side plank, X-Plank, BOSU topside plank, side plank with leg lift, knee to outside elbow plank, side plank crunches, plank jacks, plank rollout on stability ball;
	Mountain climbers	Cross body mountain climber, BOSU or stability ball mountain climber
Trunk flexion-extension	Abdominal curl	Bow-to-boat, Russian twist (with or without weight), V-ups, dead bugs, raised leg crunch, dumbbell crossover punch sit-up
	Lumbar extension (Supermans)	Lift one leg and opposite arm and switch
Dynamic balance	Single-legged squats	Single-legged squats while catching or throwing a ball, throwing off a rebounder, throw lacrosse ball off rebounder while standing on one leg, skaters
	Dual-legged balance on unstable surface	Throwing and catching light medicine ball off of a rebounder
	Lunges	Lunges with twist, weighted lunges with twist (dumbbells or cable cross), lunges with front leg on wobble board, lunges carrying crosse
Core synergistic movements	Woodchoppers (horizontal cable)	Medicine ball high-to-low, woodchoppers
	Squat running	Squat run with light dumbbells
	Steam engine	
	Medicine ball throws (lateral with partner)	Medicine ball slams on ground
	Overhead trunk circles	Holding medicine ball or dumbbell in hands
	Up, run, and shoot	Lay down on supine on ground and rapidly get up, grab the crosse and run toward goal, catch a pass and shoot
Plyometrics	Side to side lateral jumps	One legged jumps, jumps holding a crosse
	Box jumps	Jumps with crosse and immediately catch a pass after landing
	Jump lunges	Carry crosse, medicine ball, or light weights during lunges
	Heisman holds	
	Alternating leg tire hops	Dual-handed light weights during hops
	Plyo push-ups	Perform using a stability ball under one hand

To ensure that exercises are performed correctly, oral and visual feedback should be provided to help improve body position (knee angulation, leg stiffness, or extension), positioning of trunk over feet and degree of trunk lean.

changes in a real-play situation. In addition to progressively increasing the complexity and challenge of each exercise, it is important to integrate sport-specific movements into the program. The exercises described have wide applicability across a range of sports to reduce the risk of injury. Incorporation of sport-specific activities, such as cradling, catching, passing, or shooting, during some of the core exercises can provide a more direct relationship between the exercise, injury reduction, and sport performance.

Planking and Trunk Flexion-extension

Planking exercise performed prone and on the side, sit-ups, and exercises with abdominal curl are important (30) to help players maintain posture and spinal neutrality. As strength increases, the two motions can be combined together, as used in side plank crunches or mountain climbers. Intensity may be increased though changing the surface, by using BOSU balls or a wobble board for creating perturbations to which the athletes must respond to maintain the plank position. A variety of abdominal crunch actions exists beyond the traditional sit-up. For example, these can include a raised leg abdominal crunch or a V-up where the arms and legs reach straight out to position the body in a V shape. Adding hand-weights or a medicine ball to perform Russian twists can not only increase the workload but also activate the abdominal and back muscles to rotate the trunk about the lumbar spine in a flexed trunk position.

Dynamic Balance

To help prepare players for running with a crosse, shooting on the run, jump landings, or pushing against defenders while running, dynamic balance exercises are critical. Dynamic balance and strengthening can be practiced using single-leg or dual-legged balance exercises. After mastering mechanics of single-leg squats, intensity of exercise can be enhanced by standing on one leg while throwing to, or catching a ball from a partner. The partner also may stand behind the athlete and throw a ball against a wall and the athlete must catch the ball on the rebound single-handed while maintaining balance. Lunges challenge dynamic balance, particularly if the motion is coupled with twisting of the trunk with or without weight, or changing the surface under the lead foot. Skaters, with movements that leverage single-leg squats to simulate long-distance skating, produce more balance perturbation and require more contribution of core stability. Exercise variations can be achieved by performing dual-legged balance on a wobble board while throwing a light medicine ball off a rebounder and catching it from the front or from the side. While these exercises challenge the core muscles, these also can protect against ankle ligament injuries (sprains) (37).

Core Synergistic Exercises

A category of exercises is available to help athletes develop better recruitment of core stabilizers during complex motions that involve turning, change of body level, or both. For example, woodchoppers can isolate trunk muscles by using a cable crossover while standing and pulling in a horizontal direction. Complexity can increase by using a medicine ball and pulling the ball from a high position laterally above the head, rotating the body to the opposite side, squatting, and pulling the ball down toward the floor. Other variations that enhance trunk stability for running include squat running or steam engines. Intensity can be increased for these exercises by adding light hand weights or increasing speed, respectively.

Plyometrics

Plyometric training involves stretching of active muscles before contraction and explosive movement. Neuromotor rehabilitation programs that include a plyometric component have been shown to help protect against knee injuries (36). This category of exercise includes jumping forward and backwards, side-stepping movement, tuck jumps, squat jumps, and jumping on one leg. Holding a crosse in one or both hands will help train positioning of the trunk over the pelvis relative to the lower extremity. The addition of light dumbbells to lower-extremity exercises can increase the intensity. Plyometric movements also can be used for the upper body, such as plyometric push-ups. Upper-body plyometrics may translate on the field to helping defensive players push against opponents, and help offensive players push around defenders to score. While there are numerous benefits of plyometrics on knee mechanics on ACL injury risk reduction (including reduction in ground reaction force, side-to-side asymmetries in landing forces) (30), these motions also require strong proximal control and core muscle engagement. Intervention studies show that trunk rotation away from the new direction during unanticipated cutting movements is decreased, and pelvis orientation toward the new direction improved after plyometric training (38). The limited data available suggest that plyometric style push-ups induce enhanced synchrony of peak muscle activation of external abdominal and back muscles compared with other push-up versions (39).

When to Start Core and Back Rehabilitation in Lacrosse Players?

Injury epidemiology shows that even younger lacrosse players experience noncontact injuries as early as 9 to

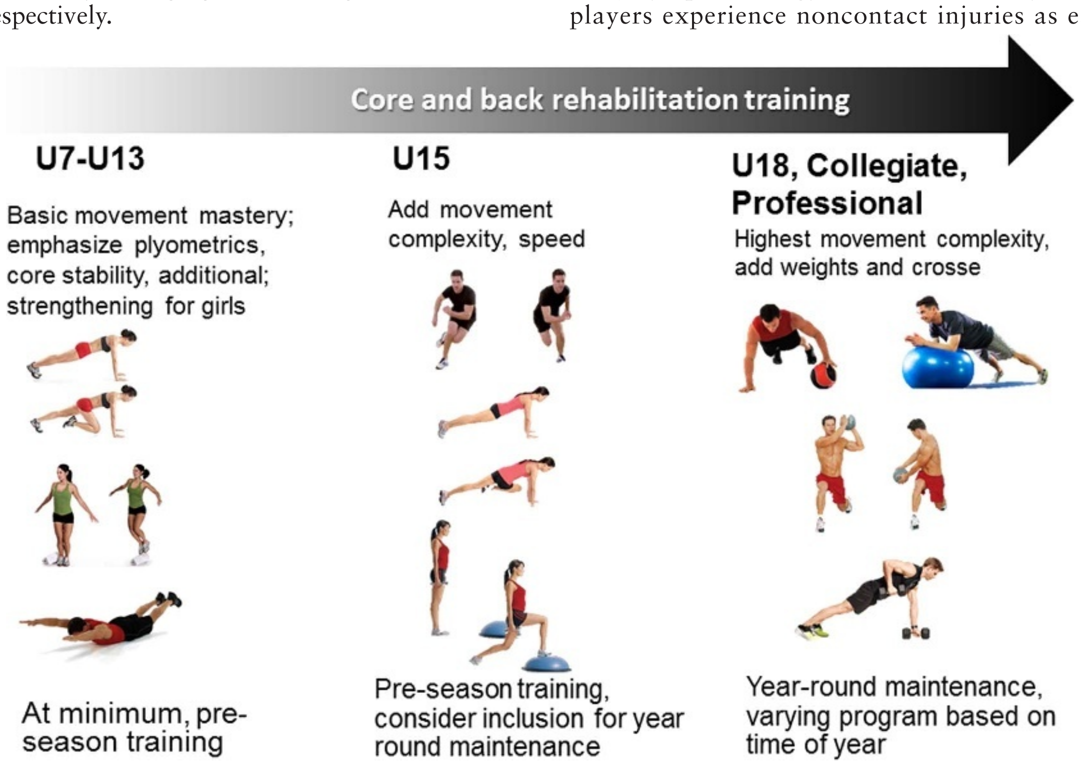

Figure: Proposed use of core and back rehabilitation in lacrosse players across the age continuum. The degree of arrow shading represents the relative level of exercise intensity and complexity.

11 years, with higher rates in girls than boys (13,16). As the competition levels and movement velocities increase from youth to collegiate (10), the incidence of injuries follows suit. U.S. Lacrosse offers evidence-based prevention programs for ACL injury (40) and general resources for injury prevention (41). However, there are not yet published recommendations on when and how to implement core and back strengthening for lacrosse players across the age continuum. We propose a progressive rehabilitation program that will build on basic core movements with age and skill. This program overview is shown in the Figure.

Even at an early age (U9/U11), boys and girls may benefit from participation in basic exercises that promote spine stabilization and core engagement. No heavy weights are necessary at this age. The focus should be on appropriate alignment and performing the exercises safely with some resistance (bands, medicine balls, light dumbbells) to enhance the motor skills (42,43) for lacrosse. As players advance to U15, body strength and skill levels will increase. The complexity of the exercises used should therefore increase, potentially with the addition of more resistance or weights if the movement form is achieved. The use of the crosse in some of the simpler drills such has single-legged balance on unstable surfaces may be helpful at this age. Finally, U18 (high school) to collegiate level players can advance exercises for faster speeds, more repetitions and/or weight and more challenging multijoint activities. The goal of this long-term plan is to maintain optimal adaptation of core and back muscle capability to meet the demands of the player level with growth and skill development. The musculoskeletal and neuromotor systems are well developed, and these players can handle complex actions with resistance. Exercises should now include combined movements that involve sport-specific challenges (*e.g.*, a combined box jump, ball catch and throw) and demanding weighted core exercise with perturbations (*e.g.*, catching a medicine ball on one leg on balance platform). Evidence synopses indicate that protective benefits for lower extremity injuries can be achieved with compliance to a program of no less than two times per week (10 to 20 min per session), with a minimum of 6 wk of training (33). This may be considered as part of a preseasonal prehabilitation and then maintained during the season. Ideally, participation in core and back rehabilitation exercises should become an integral part of the normal off-season lacrosse training program, and this would increase player durability as they transition to regular seasonal play.

Conclusions

Male and female lacrosse athletes are at risk for noncontact injuries and male lacrosse athletes are at risk for contact injuries. Lacrosse players of all ages are at risk for several noncontact injures during play, with injury risk increasing with competitive level. Key motions in the sport require core and back muscle strength, coordination, and optimal timing of lumbopelvic and abdominal muscle activation for optimal performance and to minimize injury risk. Core and back rehabilitation should be comprised of a variety of exercises that prepare athletes to respond safely to rapid perturbations to movement on the field. In the absence of evidence summaries demonstrating optimal core-back rehabilitation implementation plans, we suggest that regular participation in basic exercises should begin in the earliest age groups and increase in complexity and demand through collegiate and professional levels.

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