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Assessment and Evaluation of Predisposing Factors to Anterior Cruciate Ligament Injury

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Objective: Injury to the knee, specifically the anterior cruciate ligament (ACL), constitutes one of the most serious disabling injuries in sports. Women are reportedly at an increased risk. Prevention depends on identifying possible risk factors that may contribute to an athlete's susceptibility to injury. The major objective of this article is to lay the groundwork for standardization of a screening protocol (1) by providing rationale for the use of selected variables that might be good predictors of noncontact ACL injury and (2) by describing appropriate measurement indices to further investigate their predictive power. Standardization of a screening protocol is the first step in developing both a reliable and valid assessment tool with predictive value for injury and outcome strategies to meet the special needs of patients.

Data Sources: MEDLINE was searched from 1980 to 1998 using the terms "anterior cruciate ligament injury," "knee joint stability," "postural malalignments," "structural abnormalities," "static structural measures," "musculoskeletal strength imbalances," "isokinetic testing," and "functional performance tests."

Data Synthesis: Many different factors, both extrinsic and intrinsic, have been investigated in the search for predictors of noncontact ACL injuries. Based on a literature review, 3 factors in particular have garnered considerable attention from clinicians and researchers: static postural malalignments with special reference to excessive foot pronation, knee recurvatum, and external tibial torsion; lower extremity musculoskeletal strength; and neuromuscular control considerations. However, much of the information known about the predictive value of these variables is inconclusive and conflicting at best, prompting the need for additional investigation.

Conclusions/Recommendations: Screening evaluations are routinely employed as part of clinical work-ups when athletes are healthy and in top form. The data collected have the potential to provide clinicians with important baseline information for maximizing structural and functional outcome strategies when deficiencies in test results are observed in subgroups of athletes matched for age, sex, and training or performance expectations.

Key Words: postural malalignments, static structural measures, functional performance tests

Many theories have been proposed as to why female athletes participating in sports involving running, cutting, and jumping maneuvers incur a disproportionate number of noncontact injuries to the anterior cruciate ligament (ACL). The incidence, severity, costliness, and potential for long-term disability resulting from ACL tears make their prevention a high priority in the medical and research communities. Preventive measures begin with an investigation of possible risk factors that may contribute to an athlete's susceptibility to injury. Many different factors, both extrinsic and intrinsic, have been investigated in the search for predictors of noncontact ACL injuries. These factors include, but are not limited to, lower extremity malalignments,[1–5] ligamentous laxity,[3,5,6–10] lower extremity muscular strength considerations,[4,8,9,11–13] neuromuscular control or proprioception,[14–23] hormonal influences,[24–27] intercondylar notch width,[28–32] and the biomechanics of player technique.[11,32–38] Much of the information known about the predictive value of these variables is inconclusive and conflicting at best. Variables that were long assumed to have credence have turned out to have questionable predictive value upon further investigation.[39] For example, ever since Nicholas[10] related ligamentous-capsular-muscular looseness to an increased susceptibility to knee ligament rupture in professional football players, this factor has been targeted for its predictive value. Subsequent investigations by Godshall,[6] Grana and Moretz,[7] and Kalenak and Morehouse[8] did not support the relationship between joint stability and injury. However, in a more recent study, Woodford-Rogers et al[5] found anterior knee laxity to be highly correlated with ACL injuries. Further research from a prospective standpoint is needed to define which factors are important and have predictive value in order to develop and implement appropriate outcome interventions to minimize injury.

The purpose of this article is to present a screening methodology, with special reference to the female athlete, for investigating only those aforementioned variables that are measurable and easily obtainable by clinicians. The challenge for clinicians lies in selecting the variables to be measured, implementing appropriate measurement indexes, and assessing

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the practicality and reliability of the measurements for standardization of a screening protocol that has broad-based medical and research applications across many investigators and clinical sites. A literature review supports the selection of the following variables for their predictive value: lower extremity malalignment considerations with special reference to excessive foot pronation,[1,3,5,40] knee recurvatum,[3,41–43] and external tibial torsion[2,44]; lower extremity musculoskeletal strength considerations specific to the quadriceps and hamstrings[9,11–14,20]; and neuromuscular control.[15,16,19–23,45,46]

LOWER EXTREMITY MALALIGNMENTS

Sahrmann[47] defines ideal posture as the state of muscular and skeletal balance that protects the supporting structures of the body against injury or progressive deformity, regardless of the attitude in which these structures are working or resting, ie, erect, lying, running, squatting, jumping, etc. Faulty alignment of limbs or skeletal segment deviations detract from the efficiency of limb motion, result in higher levels of energy consumption and mechanical stress, and contribute to potential or actual pathology of the neuromusculoskeletal system.[47] During periods of loading with excessive and altered force application, the supporting structures, particularly the ligaments, experience microstructural damage over time in addition to alteration of their neurosensory role, increasing the likelihood of functional instability.[48] In circumstances of faulty postural alignments, it is theorized that the joints are already in positions that have a preloading effect on the ligaments, subjecting them to complete structural failure under external forces well below critical stress limits.[48,49]

The impetus for studies relating lower extremity malalignment considerations to knee problems, especially patellofemoral and ligamentous pathologies, has stemmed from known structural differences between males and females. Females have a wider pelvis, increased femoral anteversion, increased physiologic laxity, increased genu valgum and genu recurvatum, more external tibial torsion, and more forefoot pronation.[43,50] These anatomical considerations can create faulty alignment positions that are common to ACL injury mechanisms reported in sports characterized by running, jumping, and pivoting maneuvers.

According to Ireland et al,[43] a mechanism for complete structural failure of the ACL is a situation in which the body is in a position of forward flexion, the hip in adduction, the femur in internal rotation, the knee in 20° to 30° of flexion, the tibia in external rotation, and the foot in pronation. Fu and Stone[51] noted that the most frequent noncontact ACL injury mechanism observed in athletes participating in soccer, football, and skiing is with the tibia in external rotation and the knee in valgus. Conversely, in basketball, the most common injury mechanism, resulting primarily from jumping maneuvers, is hyperextension of the knee with tibial internal rotation.[51] Mechanisms producing ACL injury are related to foot fixation, hyperextension, and torsional stresses. Injuries occurring as a result of these mechanisms often include a component of deceleration/landing forces.[33] Boden and Garrett[52] reviewed mechanisms of ACL injury in 40 videotapes to ascertain the events surrounding the injuries. Sixty-two percent were noncontact, 19% were sustained while executing a deceleration or landing maneuver, and the average knee flexion angle at the time of injury was 20°. Lower extremity malalignments that allow these positions to occur can increase stress on the ACL and have a preloading effect that, in combination with the uncontrolled movements, leads to traumatic injury.[42,43]

The mechanical effectiveness of force-transferring or force-generating levers of the lower extremity must be enhanced to maximize knee joint stability and functioning.[42] This begins with a detailed examination of lower extremity alignment. Such an examination permits recognition of anatomical or biomechanical abnormalities that could predispose an athlete to knee injury. To reiterate, structural variables that might have predictive value for ACL pathology include excessive foot pronation, knee recurvatum, and external tibial torsion, in addition to a combination of postural faults that will be elaborated on as the discussion progresses. Structural measures used to quantify the degree of malalignment associated with each of these variables will be described, their rationale for use will be explored, and illustrations will be included where appropriate.

Excessive Foot Pronation

A risk factor contributing to alterations in lower-extremity kinematics that may increase an individual's susceptibility to musculoskeletal injury is excessive foot pronation.[38,40,53–57] Investigations of movement dysfunction of the foot relative to pronation tendencies frequently focus on the subtalar joint (STJ) because of its significant role in force attenuation. The STJ is a single-axis joint that acts like a mitered hinge connecting the talus and the calcaneus.[55] The joint also includes the posterior surface of the navicular bone, which articulates with the head of the talus. According to Mann,[55] it is the determinative joint of the foot that affects the performance of the more distal articulations and modifies the forces imposed on the skeletal and soft tissues transmitted upward through the ankle, knee, and hip joints, in addition to the pelvis and spine. In normal gait kinematics, at the time of heel strike, there is eversion through the STJ that reaches a maximum as the foot is loaded during the contact phase of the gait (foot-flat position) until heel rise and lift-off.[58] Eversion through the STJ is one of the components of foot pronation. Excessive motion of the STJ in the direction of eversion influences more pronatory effects of the foot. The occurrence of pronation, to a degree, is important during the support phase of the gait since it provides proper shock absorption to the stresses of standing, walking, jogging, and sprinting.[54] Pronation is referred to as the decelerating phase of movement and is accompanied by tibial internal rotation.[43,54,55] An important observation is whether the foot remains pronated during the period of heel

rise and lift-off. If excessive or prolonged pronation of the foot occurs beyond the first half of the stance phase, the tibia undergoes additional internal rotation, resulting in abnormal forces transmitted upward through the kinetic chain. The ACL tightens with tibial internal rotation.[43] Therefore, excessive foot pronation may produce a preloading effect on the ACL. An association has been shown between excessive pronation tendencies and ACL injuries.[1,3,5,40]

A composite measure of excessive pronation routinely employed by researchers is the navicular drop test.[4] This test describes the distance between the original height of the navicular taken in a seated, STJ-neutral position to the final weightbearing, compensated position of the navicular in relaxed stance.[4,43] Establishing STJ-neutral position[54] (Figure 1), defined as the position of maximum congruency between the talus and the calcaneus, is a prerequisite to measuring navicular drop (Figure 2).

Woodford-Rogers et al[5] measured navicular drop in an ACL-injured group consisting of 14 football players and 8 gymnasts and an age-, sex-, and sport-matched control group. The investigators found that the ACL-injured group had greater amounts of navicular drop, suggesting increased pronation. Beckett et al[1] found that subjects with ACL injuries had greater amounts of pronation as measured by navicular drop than noninjured subjects and concluded that hyperpronation of the foot and ankle may increase the risk of injury to the ACL. They reported a mean navicular drop of 6.9 mm in 50 healthy subjects as compared with a mean of about 13 mm in patients with ACL injuries. Similarly, Loudon et al[3] studied the relationship between static posture and ACL injury in female athletes. Of the variables assessed, excessive pronation as measured by the navicular drop test was a significant discriminator between the ACL-injured and noninjured groups.

Navicular drop is not the only measurement for assessing excessive pronation tendencies. Measurement of rearfoot valgus or rearfoot-to-leg orientation (Figure 3) is considered an acceptable indicator of pronation.[40,57] Also, since STJ movements are associated with dorsiflexion, which occurs primarily at the ankle joint,[55] assessment for restricted dorsiflexion of the ankle[39,57] with the knee flexed and extended should be included as part of the screening protocol. Foot and ankle rigidity combined with STJ compensations contribute to early knee deformation.[48]

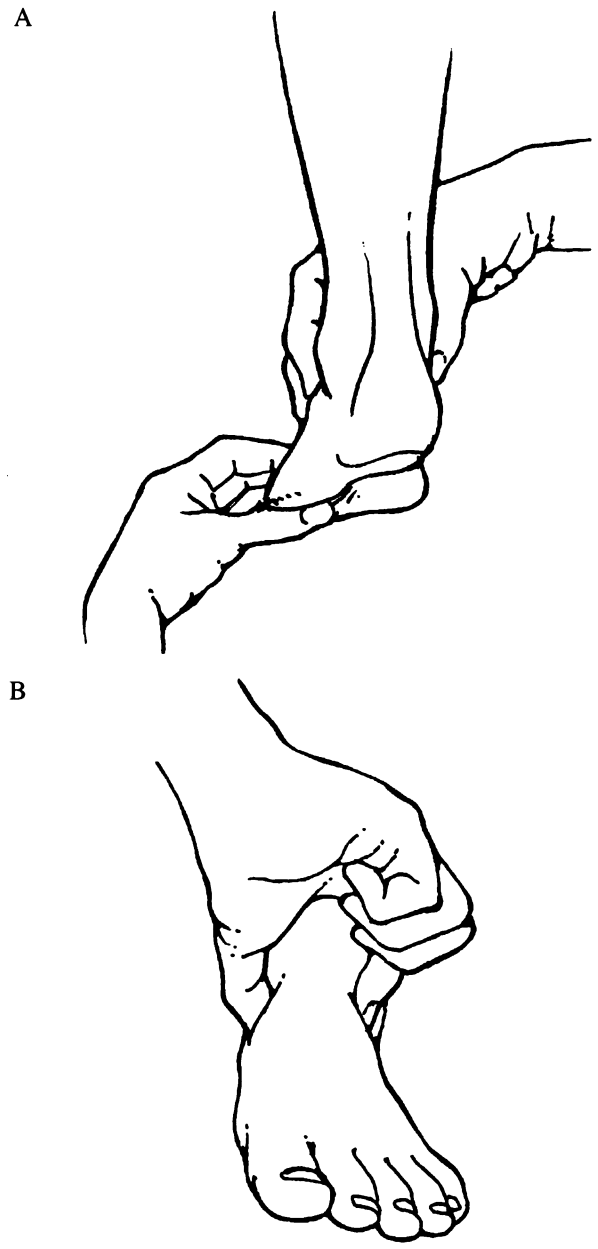

Figure 1. Establishing subtalar neutral. (1) Place the subject in a kneeling position with the foot hanging over the table edge. (2) Palpate the talus both medially and laterally, anterior to the malleoli, as the foot is everted and inverted. Use the thumb and index finger of one hand to palpate the medial and lateral talar depressions. With the opposite hand, grasp the web space between the 4th and 5th metatarsals to invert and evert the foot (A). (3) Neutral position is established when the medial and lateral talar depressions are equal (B).

Genu Recurvatum

Another risk factor involving lower extremity alignment considerations that may increase an athlete's susceptibility to ligamentous injury is genu recurvatum, or knee hyperextension. It is usually an acquired structural abnormality secondary to changes in distal skeletal joint alignments and compensatory movement patterns and is characterized by soft tissue laxities of the posterior, posteromedial, and posterolateral joint structures.[42] Genu recurvatum results from an occasional hyperextension moment during ambulation that stresses the soft tissue ligamentous structures with repetitive and chronic loads.[42] Each degree of deformation over time can produce tensile strain on the ACL and result in ACL impingement in the intercondylar notch.[43]

Loudon et al[3] demonstrated that genu recurvatum in combination with excessive foot pronation can result in greater strain on the ACL. They found an increased susceptibility for

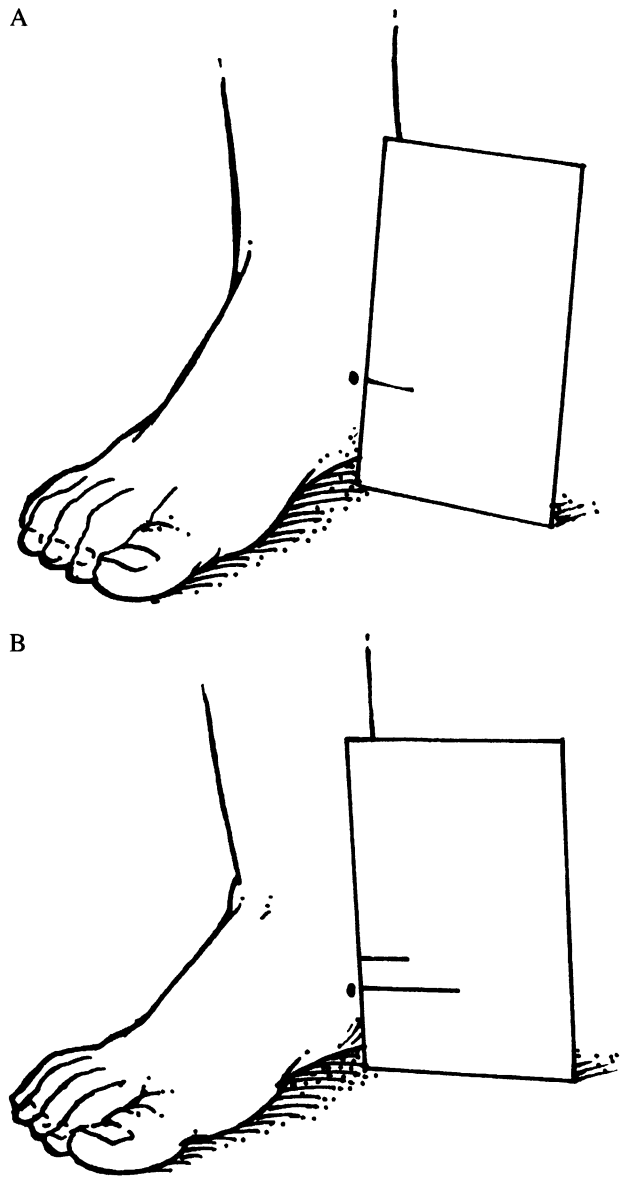

Figure 2. Navicular drop test. (1) Place the subject in a sitting position with the feet flat on a firm surface and the knees flexed to 90°. (2) Establish subtalar neutral position. (3) Identify and mark the most prominent point of the navicular tubercle while maintaining subtalar neutral position (A). (4) With an index card placed on the inner aspect of the hindfoot, mark the level of the navicular on the card. (5) Instruct the athlete to stand without changing the position of the feet. Equal weight should be distributed on both feet. (6) Mark the resulting lower position of the navicular on the card (B). (7) Calculate the distance in millimeters between the original height of the navicular (with the STJ in neutral) and its final weightbearing position.

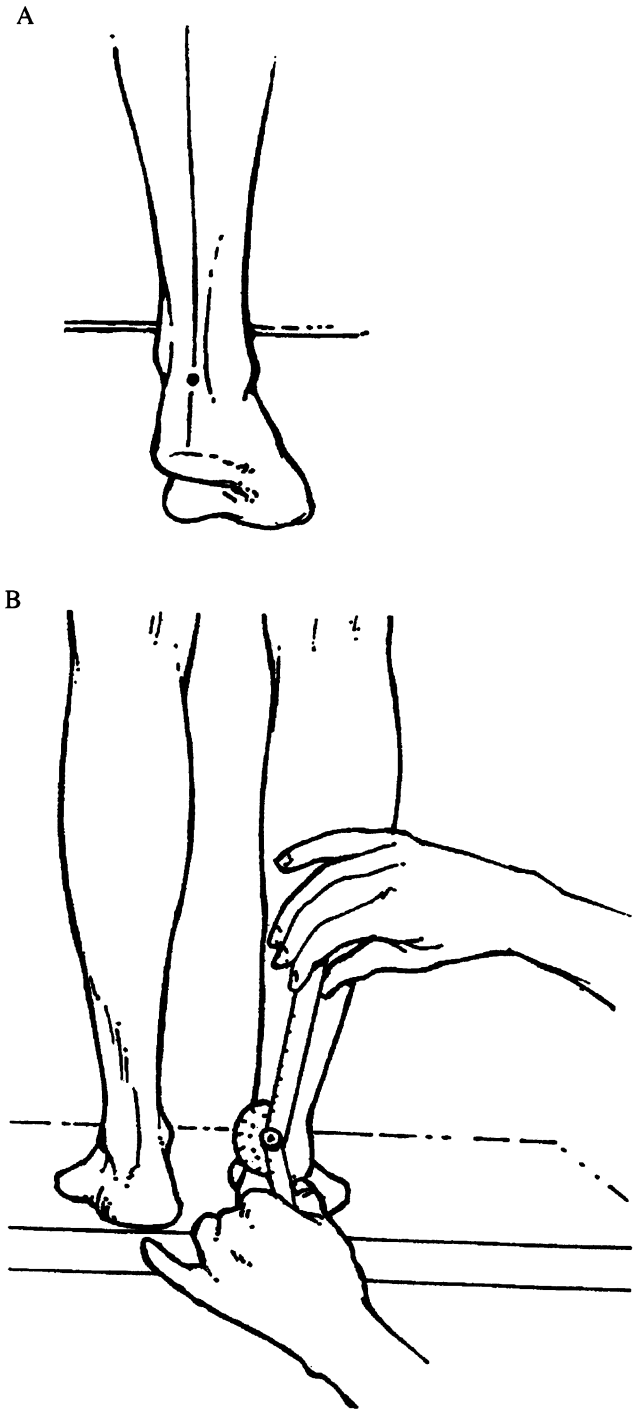

Figure 3. Rearfoot-to-leg orientation. (1) Place the athlete in a kneeling position with the foot hanging over the table edge. (2) With a marker, bisect the posterior calcaneus and the lower two thirds of the calf. These two lines are points of reference for goniometric placement. The axis of rotation is marked with a dot 1 cm above the superior border of the calcaneus (A). (3) To obtain leg-heel alignment, instruct the athlete to stand on a stepping stool with the heels placed at the edge of the stool and feet shoulderwidth apart. (4) Instruct the athlete to transfer the weight from the left foot to the right without allowing the foot to leave the stool. Measure the valgus and varus angles of the right foot by placing the stationary arm along the tibia and the movable arm along the calcaneus (B). (5) Record the results and replicate the procedure for the opposite extremity.

ACL injury in female athletes displaying a combination of these variables as compared with those subjects displaying only pronation or no postural faults.

Measures of genu recurvatum (Figure 4), in addition to hyperextension of the fingers and elbows and abduction of the thumb to reach the forearm (Figure 5), generally indicate joint

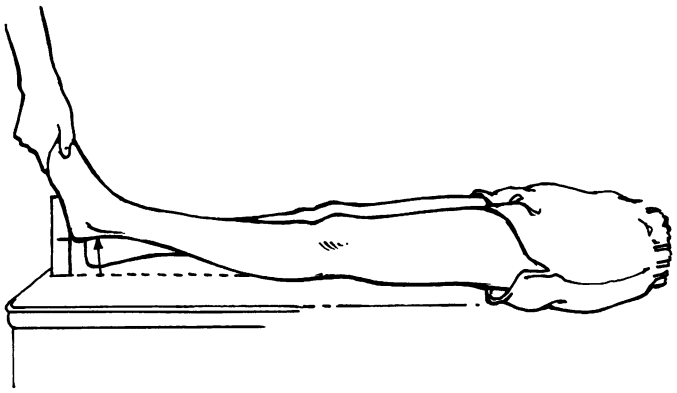

Figure 4. Knee recurvatum. (1) Position the athlete supine with the knee maximally extended and the foot in a neutral position. (2) Grasp the forefoot with one hand and stabilize the distal segment of the femur with the other hand. Lift the forefoot upward to achieve passive hyperextension at the knee joint. Care should be taken to maintain the posterior aspects of the knee and thigh on the table. (3) Measure the distance (with the help of an assistant) from the posterior border of the heel to the table in centimeters. (4) Use a goniometer to quantify the angular degree of hyperextension. Align the goniometer laterally along the long axis of the fibula and laterally along the longitudinal axis of the femur from the greater trochanter to lateral femoral condyle. (5) Record the 2 measurements and replicate the procedure for the opposite extremity.

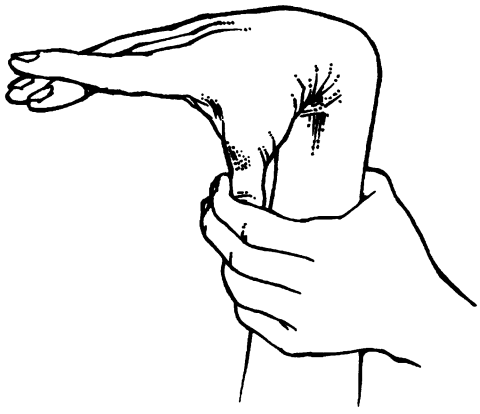

Figure 5. Thumb to reach forearm. Document (yes or no) whether the athlete can passively appose the thumb to the flexor surface of the forearm. Test both extremities.

laxity.[41] The relationship between physiologic joint laxity and ligamentous injury requires further investigation.

Rotational Alignment: External Tibial Torsion

Rotational alignment considerations or differences in tibial torsion warrant discussion as a risk factor for injury.[19,44,59,60] Torsional deformities are assessed using the thigh-foot angle measurement popularized by Staheli.[60] The thigh-foot angle is defined as the angular difference between the axis of the thigh and the foot as viewed directly down with the knee flexed to 90° (Figure 6). The mean value for thigh-foot angle is approximately 10° of external rotation during most of childhood.[59,60] With increasing age, the angle becomes more externally rotated. Huegel et al[2] investigated the influence of lower extremity rotational alignment in the female population on the incidence of noncontact ACL. Data suggested that differences in thigh-foot angle, used as an assessment of external tibial torsion, may play a predisposing role. The authors concluded that a tendency toward foot plant in a position of increased external rotation may result in increased tightening of the ligament, which can increase susceptibility to injury.

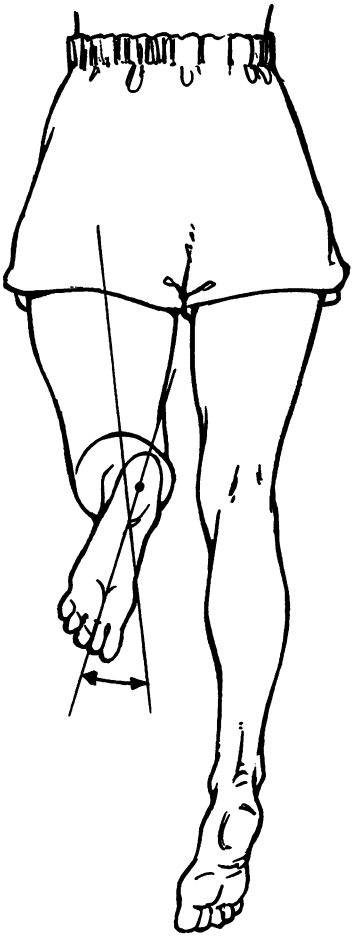

Figure 6. Thigh-foot angle. (1) Position the athlete prone with the legs extended. (2) Flex the knee to 90°. (3) With 1 finger, depress the foot to bring the ankle into a neutral position. (4) With a long arm goniometer, bisect the thigh and progress this line with a marker through the plantar aspect of the foot. (5) Bisect the plantar aspect of the foot with a marker using the center of the heel as the reference point. (6) Measure with the goniometer the angular difference between the axis of the thigh and foot as viewed directly down with the knee flexed to 90°.

Other Malalignment Considerations

It is important to remember that 2 or more postural faults may compensate for each other, as in the case of external tibial torsion and femoral anteversion.[60] Similarly, an increased Q-angle can result from increased femoral anteversion, exces-

sive external tibial torsion, or excessive pronation.[61] Therefore, the selection of skeletal measurement indexes must take into account these compensation tendencies and must be included in the screening protocol. Femoral anteversion is characterized by excessive internal rotation of the femoral shaft in stance.[3] It is defined as the projection of the angle between the long axis of the femoral neck and the axis through the femoral condyles in the transverse plane.[60,62] This angle measures approximately 15° in the mature adult. Variations in the angle of torsion will cause compensatory changes in lower extremity rotation to maintain the femoral head within the acetabular cavity. These changes can predispose an individual to musculoskeletal conditions. Q-angle is defined as the angle formed between the line of resultant force produced by the quadriceps muscles and the line of the infrapatellar tendon.[61,63] The physiologic valgus of the knee gives an angle, Q, between the pull of the muscle and that of the tendon.[61] The normal Q-angle ranges from approximately 10° to 15° with the knee in full extension.[61,64,65] The importance of an increased Q-angle and its contribution to patellofemoral disorders (for which the primary biomechanical cause is malalignment of the knee extensor mechanism) is well documented.[44,61,64,65] However, its role in ACL injuries is less clear and requires further study.[3,13,39] See Figure 7, A, B, and C, for a descriptive method for measuring femoral anteversion,[3,66] and see Figure 8 for measuring Q-angle.

MUSCULOSKELETAL STRENGTH

Stabilization of the knee results from a complex interrelationship that exists among bony geometry, capsuloligamentous structures, and muscles. Dynamic stabilization is supplied primarily by the neuromusculoskeletal action of the quadriceps and the hamstrings. The hamstrings are in a position to act as protagonists to the ACL by providing both rotatory stability and resistance to anterior drawer.[11–15,33,46,67] If the stabilizing influence of appropriate muscle action is compromised, the potential for injury to the capsuloligamentous structures is heightened.

Strength imbalances have been suggested as possible predisposing factors to injury. Knapik et al[9] found that female athletes with one hamstring more than 15% weaker than the other were 2.6 times more likely to sustain a lower extremity injury and reported that such left-right imbalances occurred in 20% to 30% of female athletes. Additionally, athletes with a flexion/extension ratio (H/Q ratio) of less than 0.75 were 1.6 times more likely to be injured. Moore and Wade[11] found that H/Q strength ratios of females were significantly lower than those of males at 60°, 180°, and 300° per second. Wojyts et al[22] reported that females had H/Q ratios in the 40% range.

Moul[13] investigated differences in selected predictors of ACL tears between male and female NCAA Division I collegiate basketball players from the same institution participating in identical conditioning programs. Sex differences in quadriceps and hamstring strength were examined isokinetically. Significant differences were noted between healthy male and female athletes for the eccentric hamstrings-to-eccentric quadriceps ratio bilaterally. The author postulated that a deficit in eccentric hamstring strength relative to eccentric quadriceps strength could predispose an athlete to an ACL injury during stressful athletic activities, particularly deceleration or landing maneuvers. During these activities, flexion moments are occurring at the knee and hip. Palmitier et al[18] reported that eccentric contraction of the hamstrings promotes hip stabilization, while eccentric contraction of the quadriceps promotes knee stabilization. In closed chain conditions, the hamstrings act as a powerful hip extensor. Forceful hamstring contraction is induced to stabilize the hip flexor moment, which helps to neutralize the tendency of the quadriceps to cause anterior translation of the tibia on the femur.[13,18]

The importance of hamstring strength in ACL-deficient (ACLD) patients during stressful athletic activities further underscores the role of the hamstrings in enhancing stability of the knee. It has been reported that hamstring substitution occurs among ACLD patients when the knee is flexed.[46] The flexed position, which is characteristic of landing and deceleration maneuvers, occurs as well in other activities, such as twisting, pivoting, and stopping from a run. Branch et al[68] demonstrated increased activity in ACL synergist muscles and decreased activity in ACL antagonist muscles in 10 ACLD subjects and 5 normal control subjects during sidestep cutting maneuvers. ACLD patients who perform sports activities under stressful conditions can protect against the rotational and translational stresses at the knee joint by increasing hamstring contraction as the limb is striking the ground. However, the muscle contraction must occur before the destabilizing loads occur.[68] Wojtys and Huston[21] found that the maximal response time of the uninvolved extremity of ACL-injured athletes was longer than in noninjured controls. Furthermore, in the noninjured leg of ACLD athletes, the quadriceps was the first muscle group to fire in response to anterior tibial translation. Neuromuscular firing order and timing may be just as important to the stability of the knee as strength considerations are.

Standard clinical examination of thigh muscle strength and reciprocal muscle group strength ratios can be accomplished though isokinetic testing. Isokinetic data acquisition provides reliable, objective information on a variety of muscle performance parameters.[69] However, to assess the preparedness of athletes for sport participation or sport reentry necessitates ambulatory testing methodology that can provide unique information not obtainable with standard clinical examination. Functional performance testing offers the opportunity for objective and quantitative assessment of athletes under conditions that replicate sport-specific activities. Still, it is important to select variables that focus on the measures directly related to the physical aspects of the problem: in this case, challenging knee joint stability.[46]

NEUROMUSCULAR CONTROL

Clinical research assessing muscle activation patterns of the knee for dynamic stability,[68–70] as well as training programs to

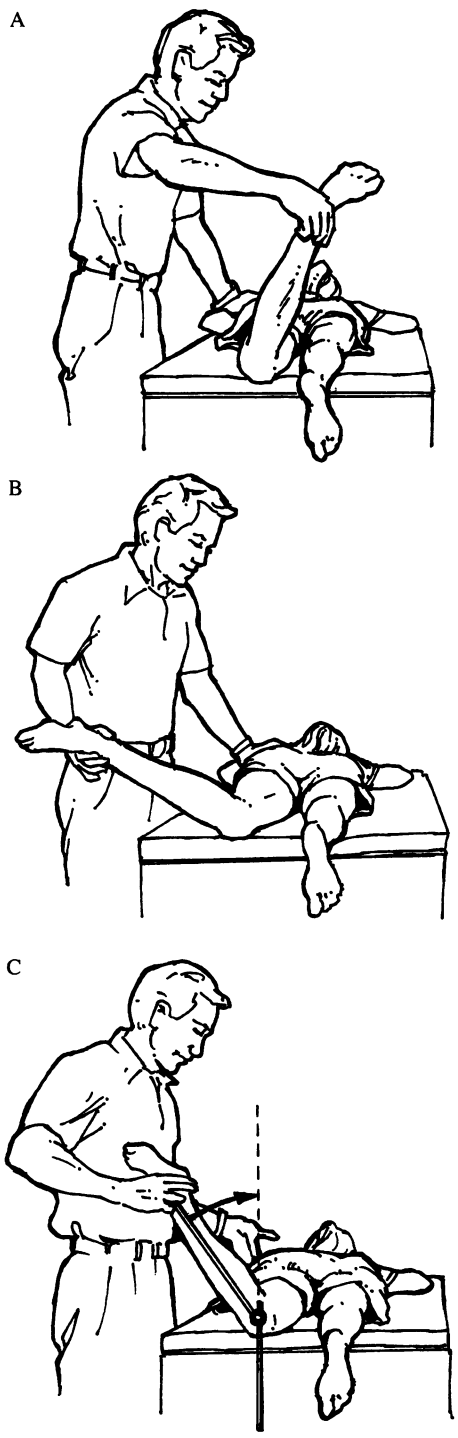

Figure 7. Femoral anteversion. (1) Position the subject prone with the knees over the table edge. (2) Flex the knee to 90° and maintain this position by holding the ankle with 1 hand. With the other hand, palpate the greater trochanter. (3) Rotate the femur laterally by moving the leg held at the ankle inward (A) and rotate the femur medially by moving the leg outward (B) until the greater trochanter is at its most lateral position and thus parallel to the examining table. (4) Measure this angle with a goniometer (with the help of an assistant) using the femur's center of rotation as the axis, the perpendicular line to the table as the stationary reference, and the spine of the tibia as the motion arm reference (C). (5) Record the results and replicate the procedure for the contralateral extremity.

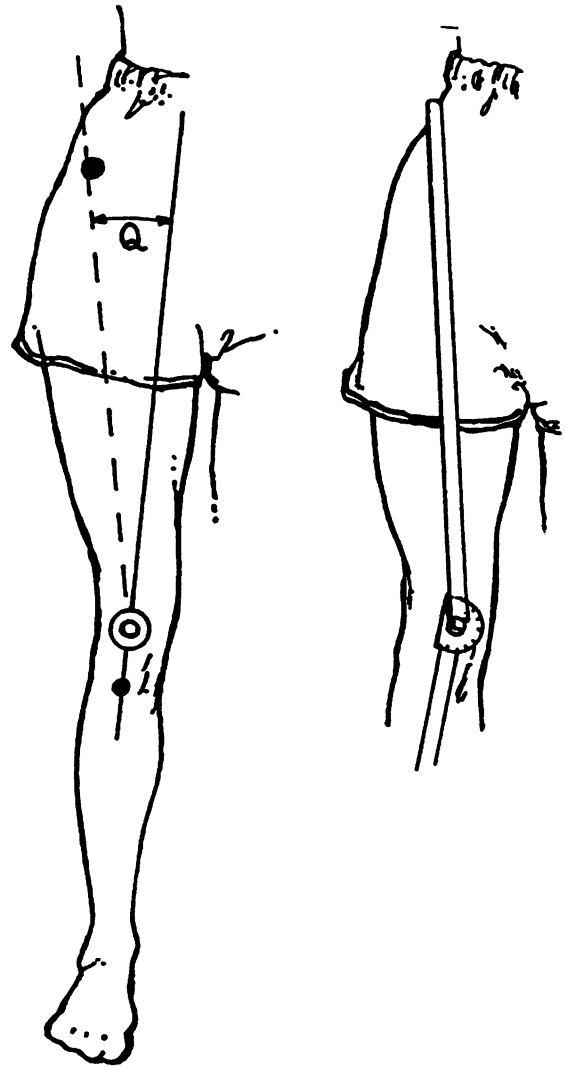

Figure 8. Q-angle. (1) Place the subject in a standing position with the feet straight ahead and hipwidth apart. (2) Bisect the patella in the sagittal and transverse planes, creating a center point of axis of rotation on the patella. (3) Mark the apex of the anterior superior iliac spine and the tibial tubercle. Place the stationary arm of a long-arm goniometer in line with the anterior superior iliac spine and the rotating arm in line with the tibial tubercle. Maintain the goniometric axis of rotation on the center point of the patella. (4) Record the angular measurement and duplicate the procedure for the opposite extremity.

restore neuromuscular status after injury,[71] frequently employs cutting, pivoting, landing, hopping, and balancing maneuvers. For example, Lephart et al[70] described 3 objective functional performance tests for athletes presenting with ACL insufficiency. The tests (including the cocontraction semicircular test, carioca test, and shuttle run) were developed with 2 goals in mind: (1) to obtain an objective measurement of function by reproducing the activities required to perform common sport skills, and (2) to challenge dynamic knee stability by producing rotational forces at the knee, causing tibial subluxation and mimicking acceleration and deceleration forces due to sudden directional and velocity changes.[70] Other tests of function that

are routinely employed to challenge the knee similarly include balance activities,[37,72] one-leg vertical jump,[37,73,74] single-leg hop for distance,[73,75] timed hop,[73,75] triple hop for distance,[75] running in a figure eight,[76,77] running up and down a staircase,[76] and sidestepping maneuvers.[72]

There are limitations to performance tests, and consideration needs to be given to maximizing their results, eg, when using one-leg hop tests to determine abnormal lower extremity symmetry. Barber et al[73] reported that more than half of the ACLD patients assessed for sport reentry activities had normal scores on the one-leg hop test but reported limitations with activities. However, when 2 one-leg hop tests were combined and compared with a single test, scores were abnormal. In a similar study involving ACLD patients, Noyes et al[75] reported higher percentages of abnormal scores when at least 2 one-leg hop tests were used, as compared with one (60% versus 42% to 50%). Wilk et al[78] reported similar findings in their work with ACL-reconstructed patients. To maximize performance test results, any combination of a minimum of 2 unilateral tests is required to establish, with confidence, lower extremity asymmetry.[69]

Data from isokinetic testing and ambulatory testing should be evaluated collectively to provide a comprehensive picture of the functional status of the athlete. The relationship between isokinetic data and functional performance tests is not yet clear. Several researchers report no association,[79,80] while others report correlations between the 2 parameters depending on the variables measured.[73,75,77,78]

LIMITATIONS OF A MULTI-INSTITUTION APPROACH

Reliability of data is known to be influenced by examiners and patient populations. Therefore, maximizing measurement reliability is an important consideration, since the proposed model involves several investigators at different clinical sites. One method to minimize measurement error under these circumstances is to standardize test procedures.[81] This requires careful planning relative to the method of protocol administration, the description of the measurement procedures, the time required to administer the tests, the equipment required, multiple practice or test trials with calculation of a mean, rest intervals, and the nature of the scoring system.[82] Clinicians must prudently attend to these test parameters in order to create valid comparisons of the data collected. Once the data are accumulated, analyzed, and consolidated into a composite picture, clinicians can develop a better understanding as to which measurements should be excluded from the screening protocol because they are difficult to take and offer examiners little confidence in the results. Monitoring the performance of the model and retooling it with data over time are essential to establishing predictive validity.

SUMMARY

A description of variables that might have predictive value for noncontact ACL pathology has been presented in an attempt to standardize a prospective screening protocol for the collection and interpretation of a comprehensive set of measurements. The variables, thought to be measurable and easily obtainable by clinicians and researchers, focus on static postural malalignments, along with lower extremity musculoskeletal strength and neuromuscular control considerations. Examining the relationship of these variables to lower extremity kinetic chain forces has the potential to aid clinicians in predicting ligamentous challenges, specifically abnormal stress to the ACL, that may occur with altered loading patterns.

A standardized, prospective screening protocol consisting of these variables is currently in use across the country as part of a multi-institution effort to determine whether common variables exist among female athletes who sustain noncontact ACL injuries. Such a protocol, advantageous from a research perspective, also has short-term clinical relevance. Screening evaluations are routinely employed as part of clinical work-ups to establish musculoskeletal profiles when athletes are healthy and in top form. This approach gives clinicians an opportunity to maximize both structural and functional outcomes strategies when deficiencies in test results are observed in subgroups of athletes matched for age, sex, and training and performance expectations.

The variables included in the screening protocol and their various interactions have the potential to provide a range of possible intervention strategies to decrease injury incidence. These strategies can range from maximizing structural outcomes through orthotic and footwear interventions[40,42,48] to maximizing functional outcomes through postural[3,42,43,47,48] and training interventions.[20,32–37] It would be premature to address which of the protocol's variables are amenable to intervention strategies. The first step is to develop and implement a reliable and valid assessment tool for scrutinizing the predictive value of the selected variables. Those variables identified as reliable predictors of ACL injury can then be interpreted by clinicians for their degree of amenability to intervention strategies.

The measures described in this paper represent only part of the knee-screening protocol characterizing the multi-institution effort. A protocol of this nature would be incomplete without a questionnaire that solicits important information about the athlete's prior injury history, present knee status, conditioning and training experiences, and equipment considerations. Additionally, an assessment tool, designed primarily for physicians, that includes manual tests of knee pathology is required to document ligamentous integrity and other pertinent anatomical considerations.

Readers interested in securing the screening protocol in its entirety, for the 2-fold purpose of (1) establishing outcomes interventions for their athletes and (2) contributing to a comprehensive database representing a systematic collection of measurements from numerous investigators that, upon ongoing interpretation, has the potential for predictive value for noncontact ACL tears, are invited to contact me.

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