ACL Prevention Programs: Fact or Fiction?

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Neuromuscular training has a significant effect on reducing relative ACL injury risk in female athletes in high-risk landing and cutting sports like soccer, basketball, volleyball, and team handball.

As many as 1 in 20 collegiate-level and 1 in 50 to 100 high school-level female athletes sustain anterior cruciate ligament (ACL) injury during any given year of varsity sports.1,2 The answer to the posed rhetorical question “do ACL prevention programs actually reduce risk?” is neuromuscular training has a significant effect, from 24% to 82% reduction of relative ACL injury risk in female athletes in high-risk landing and cutting sports like soccer, basketball, volleyball, and team handball.

Growth in female sports participation at a two- to ten-fold higher rate has led to a great gender inequity in ACL injury. The National Collegiate Athletic Association (NCAA) reported >150,000 female participants in varsity sports each year.3 The National Federation of State High School Associations (NFSHSA) reported >3.2 million female participants annually in high school sports programs.3 Based on these figures, >50,000 debilitating ACL injuries likely occur in female athletes at the high school and intercollegiate varsity levels during an average year.

Most ACL injuries occur by noncontact mechanisms, during deceleration from a landing or making a lateral pivot.5 Neuromuscular training is effective in the reduction of ACL injury risk in females because females demonstrate 4 neuromuscular imbalances that may put them at greater risk of ACL injury than males and that may be ameliorated with neuromuscular training. These potentially correctable neuromuscular imbalances—ligament dominance (increased load on the knee joint), quadriceps dominance (decreased knee flexor recruitment and strength), leg dominance (increased leg-to-leg differences in muscle coordination and strength), and trunk dominance (increased motion of the body’s center of mass)—may decrease dynamic knee stability in females and lead to the gender bias in ACL injury risk.6,7

Are Female Athletes Really at Higher Risk for ACL Injuries?

Female athletes are 2 to 10 times more likely to sustain an ACL injury compared to male athletes playing the same landing and cutting sports.5-11 Since the enactment of Title IX, male participation at the high school level has remained steady, while female participation has increased approximately ten-fold (from <0.3 to >3.2 million).4

High school and collegiate athletics contributes to >50,000 ACL injuries in female athletes each year. An estimated 1 in every 100 high school female athletes will sustain an ACL tear. At an estimated cost of $17,000 per patient2 to reconstruct and rehabilitate the ACL in these athletes, overall costs would exceed $680 million annually. Of additional concern is the fact that successful ACL reconstruction in 2009 has shown the ability to return the athlete to the playing field at his or her previous level of performance in the majority of cases.

More than 50% of the patients show early signs of irreversible osteoarthritis within 10 years of ACL reconstruction, particularly female athletes. This is in addition to the traumatic ef-
fect to these individuals of the potential loss of entire seasons of sports participation, possible scholarship funding, and potential decreased performance in the academic arena.12

A major theory to account for higher knee injury incidence in female athletes is that neuromuscular imbalances, due to training deficiencies, developmental differences, or perhaps hormonal influences, lead to higher injury rates. Other variables that may be contributory include lower limb alignment as well as biomechanics and kine-
matics, overall ligament size and strength, and muscular fatigue over a given length of time.

This article focuses on the neuromuscular theory for 2 reasons. First, if neuromuscular training can alter observed neuromuscular imbalances in the laboratory and if the same neuromuscular training can de-
crease ACL injury risk on the field and court, then neuromus-
cular control must be a primary underlying factor for increased risk.5,11 Second, intervention and prevention are likely to have the greatest impact on neuromuscular control, where adaptation readily occurs, if properly guided by trained health care professionals.

**DOES NEUROMUSCULAR TRAINING DECREASE THE INCIDENCE OF ACL INJURY?**

The majority of published studies demonstrate that neuromuscular training has an approximately 50% efficacy rate for decreasing relative ACL injury risk in female athletes in landing and cutting sports like soccer, basketball, volleyball, and team handball. Neuromuscular training alters active knee joint stabilization in the laboratory and aids in decreasing ACL injury rates in female athletes in the field.

Hewett et al2 reported the first prospective study of the ef-
facts of a neuromuscular training program on ACL injury in the high-risk female sports population. The rate of ACL injury was decreased 45% in the trained group relative to the untrained group. The findings of Hewett et al2 have been sub-
sequently confirmed by several studies that used similar neuromuscular training protocols in young female athletes.13,14 Conser-
dered together, these studies provide strong evidence de-
mountain that neuromuscular training is likely to prove an ef-
fective solution to the problem of sex bias in ACL injury risk.

In a prospective study by Hewett et al2 trained females were no different than untrained males. Training resulted in great differences in noncontact ACL injuries between the female groups. These results indicate that neuromuscular training decreases injury risk in female athletes. Although the study by Hewett et al2 was the first to demonstrate significant decreases with neuromuscular training specifically in the female athlete, other studies have demonstrated similar significant decreases or trends toward significant changes in female, male, and mixed gender populations. Figure 1 shows the relative percentage decreases in relative injury rates following various training programs.

**HOW DOES NEUROMUSCULAR TRAINING DECREASE INCIDENCE OF ACL INJURY?**

Four neuromuscular imbal-
ances are observed more often in female than male athletes. The first observed neuromuscular imbalance is the tendency for females to be ligament dominant. Females demonstrate a tendency to allow stress on ligaments prior to muscular activation to absorb ground reaction forces. Typically during single-leg landing, pivoting, or deceleration, as often occurs during ACL injury, the female athlete allows the ground reaction force to control the direction of motion of the lower extremity joints, especially the knee joint. The lack of dynamic muscular control of the joint leads to increased valgus motion, increased force, and high torque at the knee and ACL.

Another imbalance is termed quadriceps dominance. With quadriceps dominance, female athletes activate their knee extensors preferentially over their knee flexors during sports movements to stabilize their knee joint, which accentuates and perpetuates strength and coordination imbalances between these muscles.

A third imbalance is leg dominance. Leg dominance is the imbalance between muscular strength and coordination on opposite limbs, with 1 limb often demonstrating greater strength and coordination. Limb dominance may place both the weaker, less-coordinat-
ed limb and the stronger limb at increased risk of ACL injury. The weaker limb is compromised in its ability to dissipate forces and torques, while the stronger limb may be subject to high forces and torques due to increased dependence and increased loading on that side in high-force situations.

The final imbalance often ob-
served in female athletes is trunk dominance. Trunk dominance is characterized by increased motion of the body’s center of mass due to the absence of neuromus-
circular control of approximately two-thirds of the body mass during single-leg landing, pivoting, or deceleration.20-22

LIGAMENT DOMINANCE—HIGH TORQUES AT THE KNEE AND HIGH IMPACT FORCES

Typically during single-leg landing, pivoting, or deceleration, the motion of the female athlete’s knee joint is directed by the ground reaction forces, rather than by the athlete’s musculature. This results in high knee valgus motion and high ground reaction forces. Figure 2 shows the gender disparity in knee abduction motion and load between female and male athletes when dropping off of a box and progressing into a maximum vertical jump.

QUADRICEPS DOMINANCE—DECREASED POSTERIOR KINETIC CHAIN TORQUES

The problem of quadriceps dominance has been documented in the literature.6,7 With quadriceps dominance, female athletes tend to activate their knee extensors preferentially over their knee flexors to control knee stability. This over-reliance on the quadriceps muscles leads to imbalances in strength and coordination between the quadriceps and the knee flexor musculature. Quadriceps dominance must be addressed and overcome with dynamic neuromuscular training.

LEG DOMINANCE—LEG-TO-LEG IMBALANCES IN MUSCLE RECRUITMENT, STRENGTH, AND STABILITY

Female athletes have been reported to generate lower knee flexor torques on the nondominant than in the dominant leg.6 Side-to-side imbalances in neuromuscular strength, flexibility, and coordination have been shown to be important predictors of increased ACL injury risk.2,6,23 Knapik et al23 demonstrated that side-to-side balance in strength and flexibility is important for the prevention of injuries, and when imbalances are present, the athlete is more injury prone. Baumhauer et al24 also found that individuals with neuromuscular (muscle strength) imbalances exhibited a higher incidence of injury.

TRUNK DOMINANCE—EXCESSIVE MOTION OF THE BODY’S CENTER OF MASS

During landing, pivoting, or deceleration, the motion of the female athlete’s trunk is often excessive and directed by that body segment’s inertia, rather than by the athlete’s core muscle contraction patterns. This results in excessive trunk motion, especially in the fron-
tal or coronal plane, and high ground reaction forces and knee joint abduction torques (knee load). Figure 3 shows the differences in trunk motion between female and male athletes rupturing their ACLs.

It is important to note that several knee injury prevention training programs have been published and shown to be effective in improving neuromuscular deficits and reducing the risk of knee injuries, particularly in the female at-risk athlete. All successful programs incorporate the following key elements: a dynamic warm-up period that is high energy and efficient; plyometric/jump training with emphasis placed on body posture and control, trunk positioning, dynamic core balance, and entire-body control through a specific task; strength training for the core and lower extremity; sports-specific aerobic and skill components; and pre-season and in-season training programs that are strictly followed. Pre-season training program may be 6 to 8 weeks in duration, 3 days a week for up to 1.5 hours per day. In-season maintenance programs can be done in 15 minutes during pre-game warm-up 3 times per week.

The goal of this program is to avoid injury by teaching athletes strategies to avoid vulnerable positions, improve strength and flexibility, and improve proprioception. Those of us fortunate enough to be involved in youth, high school, and collegiate athletics should pass this information on to our sports medicine team colleagues whenever possible. If we are able to prevent just 1 ACL injury, it is worth the effort. Only with education will we hopefully see a decrease in this dreaded injury, which is often season- and career-ending to some.

REFERENCES