Anterior Cruciate Ligament Injury Prevention in the Young Athlete: Evidence-Based Application

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ABSTRACT

_Sport participation is on the rise with approximately 35 million children aged 5–18 participating in organized sports in the United States (33). Children are training year-round and specializing in sport at earlier ages. Increased injury rates and changing injury patterns are paralleling this trend (48). Intrasubstance tears to the anterior cruciate ligament (ACL) in children were once rare, however, now are being seen with greater frequency (18,44–47,54,68,71). Approximately 200,000 ACL injuries occur annually in the United States (33,64). About 1 in 20 female high school varsity athletes per year sustain a primary ACL injury (3,12,13,39). In a clinical series of pediatric patients aged 10–15 years with acute traumatic hemarthrosis of the knee, ACL injury was reported in 10–65% of such patients (18).

In addition to causing short-term disability, those who sustain an ACL rupture are at a high risk for developing knee osteoarthritis as early as 10 years after injury (7,39,50,51). In addition, studies have demonstrated a higher risk of subsequent reinjury after anterior cruciate ligament reconstruction (63). Injury may result in time loss from physical activity, lowered academic performance, and increased risk for psychosocial issues and may threaten general health maintenance efforts and contribute to obesity (26).

Consensus exists in the literature that gender differences in injury rates and neuromuscular risk factors appear to emerge with puberty and are most common among individuals 16 and 18 years of age (15,67,76). However, the frequency of ACL injury in young athletes has been increasing steadily around the ages of 10–12 years (54,58,69,76). Currently, children as young as 10 years of age demonstrate movement patterns associated with injury risk (34,69,72). Movement patterns play a critical role in ACL injury because they influence anterior tibial shear force, which directly strains the ACL. Late childhood (age, 10–12 years) is a critical period for refining movement skills because of steady and gradual growth (27,28,30,41).

Therefore, this may be an ideal time to intervene in movement modification during sport-specific tasks to reduce future injury risk._

_Prevention is paramount to allow young athletes to safely receive the health benefits of recreational activity. Current literature displays no certainty as to whether this young age group responds to traditional ACL injury prevention._

KEY WORDS:

anterior cruciate ligament; children; prepubescent; injury prevention; risk factors; knee; young athlete; skeletally immature
Prevention programs that typically involve complex movement patterns that may be beyond their level of comprehension. However, given the success of prevention programs modifying neuromuscular risk factors in adolescents, it follows that intervening with children at a younger age may result in better long-term outcomes.

The purpose of this article is to review risk factors specific to children to efficiently work toward a preventive model that would reduce risk of ACL injury in young athletes.

**RISK FACTORS SPECIFIC TO THE YOUNG ATHLETE**

Early specialization, maturation, undeveloped physical skills, high-risk movement patterns, and an inadequate strength base all contribute to increased injury rates (33,34,37,49,66,70). Early specialization focuses on developing motor skills for a specific sport as opposed to developing overall fundamental motor skills. Young athletes are vulnerable to injury secondary to growth-related factors such as growth spurts, maturity-associated variation, and immature or underdeveloped coordination and skills (8,10,52,66). These factors may exert their influence with more frequent and intensive training and competition seen today (16).

To successfully reduce the incidence of ACL injuries in young athletes, one must take a look at modifiable risk factors specific to this population.

**PHYSICAL FITNESS DEFICITS**

Fatigue, which is associated with inadequate physical fitness, has been correlated with injury risk (20,54). Youth with increased body mass index (BMI) were found to have a significantly higher risk of sustaining a sports-related injury than their normal-weight peers (55). A higher BMI may impact poor postural control affecting balance and coordination, poor physical fitness associated with muscle fatigue and subsequent injury, and low preparticipation physical activity levels associated with impaired neuromuscular and motor learning (55).

Kidd et al. (43) documented that those who are unfit and perform “too much too soon” as well as athletically fit athletes who overexert themselves are at risk for injury. Thus, gradually increasing training load and improving flexibility, strength, and biomechanics according to age-appropriate guidelines is essential.

**GROWTH SPURTS**

The average age of onset for growth spurt is 10.5 years for girls and 12.5 years for boys (73). A young athlete’s body changes as he/she grows, affecting bony levers and center of body mass, which impact postural alignment and neuromuscular control (37). During growth spurts, core strength, neuromuscular ability, coordination, and proprioception become imbalanced and contribute to injury risk (30,37).

Increasing demand of peak performance is expected at younger ages during a time of major physiological change (10). Care should be taken to ensure that demands such as expected sports-specific movement patterns or training loads placed on the athlete’s body do not exceed their physiological capabilities. In addition, a child may master a skill before his/her growth spurt but may need to revisit that skill later on to refine the movement patterns secondary to the changes he/she incurs.

**FUNDAMENTAL MOTOR SKILLS: MATURATION AND EFFECTS ON ALIGNMENT AND NEUROMUSCULAR CONTROL**

Injury predisposition has been correlated to undeveloped physical skills (43,66) and is inevitable if a child lacks fundamental motor skills to meet the demands of the activity. Children do not master complex motor skills until late childhood (age, 10–12 years) and therefore are at risk when their age-appropriate skill set does not meet the demands imposed on them (1). Overuse injuries sustained by young athletes could be prevented if more emphasis was placed on the development of fundamental fitness skills, as opposed to sports-specific training (20).

**PUBESCENT AND POSTPUBESCENT ATHLETES**

Female athletes have a 2-fold to 8-fold greater ACL injury risk than male athletes (3,30–33,40). As a result, hundreds of studies have been published establishing risk factors and preventive measures for this at-risk population. Puberty has been associated with deficits, delays, and regressions of neuromuscular function, and many sex-related differences emerge that have been correlated with ACL rupture (11,12,25,37). Examples of modifiable risk factors include muscle strength and coordination, dynamic hip and knee control, lower extremity joint stiffness, and force attenuation during landing (13,21–25).

Adolescent females demonstrate measurable neuromuscular imbalances such as quadriceps dominance, ligament dominance, leg dominance, and trunk dominance, which have been associated with increased injury risk (17,25,37,39,40). Ligament dominance demonstrates tendency to stress the ligament before muscular activation to absorb ground reaction forces (GRFs). This may occur secondary to lack of dynamic muscular control, leading to increased valgus motion and high torque at the knee and ACL (Figure 1A and 1B). Quadriceps dominance results from preferential activation of knee extensors over knee flexors during sports-specific tasks. Ebben et al. (17) reported that women sustain quadriceps activation longer during cutting maneuvers and that their hamstrings to quadriceps activation ratios were lower. Leg dominance pertains to imbalances in muscular strength and coordination of the limbs, which may place both limbs at risk. The weaker limb is compromised secondary to inability to dissipate forces; therefore, the stronger limb is subjected to high forces because of increased dependence and loading on that side (Figure 2A and 2B). Trunk dominance is caused by increased motion of the body's center of mass during single-leg landing, pivoting, or deceleration (17,37–39) (Figure 3A and 3B). Excessive trunk motion in the frontal plane...
and high GRFs and knee joint abduction load leaves the knee joint vulnerable to injury (37,39,40).

Males appear to have a neuromuscular spurt in strength, power, and coordination during puberty to adapt to increased bony lever arms and greater mass, whereas females show little change (39–41). However, before puberty, minimal gender differences have been demonstrated.

**PREPUBERTAL**

Even though minimal lower extremity biomechanical and neuromuscular differences in ACL ruptures have been observed before puberty, differences have been noted when comparing prepubescent and postpubescent subjects (8,15,36,37,44,52).

Children as young as 10 years demonstrated lower extremity neuromuscular movement patterns associated with injury risk during sport-related movements, such as landing and cutting (16,35,68). These movement patterns include reduced knee flexion, knee...
valgus, and excessive leg rotation. Swartz et al. (72) demonstrated that a group of prepubescent children aged 7–11 years (boys and girls) exhibited greater GRFs and knee valgus and less hip and knee flexion at initial contact from a jump landing than the postpubescent subjects aged 19–29 years. The ability to modulate vertical GRFs upon impact and throughout landing may improve with aging, potentially because of various levels of contribution from physical maturation, skill development, and experience (72).

MODIFICATION OF RISK FACTORS FOR ANTERIOR CRUCIATE LIGAMENT INJURY PREVENTION IN YOUNG ATHLETES

Trends are changing and an increased number of ACL injuries are being seen at younger ages. Injury risk may be less during this stage of childhood; however, it may be an opportune time to intervene to modify risk factors and reduce further injury risk. The following section will discuss interventions and exercises that can be used with prepubescent children to effectively modify risk factors and therefore reduce future injury.

EFFECTS OF STRENGTH TRAINING: SPECIAL CONSIDERATIONS

Strength training programs have been shown to reduce the number and severity of knee injuries in adolescent athletes (6,35,56,57,74). Although these studies involve adolescents, it seems that strength training could provide similar protective effects to preadolescent children (20). There had been controversy in the past regarding safety of strength training for young children; however, it is proven safe and effective as long as supervision is provided and age-appropriate guidelines are followed (20).

It is important to note that skeletally immature children are prone to overuse injuries (19,29). Therefore, gradually increasing training loads and improving flexibility, strength, and motor skills according to age-appropriate guidelines is essential (20). Care should be taken to ensure demands or training loads do not exceed their physiological capabilities. It has been recommended that young athletes start with preparatory conditioning and instructional practice sessions versus competition (56).

GLUTEUS MEDIUS AND MAXIMUS STRENGTHENING FOR CORRECTION OF DYNAMIC VALGUS

Hewett et al. (37) showed that those who demonstrated knee valgus during jump landings were 2.5 times more likely to suffer ACL injury than those who did not. Gluteus maximus and medius play an increased role in preventing dynamic valgus collapse by controlling hip adduction and femoral rotation. Weakness has been identified as a predictor of injury secondary to inability of the weak muscles to keep the hip abducted during high single-leg activities such as landing and cutting (4,53,67). Studies have demonstrated improved control of dynamic valgus collapse of the knee with gluteus maximus and medius strengthening (53,61).

Electromyographic studies have reported that side-lying hip abduction, side planks, and lateral band walk have demonstrated sufficient maximal voluntary activation to allow strengthening of the gluteus medius (Figure 4A and 4B). Single-limb exercises such as single-limb squat may be used to activate gluteus medius more than double
stance exercises (48). Single-limb squats and single-leg deadlifts maximally elicited gluteus maximus (Figure 5A and 5B). It should be noted that one should not simply start with these exercises. These exercises are progressed to form double limb to single-limb stance once proper technique and safety is demonstrated.

ADDRESSING HAMSTRING STRENGTH FOR CORRECTION OF DYNAMIC VALGUS AND IMPROVED KNEE FLEXION WITH JUMP LANDINGS

Hamstring weakness and activation deficits play a role in controlling dynamic valgus postures by resisting anterior and lateral tibial translation and tibial rotations (2). Studies have demonstrated that weak hamstrings result in quadriceps dominance secondary to increased knee extensor moments over knee flexor moments during tasks that require increased lower extremity demand, therefore increasing risk (60). Adolescent girls exhibited less hamstring strength in comparison to age- and size-matched boys, confirming need for earlier intervention (59). Hamstring activation is modifiable through strengthening and neuromuscular training (4,79). Studies have demonstrated improved dynamic valgus control and prelanding and landing activation with jump landings with neuromuscular training (79). Eccentric loading of the hamstrings, such as partnered Russian hamstring curls, has been found to be more effective in improving hamstring to quad ratio than traditional concentric exercises (42,59).

Agility training programs that have incorporated unanticipated directional changes have demonstrated improved medial hamstring activation during pivoting as well as a significant reduction in knee valgus loading during planned and unplanned conditions (13,75).

CORE STRENGTHENING FOR CORRECTION OF TRUNK DOMINANCE

Core weakness and proprioception have been associated with lateral trunk displacement, altered dynamic knee stability, and predicted knee injury risk (4,5,37,77–79). Effective programs should include core stability training, proprioceptive exercises, perturbations, and postural sway corrections. Core proprioceptive neuromuscular training has improved body sway; however, more research is needed secondary to the paucity in the literature on its effects on non-contact ACL rates.

CORRECTION OF LEG DOMINANCE AND LOWER EXTREMITY ALIGNMENT VIA CUEING

Leg dominance may be secondary to asymmetrical muscle weakness, flexibility, and/or pain avoidance. Training should focus on each leg in isolation if dominance is noted. If pain is reported,
then the child should be referred to a physician for proper evaluation.

**TECHNIQUE MONITORING AND FEEDBACK**

Secondary to decreased attention span compared with adults, children should be actively monitored to ensure proper and safe technique. Mizner et al. (57) found that athletes were able to make significant positive changes in landing mechanics in repeat trials after brief verbal instruction. Padua and DiStefano (62) reported in a systematic review that verbal instruction and feedback for proper landing technique, auditory cues for minimizing landing forces, and performance under direct supervision on a regular basis significantly decreased vertical ground reaction forces. Studies that did not note change did not incorporate regular verbal or auditory feedback and did not provide direct supervision on a regular basis (79). Prapavessis and McNair (65) demonstrated a decrease in GRF with jumping via altered technique after only 1 feedback session.

**ADDRESSING, FLEXIBILITY, PROPRIOCEPTIVE AND NEUROMUSCULAR DEFICITS DURING GROWTH SPURTS**

During growth spurts, neuromuscular ability, coordination, and proprioception become imbalanced and contribute to risk of injury (37). Quadriceps and hamstring flexibility is critical to allow for sufficient knee and hip flexion during sports maneuvers to reduce ACL strain (37). In addition, proprioceptive training is vital to incorporate into one’s program to allow children to improve within their new center of mass. Multiple studies demonstrated ACL injury reduction with use of balance and proprioceptive training as part of a multifaceted program with strengthening and neuromuscular training (9,37).

Recently, DiStefano et al. (15) demonstrated that athletes aged 9–11 years improved balance ability and vertical jump height after an injury prevention program that included core and lower extremity strengthening as well as balance activities including single leg ball toss and single-leg forward hopping.

**MULTIFACETED PREVENTION PROGRAMS**

Multifaceted programs that include strengthening, proprioception and neuromuscular training, plyometrics, and technique training have historically demonstrated the most success. However, limited research has been done with prepubescent children. Adapting a program specifically geared toward children may improve the ability to change neuromuscular risk factors for ACL injury and therefore reduce rate of injury entering into adolescence.

DiStefano et al. (14) assessed the effects of a Pediatric ACL Injury Prevention Program, specifically designed for children younger than 12 years. To maintain compliance, the program took approximately 12–14 minutes. It consisted of 3 phases over 9 weeks and gradually progressed core and lower extremity strength, flexibility via a dynamic warm-up, proprioception, plyometrics, and agility. The first week placed emphasis on technique and reduced repetitions to allow mastery of tasks. Reduced knee external rotation at initial ground contact during cutting was demonstrated in the young athletes (14). Children require more feedback when learning a new task and therefore may benefit from a specialized program to meet their needs and to allow for success.

**DISCUSSION**

Historically, intervention strategies were focused on the adolescent athlete secondary to increased injuries incurred from 16 to 18 years of age. However, children between the ages of 10 and 12 years are demonstrating movement patterns associated with injury risk during sports-related movements (15) and injury rates are rising. Even though immediate injury risk may be less during this period, it serves as an ideal time to intervene and refine movement patterns to reduce future injury risk that tends to occur during adolescence (15).

The benefits of strength training, proprioceptive and neuromuscular training, flexibility, and plyometrics have been demonstrated in the literature to reduce injury rates in the adolescent athlete. In addition, it is evident that intervening at a young age is critical to the success in ACL injury prevention and may perhaps be the missing link. However, it is unclear whether this age group will respond to current adolescent ACL injury prevention programs that involve complex directions and may be beyond their level of comprehension and ability (14–16).

Children require more feedback when learning a new task and acquire new motor skills more efficiently when tasks are separated into basic components (15,16). Therefore, a program geared toward a young athlete’s needs and skill set is highly recommended and would provide adequate intervention to possibly reduce the number of injuries incurred in childhood and possibly carried over into adolescence.

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