Anterior Cruciate Ligament Injury Prevention: Concepts, Strategies, and Outcomes

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INTRODUCTION AND HISTORY

A recent 10-year survey of knee injuries in 6,434 patients revealed that tears of the anterior cruciate ligament (ACL) were responsible for 20% of joint complaints. It is estimated that each year between 75,000 and 250,000 individuals in the United States will suffer a new injury to the ACL. The burden of disease is particularly high in the female athlete. It is estimated that 1.4 million women and girls have torn their ACL during the last decade, and the incidence of noncontact ACL injury in female collegiate athletes is as high as 1 in 10.

The epidemic of ACL injuries in both noncontact and contact athletics has resulted in a two-pronged strategy of prevention and treatment. As surgical treatment for ACL injuries carries with it morbidity, long rehabilitation and recovery, and large costs, attention has been focused on prevention of the sentinel ligament injury. During the last 35 years, orthopaedic research has contributed to a better understanding of cruciate ligament biomechanics, physiology, and failure patterns. ACL injury prevention models have been developed to address differences in cruciate injury among female athletes and contact athletes.

A complete tear of the ACL has been historically regarded as a significant injury. This opinion was based on the morbidity of surgical treatment, the length of time for recovery and rehabilitation, and the cost of medical treatment. The evolution of arthroscopic knee surgery, with reliable ligament reconstruction techniques, has limited the associated surgical morbidity of ACL treatment, but issues of recovery time and cost remain. Typically, ACL reconstruction requires a minimum of 6 months of functional therapy to ensure adequate muscle strength and knee joint proprioception. Additionally,
the direct medical costs of a torn ACL approach $17,000 within the first year; a cumulative yearly cost of $1.5 billion in the United States. This figure does not account for long-term cost of posttraumatic knee osteoarthritis or emotional cost of a major injury to active individuals.

A successful prevention strategy must address goals of efficacy, compliance, reproducibility, and cost. Several approaches to prevention have been taken, including identifying high-risk athletes, encouraging better biomechanics, and providing structural support to a healthy knee. This chapter presents current information on concepts, strategies, and outcomes related to ACL injury prevention.

BIOMECHANICS AND THE FEMALE ATHLETE: THE NONCONTACT ANTERIOR CRUCIATE LIGAMENT INJURY

The first concept of ACL injury prevention begins on the tissue level and expands to include the interaction among biologic tissues and systems. A simple hypothesis would state that achieving optimal biomechanics of a tissue system would lead to a lower chance of injury to that system. The corollary argument being that less than optimal biomechanics of a tissue system would lead to a higher chance of injury to that system. Expanding this hypothesis to the competitive athlete, one would propose that well-conditioned athletes have a lower rate of injury and that poorly conditioned athletes have a higher rate of injury. More specifically, an athlete with worse biomechanics would have a greater risk of ACL injury. A dynamic, multifactorial model of sports injury etiology proposes that internal risk factors combine to make an athlete predisposed to injury. Exposure to external risk factors lead to a susceptible athlete who is then exposed to an inciting event, leading to injury (Fig. 5.1).

What often distinguishes this injury from that of the female basketball player, however, is the presence of an external force beyond that of gravity; hence, “a contact sport.” It is thus the challenge to further define the proposed hypothesis in the context of contact versus noncontact activities. The female athlete has been used as the model for the stated hypothesis in the setting of noncontact ACL injury and, thus, is the basis for this discussion.

According to Hewett et al., gender differences between male and female ACL injuries are thought to result from differences in anatomy, hormones, and neuromuscular patterns. Another study has defined these differences as nonmodifiable and modifiable. Nonmodifiable differences, such as femur length, femoral notch width, patient height, and menstrual cycle hormone levels contribute in different capacities to ACL injury risk. Modifiable differences, such as neuromuscular patterns, appear to result from a lack of synchronization between growth and maturity of the lower extremity and appropriate neural control of the lower extremity in high-risk sporting movements.

ACL injury of the female athlete has typically two defining characteristics: noncontact and deceleration. Based on these characteristics, investigators have sought to understand the implications of modifiable biomechanics on female ACL injury risk patterns and the subsequent effects of
neuromuscular training designed to protect at-risk athletes. The female ACL injury risk pattern is best defined as a patho-
kinetic chain. This chain begins as an increased adducto
moment at the hip leading to lower extremity valgus and, ultimately, increased ACL strain. Hewett et al. prescreened
205 female athletes for neuromuscular control using mea-
surements of lower extremity joint angles and moments
during a jump landing task. They noted that the nine ath-
eltes with subsequent ACL tears had an 8 degree greater ab-
duction angle (knee valgus), 2.5 times greater abduction
moment, and 20% higher ground reaction force as noted
on the prescreening examinations. They concluded that
landing task knee motion and loading are predictors of ACL
injury risk in female athletes.

Other investigators have defined the at-risk position for
ACL injury to be either knee varus or valgus with flexion of
10 to 30 degrees (Figs. 5.2 and 5.3). Markolf et al. were more specific in their study of ACL forces and speci-
ified that a varus force at the knee in combination with an
internal rotation moment at the knee placed the ACL at
greatest risk for tearing.

Encouraged by earlier investigations, Sell et al. examined gender differences in planned and reactive stop-jump
tasks of different directions. Comparing 18 males with 17
females of high school age, biomechanical and neuromus-
cular patterns were observed in the right knee. Of the three
jumping directions, lateral jumping tasks to the medial as-
pect of the right knee demonstrated the greatest ACL risk
profile by increasing ground-reactive forces, increasing

Figure 5.3 Clinical example of the valgus lower extremity at-risk alignment. (Reprinted with permission from Hewett TE, Shultz SJ, Griffin LY, eds. Understanding and Preventing Noncontact ACL Injuries. Champaign, IL: Human Kinetics; 2007.)

proximal tibial shear forces, increasing valgus and flexion
moments, and lower flexion angles. These findings were
potentiated in female athletes and by switching from a
planned to a reactive task. The authors concluded that fu-
ture neuromuscular and proprioceptive ACL injury preven-
tion programs should incorporate reactive task training as
well as lateral jumping strategies.

Anterior Cruciate Ligament
Injury-Prevention Studies

Several ACL injury prevention studies have been per-
formed, with many showing a reduction in the risk of non-
contact ACL injury. A summary of ACL injury prevention
studies is shown in Table 5.1.

Most injury-prevention schemes have focused on neu-
romuscular control and proprioception. Caraffa et al. studied 600 soccer players in Sweden. Half (300 players)
were assigned proprioceptive training and the other half no
training. The players were followed for three soccer seas-
sons. The group treated with proprioceptive training
demonstrated a statistically significant decrease in the rate
of ACL injury compared with the untreated group.

Hewett et al examined the effect of corrected jump and
landing technique training on 11 female subjects (Figs. 5.4
and 5.5). They noted significantly reduced abduction mo-
mements at the knee. A similar study showed that phase-or-
iented and technique neuromuscular training in female ath-
eletes reduced the rate of ACL injuries to that seen in a male
cohort. A similar risk reduction was seen in elite female
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<tr>
<th>Study</th>
<th>Sport</th>
<th>Duration</th>
<th>Randomized</th>
<th>Equipment</th>
<th>Strength</th>
<th>Flexibility</th>
<th>Agility</th>
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<th>Proprioception</th>
<th>Strengths</th>
<th>Weaknesses</th>
<th>Outcome</th>
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<tr>
<td>Caraffa et al., 1996</td>
<td>Soccer semi-professional and amateur; N = 600 males on 40 teams (20 intervention, 20 control)</td>
<td>3-season intervention (preseason)</td>
<td>Prospective, nonrandom</td>
<td>Rectangular, oblique, circular, and BAPS boards (20 min from level I to V) over 3 to 6 days a week with self-determined advancement to next level = 30 preseason days</td>
<td>PNF exercises</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Balance board activities: multi-level I-V on four boards</td>
<td>Mechanoreceptor/ proprio training</td>
<td>Additional equipment (BAPS); not cost-effective in a large scale cohort</td>
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<td>Etlinger et al., 1995</td>
<td>Alpine skiing; N = 4,000 ski personnel in 20 ski areas</td>
<td>1-year intervention (1993-94) with two previous years of historic controls (1991-93)</td>
<td>Prospective, nonrandom</td>
<td>Educational video clips of skiers sustaining ACL injuries and those that avoided injury in very similar falls; injury prevention education utilized (mechanism of injury, avoidance of high-risk behavior; fall technique)</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Fall analysis and accident analysis; cost-effective intervention and highly feasible with large skiing populations</td>
<td>Nonrandomized; not all potential participants trained; historic controls; exact diagnosis of serious knee sprains not always available; exact exposure to risk cannot be precisely determined</td>
<td>Severe knee sprains reduced by 62% among trained skiers (patrollers and instructors) compared to unperturbed group, who had no improvement during study period</td>
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<td>Gilchrist et al.&quot; 2004 (abstract only)</td>
<td>Soccer U-18 to U-22; N = 561 females from 61 Div I NCAA universities</td>
<td>1-year intervention</td>
<td>Yes</td>
<td>Educational video, cones, soccer ball</td>
<td>Gillet-med, Yes</td>
<td>Deceleration, sport specific</td>
<td>Hip and knee position, landing technique, multiplanar</td>
<td>Strength on field perturbation on grass</td>
<td>Instructional video; Web site, compliance monitored (random site visits)</td>
<td>Randomized, 1-year intervention, began at day 1 of season</td>
<td>Overall 72% reduction in ACL injury; 100% reduction in practice contact and NC ACLs; 100% reduction in contact and NC ACLs in last 6 weeks of season</td>
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<td>Griffis et al., 1989</td>
<td>BB females</td>
<td>8-year intervention</td>
<td>Prospective, nonrandom</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Landing technique; deceleration patterns (3-step shuffle)</td>
<td>Rounded cut, cutting, deceleration, and landing techniques (encouraging knee and hip flexion)</td>
<td>Changing cutting, deceleration, and landing techniques (not published (abstract only))</td>
<td>Nonrandomized; 89% decrease in NC ACL injury in female basketball athletes</td>
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<td>Mandelbaum et al., 2005</td>
<td>Soccer U-14 to U-18; N = 1041 (year 1) and 844 (year 2) females</td>
<td>2-year intervention</td>
<td>Prospective, nonrandom</td>
<td>Educational video, 2 in. cones, soccer ball</td>
<td>HS, core training</td>
<td>Soccer specific with deceleration techniques</td>
<td>Hip and knee, landing technique, multiplanar</td>
<td>On-field program: strength, ploy, agility on grass</td>
<td>Instructional video; Web site, compliance monitored (random site visits)</td>
<td>Nonrandomized; inherent selection (motivational) bias</td>
<td>Injury rates: year 1-88% reduction in NC ACL injury; year 2% - 74% reduction in NC ACL injury</td>
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<th>Study</th>
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<th>Weaknesses</th>
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<tr>
<td>Myklebust et al., 2003</td>
<td>European team handball; N = 900 females Div I-II</td>
<td>3-year intervention, nonrandom five-phase program</td>
<td>Prospective, randomized</td>
<td>Educational videotape, poster wobble board, balance foam mats</td>
<td>No</td>
<td>Yes</td>
<td>Planting, cutting, NM balance control activities</td>
<td>Balance activity on foam mats and boards</td>
<td>Compliance monitored by PT, instructional video poster</td>
<td>Nonrandomized; insufficient power</td>
<td>In elite division, risk of injury reduced among those who completed the program (OR: 0.06 [0.01–0.54]) compared with control; overall 53.8% and 61.5% reduction of ACL injury</td>
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<td>Pfeiffer et al., 2004</td>
<td>Soccer, VB, BB HS females; N = 577 intervention, N = 862 control</td>
<td>2-year prospective intervention over a 9-week treatment, 15 min, two times a week</td>
<td>Prospective, nonrandom</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Landing technique</td>
<td>No</td>
<td>Compliance monitored; sig. reduction in GRF and RFD in intervention</td>
<td>No decrease in injury in intervention group; performed posttraining; fatigue phenomenon; only 9 weeks in duration</td>
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<td>Soderman et al., 2000</td>
<td>Soccer females; N = 121 (control N = 100); only 62 intervention and 78 control completed study</td>
<td>1-season intervention (April-Oct); 10–15 min training program in addition to regular training</td>
<td>Prospective, randomized</td>
<td>Balance board, 10–15 min training program in addition to regular training</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Balance</td>
<td>Randomized clinical trial; sig. more injuries in control vs. intervention</td>
<td>37% dropout rate; not all subjects received same amount of training; unknown if training other than balance board was the same; numbers of ACL injuries very small</td>
<td>The training did not reduce the risk of primary traumatic injuries to the lower extremities; four of five ACL injuries occurred in the intervention group</td>
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<td>Study</td>
<td>Intervention Details</td>
<td>Outcome Measures</td>
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<td>Hewett et al., 1999</td>
<td>6-week pre-season intervention, 1-year monitoring, 3 days a week</td>
<td>Yes, Yes, No, Yes, Yes, Yes, Yes</td>
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<td>Heidt et al., 2000</td>
<td>7-week pre-season intervention, 1-year monitoring, 3 days a week</td>
<td>Yes, Yes, Yes, Yes, Yes, Yes, Yes</td>
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<td>Olsen et al., 2005</td>
<td>15-20 min training, 8 months (one handball season), 15 consecutive sessions and once a week thereafter</td>
<td>Squats, Yes, Kneel over, Planting, Cutting, NM control, Balanced activity</td>
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<td>Wobble board (Norpro), balance foam mats (Airex)</td>
<td>Uncertain what parameter of program effective; male and female; cannot extrapolate to other sports</td>
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<td>Randomized, controlled cluster trial</td>
<td>129 acute knee and ankle injuries overall; 81 in control (0.9 overall, 0.3 trained, 0.2 matched); 80% reduction of ACL injuries</td>
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<td>Video tape, decrease peak landing forces, decrease valgus/varus perturbation, increase vertical leap, increase hamstring strength and decrease time to hamstring contraction</td>
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<td>Nonrandomized; low VI enrollment; motivational bias; 1-on-1 program in sport facility; not feasible to implement across large cohort</td>
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<td>14 ACLs reported; female injury rates 0.43, untrained vs. 0.12 trained vs. male control 0.9 over 6-week program; untrained group 3.6-4.8 higher injury rates of ACL injury</td>
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<td>Wendenkopp et al., 2003</td>
<td>European team</td>
<td>10-month</td>
<td>Randomized</td>
<td>Balance board</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Balance training with ankle discs</td>
<td>Randomized clinical trial</td>
<td>Specific injury types not given; description of ankle disc training not given; &quot;warm-up&quot; exercises also provided to trained group but not specified; compliance with all exercises not mentioned</td>
<td>Ankle injuries sig. greater in control group (2.4 vs. 0.2); unspecified knee injuries not sig. less in trained group (6.9 vs. 0.6); 5 knee sprains and 1 knee &quot;luxation&quot; in control group vs. 1 knee sprain in trained group</td>
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</table>

BAPS, biomechanical ankle platform system; PNF, proprioceptive neuromuscular facilitation; proprio, proprioceptive; NC, noncontact; ACL, anterior cruciate ligament; U, under; NCAA, National Collegiate Athletic Association; Glut med, glutus medius; abd, abduction; ext, external; HS, high school; BB, basketball; plyo, plyometric; NM, neuromuscular; PT, patient; OR, odds ratio; VB, volleyball; GRF, ground-reaction force; RFD, rate of force development; sig., significantly; stat., statistically.


of female players. This led the study authors to conclude that compliance and time for training likely play a role in the success of such prevention programs. Furthermore, in a randomized trial of handball clubs in Norway, Olsen et al.\(^2\) found that a structured program of warm-up exercises to improve running, cutting, and landing technique as well as neuromuscular control, balance, and strength resulted in a reduction of knee and ankle injuries. However, a follow-up video-based intervention program studied by Arnason et al.\(^2\) did not show a reduction in ACL injury.

More recently, Paterno et al.\(^1\) examined the role of neuromuscular training on 41 female high school students. The intervention lasted 6 weeks and measured single-limb postural stability, anteroposterior stability, and medial-lateral stability. With focused neuromuscular training, the authors noted a significant increase in overall single-limb stability and anteroposterior stability. There was no change in medial-lateral stability. The potential for this type of neuromuscular training to reduce ACL injury in a susceptible female population will need to be determined across a larger study group.

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**BRACING THE INTACT NATIVE ANTERIOR CRUCIATE LIGAMENT**

One of the most tangible historical and current interventions for protection against ACL injury has been knee bracing. Knee braces have been developed for prophylactic, functional, and rehabilitative purposes. Support for prophylactic knee bracing (PKB) has come from athletic trainers, coaches, physicians, and, most importantly, an athlete's family members. The effectiveness of knee bracing in protecting native ligament integrity has been studied both biomechanically and clinically.

**The Biomechanical Experience**

In assessing PKBs, the use of cadaveric and surrogate knee models has been viewed with skepticism. The braced knee models, while controlled, do not account for weightbearing, physiologic loads, or muscle tone. In light of these limitations, the laboratory investigations of PKBs off the playing field have provided some insight into their effectiveness in protecting against knee ligamentous injury. Further, newer laboratory methods that examine additional risk factors for noncontact injuries have led to research that accounts for the deficiencies of previous studies, including weightbearing and muscle tone.

In 1987, Paulos et al.\(^1\) published a study of 18 cadaveric knees tested with one of two lateral stabilizing braces: Anderson Knee Stabler (Vision Quest Industries, Inc., Irvine, CA [Out of Production]) or McDavid Knee Guard (McDavid Knee-Guard, Inc. Woodridge, IL). In the presence or absence of one of the lateral braces, the application of valgus force was analyzed with respect to joint line opening and resulting ligament tensions/failure. No correlation was
seen between the use of a brace and reduced joint line opening or ligament failure with application of valgus stress. The authors correlated these results to a lack of protection of the medial collateral ligament (MCL).

Also in 1987, Wojtys et al. focused specifically on the influence of the Lennox Hill Brace, a functional brace, in protecting the knee from excessive anterior translation or external rotation moments. The authors used four cadaver specimens tested at 30 degrees of knee flexion to compare non-braced and braced ligament-intact and ligament-deficient knees. Although the sample size was too small for statistical significance, the brace was noted to decrease anterior translation in the ACL intact knee and the isolated ACL-deficient knee. No effect was noted in the braced MCL-/ACL-deficient or MCL-lateral collateral ligament-deficient knee. With regard to rotation, the brace effectively limited external rotation in all specimens regardless of ligament condition.

The variability of cadaveric knees in biomechanics testing led some research teams to test brace wear using a surrogate knee model. These models were typically made from composite materials that could be manufactured to mimic the bulk, size, and mechanics of human tissue. Additionally, some research teams employed hybrid cadaveric-surrogate knee models to capture brace effects in a reproducible and anatomic way.

France et al. introduced a human cadaver validated, free-standing, two-legged surrogate model for the assessment of lateral brace effectiveness in a contact type knee injury. Overall, six different brands of lateral prophylactic braces were tested. Brace effectiveness was based on an arbitrary standard defined as the Impact Safety Factor (ISF). An ISF of 1.50 or 30% load reduction across the MCL was considered adequate for protection against a lateral knee blow. The authors observed that greater brace stiffness and length were associated with a higher ISF. No brace consistently performed above the ISF rating of 1.50. This study did not examine the effect of ISF on ACL protection.

In 1990, eight PKBs were evaluated in a surrogate model by Brown et al. Higher brace tension was associated with greater strain reduction across the model. All braces were noted to protect the MCL from significant strain of 20% to 30% compared with no lateral brace wear. The customized off-the-shelf braces performed better than the noncustomized braces. A year later, Paulos et al. using the model of France et al., tested the use of prophylactic bracing in a lateral knee contact to reduce MCL and ACL contact forces, contact initiation times, and ISFs. The surrogate limb in the study by Paulos et al. was rigidly fixed and the applied lateral force was increased over the 1987 model of France et al. The authors demonstrated that by increasing impact duration, a lateral brace may selectively protect the ACL over the MCL. In 1993, a PKM MCL protection was seen in a surrogate knee model comparing prophylactic bracing versus no bracing. Significant findings of increased valgus load to failure and MCL strain relief were noted in the models with single, upright, hinged braces. Increases in hinge length or offset, upright length, breadth, thickness, or cuff area did not lead to increased protection of the knee model.

Erickson et al. published a study using a hybrid cadaveric-surrogate knee model. In eight specimens, the authors measured strain across the MCL and ACL in the setting of prophylactic bracing and lateral loading. The authors reported that the presence of a brace reduced the amount of force experienced by the knee during external contact; however, no significant change was seen in ACL strain between specimens with or without a brace. Also, there was a trend in the braced knees tested at 30 degrees for the MCL to experience less strain.

Prior criticism of the inanimate research of brace protection has led other authors to measure different clinical parameters besides load to failure, anterior joint translation, and rotation. Yu et al. compared a PKB in its effect to alter landing mechanics of a stop-jump task. Using 20 human subjects with and without a specially designed knee brace, parameters of jumping performance, maximum knee flexion angle, and maximum ground-reaction force were tested. In the setting of brace wear, the authors noted a statistically significant increase of 5 degrees in maximum knee flexion angle. The other metrics of performance and ground reaction force were unchanged by brace wear. The authors concluded that special brace design may protect athletes from noncontact ACL injury through kinematic modification without compromising athletic performance.

Direct measurement techniques of ACL strain in human subjects has been pioneered by Beynon and Slaterbeck. Custom and off-the-shelf brace designs significantly reduced ACL strain values for anterior-directed loads applied to the tibia up to the maximum anterior load of 140 N. Similarly, bracing reduced ACL strain in response to internal and external rotation torques.

The Clinical Experience

The first high-profile athlete to compete with a knee brace and succeed was "Broadway" Joe Namath in the 1970s. He used the Lennox Hill Derotation Brace, a functional knee brace. Following Broadway Joe, the subsequent decade was filled with hope of a greater role for knee bracing as surgical treatment techniques for ACL-deficient knees were typically nonanatomic and rehabilitation was poorly understood. Ken Stabler, the quarterback for the 1970s Oakland Raiders, was fitted by the team's athletic trainer with a dual-hinged knee brace following an MCL injury. This experience, and that of eight other players, was detailed in the 1979 study by Anderson et al. The authors speculated that braces could potentially reduce valgus loads and anteroposterior translation, and, thus, ligamentous injury to the knee. Consequently, a sports medicine movement emerged to protect the contact athlete against valgus-rotatory knee trauma and the "unhappy triad" of O'Donoghue.

During the 1980s, enthusiasm for knee bracing waned then waned. Several studies were published about knee bracing in contact athletics. Most of these studies were incon-
clusive about the role of prophylactic knee bracing and some concluded that bracing could increase the rate of injuries sustained by players who wore them. In response to the heightened interest within the orthopaedic community, the American Academy of Orthopaedic Surgeons (AAOS), in 1987, released a position paper entitled, "The Use of Knee Braces." This manuscript stated that the AAOS remained negative to neutral at best on the role of prophylactic bracing of knees based on a lack of clear efficacy and some suggestion of potentiating injury. The orthopaedic community's response to this position paper was a retreat from recommending knee braces as a reliable way to prevent injury. Based on the expense of most knee brace systems and the purported increased risk to the player, teams across the United States avoided bracing their athletes.

Although the field of surgical treatment for ACL injury advanced with arthroscopic techniques, the concept of PKBs was not completely abandoned in the 1990s. The advances in brace technology, including polycentric hinges, lighter and stronger materials, as well as custom fitting, provided the impetus to revisit the use of knee bracing in prevention of knee injury. Further, while surgical techniques had improved to more anatomic reconstructions, the large financial cost and lengthy rehabilitation time were still substantial, leading many institutions and their teams to explore prevention alternatives. The identification of high-risk players, in conjunction with improved compliance with brace wear during at-risk activities, were fundamental to two studies published in the 1990s from West Point and the Big Ten Conference.

The West Point prospective and randomized study of 1,396 cadets during 2 years looked at the role of knee bracing in the intramural tackle football population. Outcomes of the study were measured as clinical injury of the knee preventing practice or game participation. Study subjects were controlled for shoe wear, competition exposure, brace type/model, and compliance. All of the cadets wore a non-custom brace. The study authors concluded that statistically significant reduction of knee injuries could be achieved with brace wear. There was also a trend toward brace wear limiting the severity of injury (e.g., MCL vs. MCL/ACL sprains) but this finding was not statistically significant. The West Point experience did not show an increased risk of injury with brace wear. A limitation of the study was the power of the study, which limited conclusions based on the severity of injury.

The Sports Medicine Committee of the Big Ten Conference commissioned a 3-year, multicenter, prospective study of ACL injuries in varsity football players. Brace wear patterns were analyzed, in conjunction with ACL injuries, across 56,722 football knee exposures. The outcome point of MCL injury was based on clinical examination. To determine the effectiveness of PKBs, players were controlled for position, string/skill level, and type of play (practice vs. game). Similar to the findings of the West Point investigation, the authors noted trends in MCL injury prevention using PKBs in the setting of practices for all players and in the setting of games for linemen, linebackers, and tight ends. During games, skill players such as cornerbacks and quarterbacks did not appear to directly benefit from protective brace wear. Once again, in contrast to the findings of Teitz et al., PKBs did not increase the quantity or quality of knee injuries sustained by National Collegiate Athletic Association varsity football players. The investigation was limited by a lack of statistical significance in all results, outcome data based on subjective assessment, and no control of brace make/model or shoe type.

**Current Opinion on Prophylactic Bracing**

The AAOS updated its position paper on knee bracing in 2003. Based on a survey of published literature, the Academy has made the following statement regarding prophylactic knee bracing: "American Academy of Orthopaedic Surgeons (AAOS) believes that prophylactic knee braces may provide limited protection against injuries to the medial collateral ligament in football players. Scientific studies have not consistently demonstrated similar protection by prophylactic braces to other knee ligaments, meniscus, or articular cartilage."

The orthopaedic community remains noncommittal on the use of PKBs. Global medical issues such as cost-effectiveness are a modern reality of orthopaedic sports medicine practice. Additionally, the issue of increased risk of injury with knee bracing has not been settled. Despite the current era of defensive medicine, the concept of committing an athletic team financially, medically, and psychologically to prophylactic brace wear is not an accepted practice based on the available literature.

**THE ROLE OF THE COACH AND ATHLETIC TRAINER**

On the front lines of ACL injury prevention are the coach and athletic trainer. Both have the goal of optimizing individual and team performance. An ACL injury to any team member can be a distraction of team focus, a drain on team resources, and a detriment to a team's success. This list does not address the complex issues faced by the athlete in the setting of an ACL tear. As such, coaches and athletic trainers should have the aligned goal of ACL prevention for the benefit of the team and the health of the players.

Several strategies for ACL injury prevention have been discussed within this chapter and include identification of high-risk athletes, neuromuscular/proproceptive training, and knee bracing. High-risk athletes include female athletes, athletes with hyperlaxity, and athletes in high-risk sports. Not all female athletes are at risk, but a majority of them require age- and skill-specific recommendations to optimize their physical condition and limit their risk of ACL injury. Hyperlaxity is a poorly defined term, but basically refers to an individual with significant ligamentous laxity. These athletes are at risk because their ligamentous restraints are compromised by disorganized collagen. Finally, high-risk sports can be noncontact or contact. Any activity, where nonlinear and pivoting motions are experienced, places the ACL at risk.
# TABLE 5.2
NONCONTACT ANTERIOR CRUCIATE LIGAMENT INJURY PREVENTION TRAINING PROGRAM

<table>
<thead>
<tr>
<th>Preprogram (Flexibility)</th>
<th>Warm-Up</th>
<th>Jog line to line, shuttle run, backward running</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stretching</td>
<td>Calf, quadriceps, hamstring, inner thigh, hip flexor</td>
<td></td>
</tr>
<tr>
<td>Neuromuscular Strengthening</td>
<td>Walking lunges, Russian hamstrings, single-toe raises</td>
<td></td>
</tr>
<tr>
<td>Plyometric Training</td>
<td>Jump-training program → lateral hops, forward hops, single-legged hops, vertical jumps, scissors jumps</td>
<td></td>
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<tr>
<td>Plant/landing skills</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Agilities</td>
<td>Shuttle run, diagonal run, bounding run</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Floor exercises: running, planting, jumping</td>
<td></td>
</tr>
<tr>
<td>Proprioception</td>
<td>Single-leg stance</td>
<td></td>
</tr>
<tr>
<td>Balance mat/wobble board: rectangular → round → multiplanar (BAPS)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anterior and posterior step-up</td>
<td></td>
<td></td>
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<tr>
<td>Reactive Tasks</td>
<td></td>
<td></td>
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<tr>
<td>Sport-specific</td>
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</tr>
</tbody>
</table>

BAPS, biomechanical ankle platform system.
Program derived from Caraffa et al., 1 1996; Hewett et al., 2 1996; Myklebust et al., 3 2003; and Mandelbaum et al., 4 2005.

Neuromuscular and proprioceptive training can be completed in the preseason conditioning phase for all athletes and continued throughout the season with higher-risk individuals as noted previously. A curriculum of correct landing and take-off, pivoting, and cutting should be introduced as an integral part of successful technique. Table 5.2 is an ACL injury prevention program modified from successful training regimens. 3,4 Endurance, conditioning, and strengthening programs should incorporate these technique recommendations. Compliance with training should be closely monitored and modified as the season progresses.

Finally, prophylactic bracing is a controversial area in ACL injury prevention. For the high-performance athlete, the effect of PKBs on speed and agility is uncertain; however, brace migration and unnatural kinematics are acknowledged nuisances. 1-3 Based on the cost, inconvenience, and lack of consistent evidence, global prophylactic knee bracing is not recommended in either the pediatric or mature athlete. In high-risk contact athletes, there may be a role for prophylactic bracing in reducing MCL sprains.

## CONCLUSION

The complex challenge of ACL tear prevention lies in the variability of injury mechanisms, as well as gender-specific neuromuscular mechanics. A successful prevention program begins with identification of the high-risk athlete.

Next, a comprehensive prevention program should be developed with the athlete, the athlete's parents, trainers, and coaches. The program should incorporate a form and function approach. In regard to form, the player should be assessed for neuromuscular deficiencies that will place him or her at higher risk for an ACL tear. In regard to function, the athlete should be educated on the controversies surrounding prophylactic bracing. The use of a prophylactic brace should be based on an athlete's string, position, and game time. Additionally, the use of a brace should take into account the contact level of the sport. Based on more than 30 years of investigations into a focused ACL prevention strategy, one is left with the impression that there is not a single approach, but custom plans that must be flexible based on the needs of the athlete. Future investigations will better define prevention strategies based on an athlete's sport and position, gender, and custom biomechanical and neuromuscular profile.

## REFERENCES

Chapter 5: Anterior Cruciate Ligament Injury Prevention: Concepts, Strategies, and Outcomes


