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CHAPTER 26

Proprioception and Neuromuscular Control Related to the Female Athlete

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An alarmingly high incidence of noncontact anterior cruciate ligament (ACL) tears has been observed in females compared to males in sports. The higher risk sports are basketball (1–11) soccer (1), and gymnastics (12, 13). Rates of ACL tears are three to four times greater in the female. Epidemiological studies comparing males and females document this increased rate (12, 14–18).

In the U.S. military, the rates of injuries such as stress fractures have equalized for females and males over the past 10 years (19, 20). The concern is that this injury rate for women is not decreasing in organized sports, particularly high school and college basketball and soccer. In Europe, similar rates occur for team handball and skiing (1). The National Collegiate Athletic Association (NCAA) surveys 18% of all colleges in sixteen sports. This survey is published as the injury surveillance system (13). Rates of injury of the ACL and meniscus are shown in table 26.1. These rates are reported based on number of injuries per 1,000 athletic exposures and averaged over a 3 yr period. Women's gymnastics, women's basketball, and women's soccer lead categories for ACL injury and meniscal injury. Rates of ACL injuries are women's gymnastics, 0 .41; women's basketball, 0.33, compared to men's basketball, 0.11; and women's soccer, 0.32, compared with men's soccer, 0.12. Meniscal injuries are highest in men's wrestling; however, women's soccer, women's basketball, women's gymnastics, and spring football are almost tied for the next highest rate following wrestling. Over the years no trend or statistically significant change in knee injury rates has occurred.

As basic scientists and clinicians, we must assess the risk—then, prioritize factors, develop an equation, and reduce it. In the 1988 Olympic Trials for the United States, which was prior to the men's preselected professional athletes' involvement, 80 males and 64 females tried out for the U.S. basketball teams. A significantly increased rate of knee injury and ACL tear was seen in the females (see table 26.2) (5, 21). Of the 64 females participating in the trials, 34 (53%) had previous knee injuries, and of the 80 males, 11 (13.7%) had previous knee injuries (statistically significant, $p < .0001$). The numbers of ACL injuries were 13 in the females and 3 in the males. Six males underwent 6 surgical procedures, 3 of which were ACL reconstructions. Twenty of the female athletes underwent 25 procedures, 8 of which were ACL reconstructions.

The increase in patellofemoral problems from miserable malalignment, patellar instability, is well known in the female athlete. Alignment, generalized physiologic laxity, excessive valgus, vastus medialis obliquus dysplasia, and quadriceps weakness are contributing factors. The normal alignment of the lower extremity is shown in figure 26.1, and miserable malalignment syndrome is shown in figure 26.2 (22). Comparisons between knees for

Table 26.1 NCAA Injury rates: ACL, Meniscus*

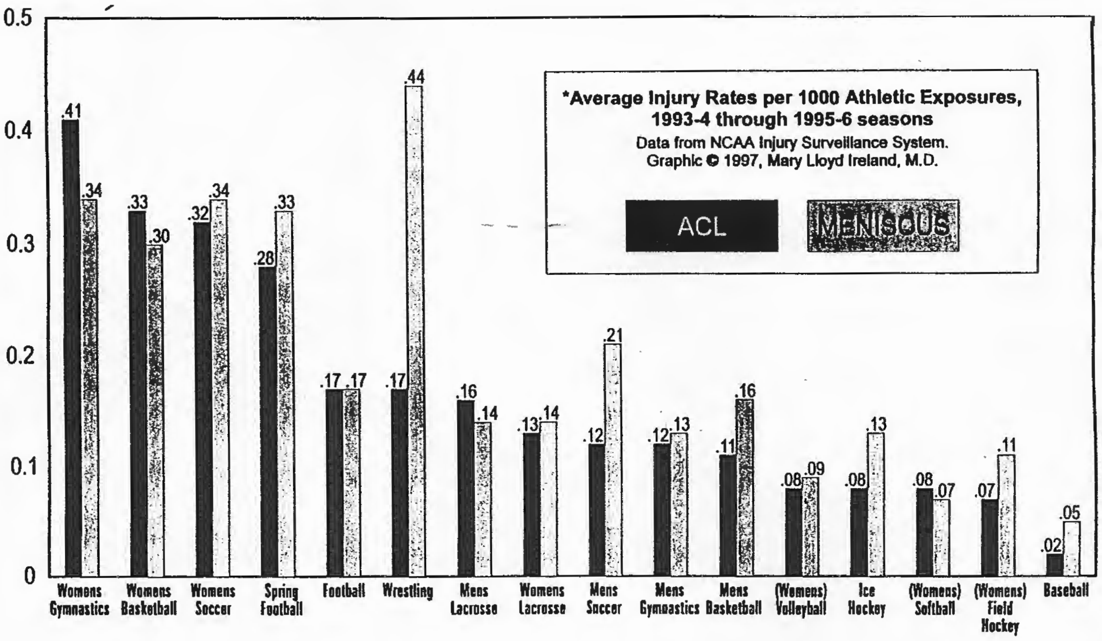

Table 26.2 Injuries Sustained During 1988 Olympic Basketball Trial

Parameter	Males	Females	Total
Number of participants	80	64	144
Athletes with knee injuries	11*	34	45
ACL injuries	3	13	16
Number of athletes requiring surgery	6**	20	26
Number of procedures	6	25	31
Type of procedure			
Arthroscopy	3	17	20
ACL Reconstruction	3	8	11

Abbreviations and symbols: ACL = anterior cruciate ligament; *,** indicate a statistically significant difference between male and female athletes (* = $p < 0.0001$; **$p < 0.0007$).

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normal alignment can be made from neuromuscular function, and dysfunction can be determined from anterior knee pain and ACL injuries. Inhibition of the neuromuscular control of the lower extremity occurs in both malalignment and dysfunction.

When comparing males and females for risk of ACL, multiple intrinsic or nonchangeable factors are observed. The male athlete is more muscle dominant, has greater knee varus, less flexibility, wider notch and hence larger ligament, and internal rotation of the tibia (36) (see figure 26.3). The female athlete is more ligament dominant and has less muscular development, generalized laxity, greater knee valgus, smaller notch and hence smaller ligament. Tibial external rotation and foot pronation is commonly seen (see figure 26.4).

Factors contributing to ACL injury can be divided into intrinsic (not controllable)—physiological rotatory laxity, size of ACL, valgus alignment, hyperextension, proprioception, neuromuscular firing order, and hormonal influences, extrinsic (potentially controllable)—strength, conditioning, shoes, motivation, deceleration forces during injury, and

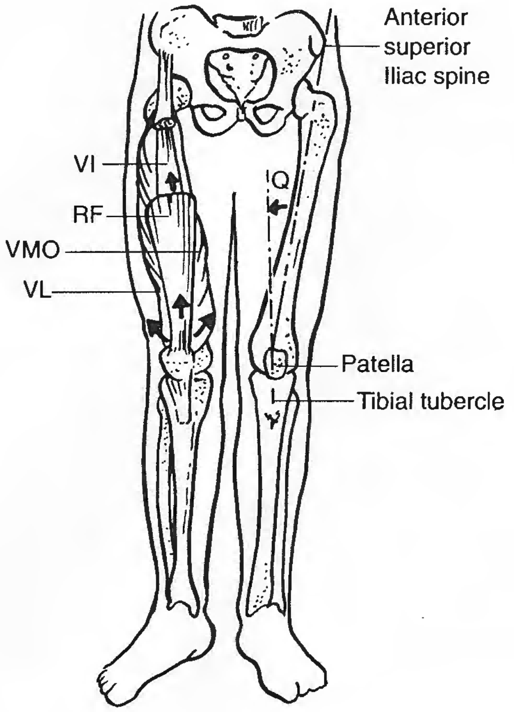

Figure 26.1 Normal alignment with normal Q angle (measured from anterosuperior iliac spine central portion of the patella) from patella to tibial tubercle of less than 15° and normal musculature of developed vastus medialis obliquus create forces that centralize the patella, which results in normal patellofemoral tracking. (Reprinted with permission: Fu FH, Stone DA (eds). *Sports Injuries: Mechanisms, Prevention, Treatment*. Williams & Wilkins, 1994.)

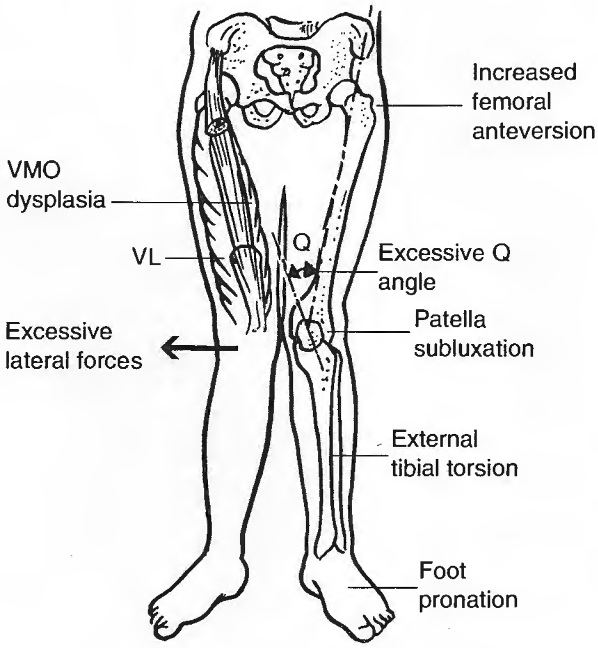

Figure 26.2 Miserable malalignment syndrome consists of increased femoral anteversion, excessive Q angle, external tibial torsion, and foot pronation. These factors cause lateral patellar subluxation. This miserable malalignment syndrome is frequently seen in females. (Reprinted with permission: Fu FH, Stone DA (eds). *Sports Injuries: Mechanisms, Prevention, Treatment*. Williams & Wilkins, 1994.)

a combination of both (partially controllable)—skill and coordination (24) (see table 26.3). The alignment, ligament dominance, and physiological rotatory laxity put the female in a high-risk position for noncontact ACL injuries.

Notch stenosis has been addressed. The notch forms in relation to the size of the ACL, that is, small ligament, small notch. The ACL is not actually amputated by a stenotic notch. Notch measurements may be reported as absolute width or ratios. Notch ratios of the width of the notch to the distal femur have been reported (24–26). Ratio versus absolute width has been discussed. The size < 15 mm is felt to place the knee at higher risk for ACL injury (27).

Basketball was the sport of injury in 40% of the ACL reconstructions that I have performed. It is the No. 1 sport of ACL injury at Kentucky Sports Medicine. Reviewing 5 years of data for reconstruction in basketball athletes, we found that 59% were age 15–18, and 67% of males were older than age 22 (38). In basketball, noncontact mechanisms were responsible in 82% of injuries in females and 87% in males. ACL injuries occurred during games in 59% of the females and 87% of males. Factors that make the female more vulnerable during her teen years include recent growth phase with change of center of gravity, leg length and valgus alignment, relative weakness, hormonal effects, particularly estrogen, smaller size of the ligament with smaller notch, and less neuromuscular control. Hormonal cyclic influences occur, but their degree of expression and significance are still under investigation. Estrogen receptors are present in the ACL (29). However, the question of receptor activity and effects remains. Estrogen and other hormones influence many tissues. The relation of the hormone cycle to ACL tears has been presented, and the ACL tears did not tend to occur at a high-estrogen level time (30).

Developmental factors cannot be overlooked. The young female participating in athletics in the '90s may not have been as active as her male counterpart during the time of free play, jumping, running, and

Figure 26.3 Male lower extremity alignment, showing narrower pelvis, more developed thigh musculature, VMO hypertrophy, less flexibility, neutral genu varum, a wider femoral notch, and internal or neutral tibial torsion. (Reprinted with permission: Fu FH, Stone DA (eds). *Sports Injuries: Mechanisms, Prevention, Treatment*, Williams & Wilkins, 1994.)

Figure 26.4 Lower extremity anatomic alignment in the female, showing wider pelvis, femoral anteversion, internal rotation, narrower femoral notch, genu valgum, less muscular development, increased flexibility, hyperextension, external tibial torsion, and pronated foot. (Reprinted with permission: Fu FH, Stone DA (eds). *Sports Injuries: Mechanisms, Prevention, Treatment*, Williams & Wilkins, 1994.)

Table 26.3 Mechanism of Injury: Contributory Factors

Intrinsic (not controllable)
- physiological rotatory laxity
- size of ACL
- valgus alignment
- hyperextension
- proprioception
- neuromuscular firing order
- hormonal influences

Extrinsic (potentially controllable)
- strength
- conditioning
- shoes
- motivation
- deceleration forces during injury

Both (partially controllable)
- skill
- coordination

cutting when the ACL and proprioception develop. A more sedentary lifestyle—sitting, being driven to practices, and sitting in front of the computer—is the trend for the '90s. In previous decades, free play walking and running was the rule. Potential changes in strength, size, and attachments of the ACL may have evolved. Are we missing the window of opportunity, the patterns of protective landing behavior, and potentially increased ACL size and strength?

Excellent ongoing research is being done comparing neuromuscular patterns in average and elite athletes (31). Delay in hamstring activity and early quadriceps firing in elite athletes has been shown, which places the ACL at risk.

Fatigue plays a role in injury patterns (32, 33). Fatigue has also been shown to influence neuromuscular performance and affect anterior tibial translation (34). Comparing the uninjured with the injured knee in basketball and volleyball female athletes, no significant differences were found in the orthopedic knee exam or KT-1000 test. We have performed studies assessing how fatigue causes changes in muscle activity and knee flexion angles in women volleyball and basketball athletes doing maneuvers involving running and rapid stopping (32). In the fatigued state, we found that there was later recruitment of rectus femoris, vastus lateralis, biceps femoris, and medial hamstrings and earlier maximal knee flexion.

Studies are underway in the lab for sport specific side cutting, rapid deceleration, and other activities, measuring joint kinematics and EMG of the musculature including back, hip, quadriceps, hamstring, calf, plantar, and dorsiflexors. Research and proprioception activation patterns of hamstrings have been reported (35–37). Reflex inhibition of quadriceps femoris occurs in certain groups' activity following injury or reconstruction. (38) The effects of back or hip injury on lower extremity proprioception cannot be overlooked. Specific research has been done on the effect of ankle sprains on proprioception of the ankle (39). Proximal control is key to injury prevention. Distal deceleration and improved proprioception sense in the entire lower extremity can be learned. It is felt that proprioception sense can be improved with sport and balance specific training programs in six to eight weeks (40).

Mechanoreceptors have been demonstrated in the ACL (41–43). After an ACL reconstruction, there is evidence of development of neural elements (28). Is there some basic deficit of control or position sense inherent in the individual who tears the ACL? There are people who cope very well without an ACL and others who do not cope well. Determining the factors that allow some people to cope well and doing specific training to make everyone able to cope with an ACL injury needs to be done.

Following an ACL injury, the nonreconstructed ACL is the one more likely to be injured (28). Proposed reasons why the opposite is torn include the following: the reconstructed ACL is larger; the importance and illustration of proprioception is emphasized on the reconstructed knee and landing patterns may increase stress on the uninjured knee; general proprioceptive deficits or neuromuscular dyssynchrony affect the uninjured ACL.

Observation of mechanisms of injury, particularly in basketball and gymnastics has been done (44). Analysis of the videotaped injuries of 40 individuals showed that their positions were varied (45), but varus thrust was most common and tibial rotation was involved.

In the most common noncontact ACL-tear mechanism and body position that I have observed, the body is falling forward, rotating to the opposite side, the hip is internally rotated and adducted, the knee is in valgus, the foot is usually fixed and pronated, resulting in external rotation of the tibia (see figure 26.5). With further analysis and additional videos of injuries, this position of no return can be determined. Hopefully, sport specific training may be possible to prevent progression to this position of no return. The ACL-injury cycle of the twisting falling-tree position must be interrupted (see figure 26.6). The athlete's position and muscle action must be antagonistic to the injury position. Important factors that reduce risk include improved body position, proximal control, improved muscle activity, timing, improved strength, distal segment changes of foot movements, and proximal segment control (see table 26.4). Muscle activity that would be most beneficial in responding to break the injury cycle, similar to the avoidance of painful stimulus, is to fire the back extensors, hip abductors, external rotator extensors, knee flexors, ankle invertors, and plantar flexors. To improve the distal segment foot movements the athlete should get more weight posterior, get back on the heels, increase the squeaking of shoes to surface, use two-footed landings and

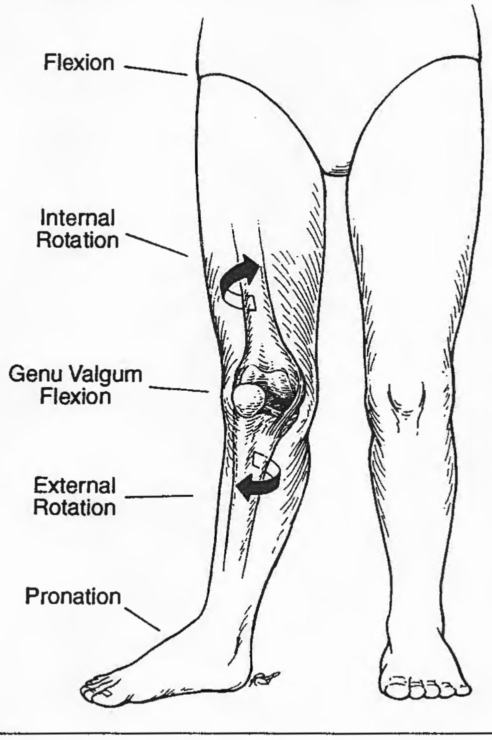

Figure 26.5 Based on videotape analysis, this diagram shows the position of no return for the ACL. The lower extremity position is one of body-forward flexion, hip adduction, internal rotation, 20-30° knee flexion, external rotation of the tibia, and forefoot pronation. The knee will buckle; the patient is usually falling forward and toward the opposite side in a rapid distal deceleration mechanism.

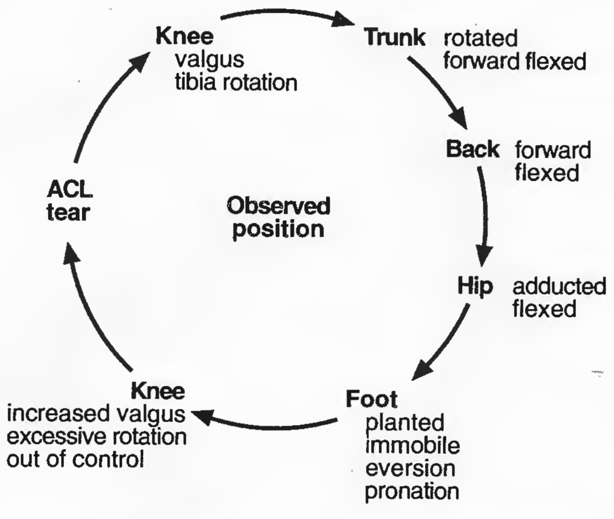

Figure 26.6 The observed body position of trunk, back, hip, knee, and foot of the noncontact ACL injury. To prevent injury, the cycle must be broken. This can be with a trained timing and neuromuscular response.

Table 26.4 Important Factors to Reduce Risk

- Improved position
- Muscle activity timing and strength
  Back extensors
  Hip abductors/ER/extensor
  Knee flexors
  Ankle inversion/plantarflexion
- Distal segmental foot movements
  More force back on heels
  Increase squeaking
  Two-footed landings
  Less fixed foot
  Improve shoe fit
  Reduce friction, shoe to floor
- Proximal segment
  Trunk balance and control
  Hip abduction/ER

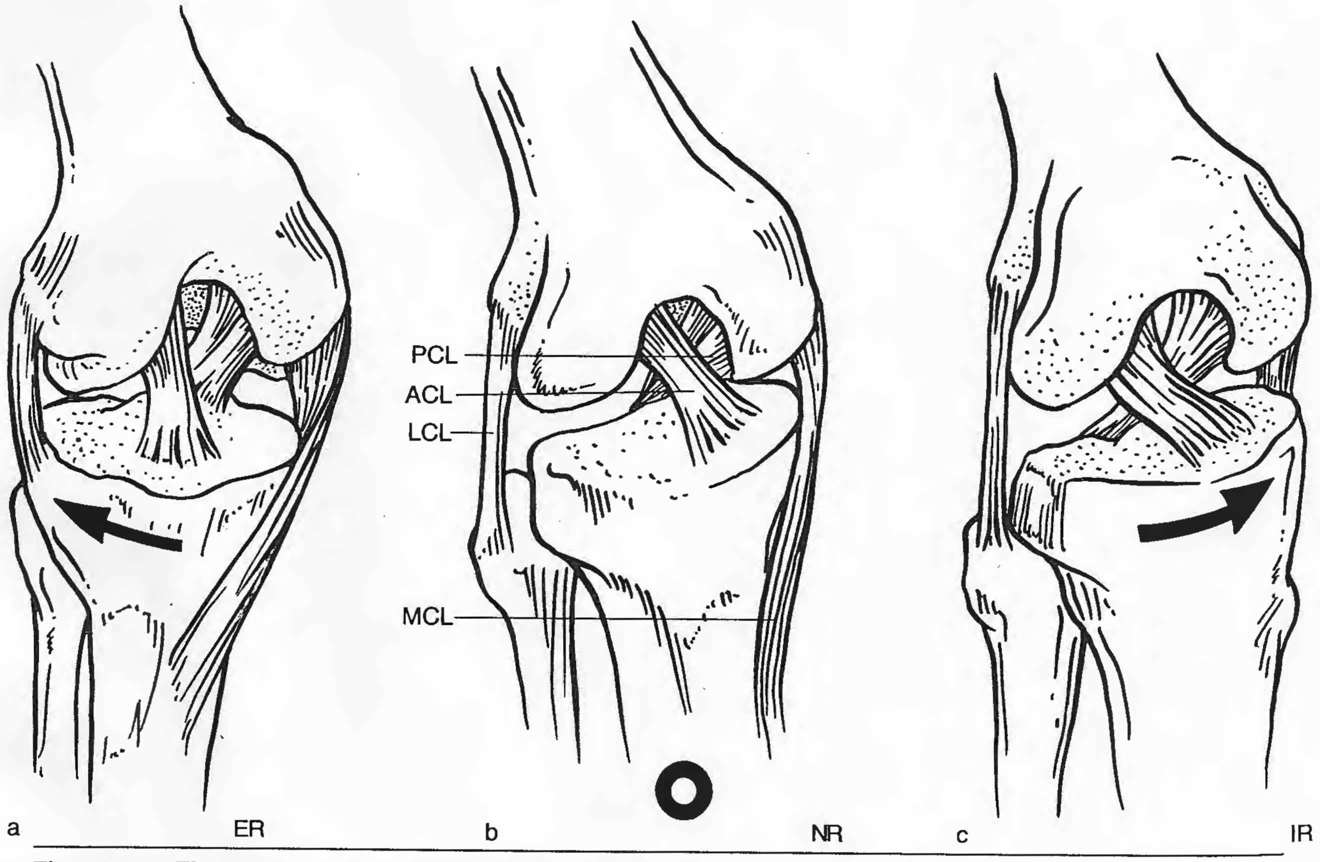

Figure 26.7 The synergistic functions of the collateral ligaments and cruciates are shown. (*a*) In external rotation the collateral ligaments tighten and cruciates relax. (*b*) In neutral, no ligaments are under unusual tension. (*c*) The cruciate ligaments tighten in internal rotation while the collateral ligaments are more vertical and lax. (Reprinted with permission: Muller W. *The Knee: Form, Function, and Ligament Reconstruction*. New York: Springer-Verlag, 1983.)

fewer fixed foot landings, improve shoe fit, and reduce the friction ratio of shoe to floor. Proximal segment improvements include balance and control and hip abduction external rotation.

In basketball and gymnastics injuries, the foot has been observed in a position of pronation and external rotation. This would indicate that the femur internally rotates on the tibia. In the valgus knee with some movement at the foot, the ACL will be loaded prior to the medial collateral ligament. Anatomically, the cruciate ligaments should be coiled on each other and tighter in internal rotation, while the lateral ligaments are then more vertical and relaxed (46) (see figure 26.7, *a–c*). In external rotation, the collateral ligaments are tighter. However, when we look at the position of injury, there are other forces involved, namely, forces anterior on the tibia and a fixed external rotation of the foot from the ground. The rotational component is therefore very important, but the ACL must be loaded in this position as injury occurs. Further studies need to be done: on tension, using cadavers and varying degrees of rotation; on valgus at the knee, with strain gauges in the collateral ligaments; on the ACL and PCL, correlating mechanism of injury to greatest strain. From this basic research, we can base teaching the avoidance of high-risk positions and muscle retraining programs.

The goal is to avoid the position of no return. When one sees an injury approaching, an intracranial alarm should sound to prepare for point of no return. Prevention programs have been outlined (14), and further programs are needed. Prevention programs in football and skiing have been published (47).

After an athlete has had an ACL reconstruction of one injured knee, it is necessary to begin studies looking at timing of muscular activity during sport specific drills, looking at joint angles and forces; and EMG measurements for timing of onset of activity studies are necessary. Attempting to keep the individual out of this point of no return ("falling-tree position") should be investigated. In the same frame as Pavlov's experiments, a virtual reality situation of avoiding that position should be demonstrated and practiced, until the athlete has an acquired position sense. Avoid painful stimuli! Sport specific programs on the prevention of getting into these positions of no return and a virtual reality video, shadowboxing types of sport specific programs, can be developed. Ongoing research will require funding, multiple center involvement, and longitudinal studies. Prevention and protection of the uninjured knee should be the goal (48). Further basic research, determining gender differences, and emphasizing those factors that can be changed are necessary. Now is the time to organize and begin these efforts.

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