**The Anterior Cruciate Ligament**

**Anatomy**

 The anterior cruciate ligament (ACL) extends from the medial aspect of the lateral femoral condyle and angles anteriomedially to insert anterior to the intercondylar eminence. The ACL can be further described as 2 bundles, the posterolateral (PL) and anteromedial (AM), and their location of attachment on the tibia1. The anteromedial bundle, on average, is larger than the posteriorlateral bundle1. With the knee fully extended the two bundles are parallel and extend vertically2. As the knee moves toward 90 degrees of flexion the two bundles cross each other, losing their vertical alignment2. Both the PL and AM bundles provide contributions to overall knee stability. The ACL primarily resists anterior translation of the tibia on the femur, but also assists with restraining knee hyperextension, varus and valgus stress, and knee internal rotation3. Each bundle provides support to the knee during a distinct range of motion (ROM)4. The PL bundle has shown the greatest in situ forces while the knee is in full extension4. From full extension to around 15 degrees of knee flexion the PL bundle is taut and is the primary restraint2. At 15 degrees of knee flexion and beyond, the AM bundle matches or exceed the PL bundle with in situ forces4. Beyond 30 degree of knee flexion the forces in the AM bundle are significantly greater than the PM, making it the primary restraint from 30-90 degrees of flexion4.

 On the micro level, the ACL is made up of water, type I collagen, and a few glycosaminoglycans5. Ligaments, including the ACL, generally have an almost parallel arrangement of collagen fibers when stressed5. The alignment of fibers includes some deviation from parallel in order to resist loading in multiple directions. Despite the ACL being intra-articular in location, it is not enveloped within the synovial membrane. Blood supply to the ACL is via the middle genicular artery, with the medial and lateral inferior genicular arteries also providing blood flow6.

**Mechanism of Injury**

 Injury to the ACL is becoming increasing common, and estimations of ACL injuries in the US range from 100,0007 to 200,0008 per year. The most common mechanism of injury (MOI) is noncontact with a decelerating or landing component. Krosshaug et al used video analysis of 39 basketball players and reported that 72% of them had no contact when injury occured9. Boden et al also found a 72% rate of noncontact ACL injuries in a sample of 100 knees10. Agel et al provide data from 13 years of NCAA volleyball injuries, stating that a majority of ACL injuries are noncontact11. However, in a second study by Agel et al, the authors investigated basketball and soccer ACL injuries, finding that more contact injuries occur in soccer12. These results show that the MOI may change based on sport. Shimokochi and Shultz reported that a knee in internal or external rotation, combined with valgus position appeared most frequently in evaluation of ACL tears13. These authors further state, in agreement with Dr. Gross, that the position of the knee near extension and a large quadriceps force produces large tensile forces on the ACL5,13. These forces are massive enough to cause detrimental effects to the ligament.

 The chance of tearing an ACL goes beyond the strength of the tissue, and research has pointed out several factors that may increase the likelihood of an individual tearing their ACL. Hewett et al suggested that poor neuromuscular control in subjects led to increased knee abduction, decreased stance time, and a larger ground reaction force during a drop-jump-landing exercise14. This position of the knee and increased forces causes abnormal loading of the joint and ligament, possibly placing it at risk for injury. Intercondylar notch width and ACL volume have also been controversially discussed as contributors to injury risk. Souryal et al discovered increased stenosis of the notch in subjects with ACL injuries, and also concluded that females generally have smaller notch widths than men15. Evans et al studied Naval cadets and found that notch width alone was not associated with ACL injury, however, the combination of an above average BMI and a smaller notch width was predictive of injury18. As discussed in this course, and supported by Nunley et al, an increased patellar tendon-tibial shaft angle generates the need for a greater internal resistance force by the ACL16. An increased ACL elevation angle also increases the risk of a mid-substance tear due to forces being near parallel with bone, a stronger substance than the ACL5. Zazulak et al, in a meta-analysis, purpose that sex hormones alter the mechanical properties of the ACL and trigger more anterior laxity of the ligament17. Alentorn-Geli et al provides insight into risk factors for soccer players, which may be contributors for other populations as well19. These authors found that playing surface conditions that are dry or artificial can increase friction between shoe/cleat and playing surface, making a player stick to the field when planting or turning19. Alentorn-Geli et al also mention muscle fatigue, decreased hamstring strength/recruitment, increased dorsiflexion during sports activities, and smaller hip, knee, and trunk flexion angles as possible contributors to noncontact injuries19. In addition, Dr. Gross discussed how lower extremity malalignments (i.e. increased Q angle, knee valgus, excessive pronation) and decreased knee flexion in landing can lead to unwarranted tensile stresses or loading of ligamentous tissues5. Lastly, research has suggested that decreased core strength or awareness may increase the risk of ACL injury, but evidence is limited19.

 Differences in injury rates between sexes may be attributed to one of the many risk factors listed above (i.e. Q-angle, hormones, strength, ACL volume, or notch width). Females have been reported to have 2.4-9.7 times more of a chance to injure their ACL then men21. Moses et al have reported an excellent systematic review of incidence rates, broken down by nation, military, professional athlete, and amateur athlete20. The authors found ACL surgery rates to be 30-52 per 100,000 people in the US, meaning injury rates were even higher20. Military personnel and professional athletes had the highest incident rates, ranging from 0.30% to 2.14% and 0.15% to 3.67% respectively20. These rates are higher because these populations are preforming high-level activities, and results don’t include the elderly or infants, as was the case in the total population estimates20. Amateur athletes also had a higher incident rate than the general population, probably for the same reasons20.

**Special Tests**

Examination of ACL injuries is commonly performed by physical therapists on and off the field. Making the decision if a patient or athlete can return to activities depends on accurately determining if the ACL is sprained, torn, or uninjured. The information from special tests and MOI lead to the most accurate diagnosis of injury when MRI is not available. Special tests must be performed with correct technique, stabilization, and vigorous force to stress the tissue similar to physiological demands produced by muscles5. The most classic special tests for the ACL include: the anterior drawer test, Lachman’s test, and the pivot shift test. Other tests may include the valgus stress test and the Slocum test. Scholten et al provide a meta-analysis of the 3 classic special tests, reporting sensitivity and specificity of each test22.

 The anterior drawer test position has the patient supine with the test knee at 90 degrees flexion and the hip at 45 degrees flexion. The examiner takes up any sagging of the joint to place the joint in neutral. With the examiner’s hands on the posterior aspect of the tibial plateau, and thumbs on the joint line, the examiner pulls anteriorly on the tibia. A positive test for a tear is greater than 10mm of movement23. Scholten et al state that the combined sensitivity of 8 studies is 0.62 (0.18-0.92, 95% CI: 0.42-0.78)22 and the combined specificity of 7 studies is 0.88 (0.78-0.98, 95% CI: 0.83-0.92)22 for the anterior drawer test. These results show that the anterior drawer test is more effective for ruling out in an ACL tear when a negative test is found.

 Lachman’s test is again performed with the patient supine. The examiner uses one hand to stabilize the femur, while the second hand grasps the posterior aspect of the proximal tibia. The knee is flexed 20-30 degrees and the examiner pulls anteriorly on the tibia. Excessive motion (greater than 10mm) is indicative of an ACL tear23. Scholten et al reported this test was more sensitive (0.86, 95% CI: 0.76-0.92) and specific (0.91, 95% CI: 0.79-0.96) than the anterior drawer test22. Based on the available data, the Lachman’s test is both valuable for ruling in and out ACL injuries, making false negatives less likely.

 The pivot shift test begins with the subject in slight knee flexion and tibial external rotation. The examiner applies a valgus stress as the knee is extended and tibia internally rotated. A “clunk” is a positive for ACL tear23. The research of the pivot shift test is limited and only 4 studies have provided calculations of sensitivity and specificity22. Sensitivity is fairly poor (0.18-0.48), while specificity is high (0.97-0.99)22. If a patient has a positive test result on the pivot shift test it is very likely they have an ACL rupture.

 No single special test can or should be used to diagnose an individual with an ACL tear. The use of several tests will provide a more accurate answer. The Lachman’s test is preferred due to its high sensitivity and specificity. A follow-up with the anterior drawer and pivot shift test can help to clarify the diagnosis of ACL insufficiency. The valgus stress test and Slocum test can assist in checking stability of other support structures and rotary instability.

**Injury Prevention**

 Due to the prevalence of ACL injuries and the large cost associated with rehabilitation, prevention programs have aimed to target specific deficits during training. The main areas of focus for prevention of ACL injury have been: athlete and coach education, balance training, plyometric training, and strengthening protocols. Ettlinger et al provided video segment education to alpine skiers on ACL injuries, avoidance strategies, and responding to injuries24. Over the next 3 skiing seasons data were collected on ACL injuries, with the researchers finding that subjects exposed to training had a reduced injury rate by 62%24. The control group showed no change in injury rates24. Noyes and Barber-Westin compared 5 different ACL prevention protocols and found Sportsmetrics and Prevent Injury and Enchance Performance (PEP) were the only two programs that significantly reduced the incidence of ACL injuries25. Between these 2 programs only 6 noncontact injuries occurred in over 80,000 athletic exposures for females25. Both of these programs emphasize agility, plyometrics, strength training, and flexibility (see Figure 1 attached)25. PEP is an in season training protocol, while Sportsmetrics is performed for 6 weeks prior to the season25. Meanwhile, these protocols also assisted in improving athletic performance as was measured by isokinetic strength and hamstring:quadriceps ratio25. The PEP protocol has also been verified to reduce injuries in several other studies26. Balance and proprioception training alone has shown mixed results with a study by Caraffa et al showing decreased incidence of injuries compared to controls in soccer players27. However, Soderman et al found injury incidence rates in female soccer players to increase in subjects trained with a balance board28. The number of participants limited Soderman et al and the training protocol was different than Caraffa et al. Incorporation of balance into protocols may require further research before a conclusion can be made.

**Conservative Treatment**

 Conservative treatment is an option usually left for someone who is less active or has given up athletics. Since the ACL is needed for stability in higher-level activities (i.e. cutting, turning, jumping) someone who will not be participating in these activities can function without an ACL. Patients with severe comorbidities (i.e. heart disease or renal disease) may not be candidates for ACL reconstruction, leaving them with an unstable knee joint.

 Physical therapists or athletic trainers have been called upon to provide rehabilitation to the lower extremity when surgery is not the selected method of choice. The treatment protocol is really no different than for someone following ACL reconstruction. The emphasis will be placed on strengthening all musculature around the knee and the joint above and below (hip and ankle). Incorporation of stretching tight soft tissues and assessment of malalignments will be necessary as well. As we learned several times from Dr. Gross, if you don’t fix the root of the problem then you will continue to have unwanted stresses or loading occur at the joint5. With an ACL-deficit knee this means the stresses will fall to other ligaments to protect the articular cartilage, capsule, and menisci. Protection, in the form of an external brace, may provide stability for low-level activities in an ACL-deficient patient5.

 Kessler et al examined the application of an identical protocol to one group with ACL-deficient knee and a second group following ACL reconstruction29. Subjects followed up 11 years later and results showed that IKDC scores were significantly better in patients with reconstructed knees29. Surprisingly, the risk of osteoarthritis was significantly less for those following conservative treatment versus reconstruction29. Sports-ability measurements with the Tegner showed a decrease in ability in the conservative treatment group, however the difference was not significant29. The authors conclude that results are mixed on the effects on conservative treatment and the development of knee OA29.

 Strehl and Eggli evaluated the effectiveness of conservative treatment and found that about two-thirds of patients sent for conservative treatment had failed outcomes30. A total of 38 subjects were treated with a standard conservative protocol, 23 ended up having ACL surgery and 1 subject dropped out30. Of the remaining 14 subjects, 12 reported good or better as their outcome, while 2 were satisfactory30. These 2 outliers both had frequent episodes of the knee giving out and so were considered unsuccessful outcomes30.

 As suggested previously, conservative treatment is for individuals with low activity loads and that won’t be running, cutting, or jumping. Bracing may help protect the knee in these low-level individuals and physical therapy may help to reduce the risk of OA development. Treatment should address the cause of the injury (i.e. malalignment) and focus on maintaining knee stability.

**Surgery**

 Restoration of knee joint mechanics is the primary goal of surgery, and in doing so allows the return to high-level activities. The ACL also serves as a protective structure so reconstruction allows for reduced risk of meniscal and articular cartilage injuries. Wong et al, compared ACL reconstructed knees versus ACL deficient knees and stated the prevalence of knee OA following ACL ruptures ranges from 24-86%31. They also agreed that the prevalence of meniscal tears was high in conjunction with ACL tears, stating that 27% of ACL deficient knees had meniscal involvement and if the knee remained ACL deficient then meniscal injury rate increased to 90%31. The decision to have surgery is not the only choice that the patient must make.

 First, patients and surgeons must decide between an allograft or autograft for the procedure. Autografts have become the more popular of the two choices and involves harvesting a graft from the patient’s own body. Common locations for harvest are the semitendinosus or the patellar tendon. Allografts are grafts harvested from a cadaver and can come from patellar tendon or Achilles tendon, among other donor sites. Both grafts have pros and cons to them and many times orthopaedic surgeons only perform one type of procedure. Autografts allow for a quicker integration into bone and don’t have the risk of disease transmission32. Unfortunately, autografts don’t allow for accurate prediction of graft length or quality33. On top of that, patients have to deal with donor site morbidity32 and longer operating times33. Allografts have the exact opposite pros and cons. Allografts allow for prediction of grafts size and quality, and there is no donor site morbidity in the patient32. The downside is a very small risk of disease transmission and the graft takes longer to integrate32. Allografts also cost more than autografts33.

 The two most common autografts used are bone-patellar tendon-bone (BPTB) and semitendinosus. Just as allografts and autografts have advantages and disadvantages, so do these two grafts. Research on BPTB grafts has shown a negative outcome in the following areas: quadriceps weakness, patellofemoral pain (PFPS), decreased ROM, possible patella fracture, patellar tendonitis, and onset of early degenerative joint changes34,35. Hamstring grafts have increased in popularity even though studies suggest an increase in failure rate36. Hamstring grafts avoid interfering with quadriceps strength and are associated with less PFPS36. Unfortunately, hamstring grafts have also been documented to provide decreased knee stability and take longer for integration36. Functional outcomes between the two options still remains a controversial topic, as neither graft choice has consistently shown superior results36.

**Accelerated Protocol**

A review of the literature led to the acquisition of the following key elements of ACL rehabilitation: early weight bearing and ROM37,38, braces locked in extension for the first week following surgery39, incorporation of sport specific exercises around 6 weeks post-operation37,38,40,41, and criterion-based progression41.

 Evidence is only moderate for a majority of these components, as there are limited RCTs and cohort studies. Subjects who began weight bearing and ROM earlier were found to have laxity similar or decreased laxity compared to nonaccelerated protocols37,39,40,42. For years the concern has been that too much force across the knee would produce increased laxity on the replacement graft. Studies are showing that laxity can be unaffected or improved with accelerated rehabilitation37,39,40,42. Melegati et al investigated the use of a brace locked in extension versus a brace allowing flexion following surgery, finding that extension was significantly better in subjects with the brace locked in extension39.

Sport specific exercise or task specific training has been applied in protocols to enhance a patient’s ability to return to prior level of function. Studies that incorporated sport specific training early (5-6 weeks post-operation) were shown to be safe on the immature graft and allowed for the earliest return to play (4-6 months post-operation)37,38,40. Only one report, Roi et al, examined the theory of criterion-based progression41. The case report of a high-level soccer player showed positive results in almost all outcome measures and allowed return to professional play at 90 days41. The authors concluded that not all individuals could return to play at 90 days, and that progression should be based on an individuals’ response (i.e pain and ROM) to treatment and not time-based41.

The literature on this subject matter is still relatively weak but the studies have produced a trend in protocols that we can apply in the clinic. The most significant results that were found were in protocols that allowed early ROM and weight bearing, sport specific training, a brace locked in extension, and criterion-base progression. Gerber et al also found overwhelmingly positive results in muscle volume and muscle strength with the use of eccentric ergometers42. Clinicians can apply this knowledge to protocols and begin to incorporate these ideas earlier than they have been with athletes with ACL repairs. Clinicians should also engage in discussions with surgeons about earlier progression and straining of the soft tissues to return athletes to play more quickly and safely. With these components in a rehabilitation protocol it appears that a safe return to sport can be made between 4-6 months post-operation.

**Outcomes Measures**

 The variation in protocols, surgery techniques, graft types, and individual preferences provides the need for standardized outcome measures for comparison of function, pain, and skills. Numerous scales are available and useful for ACL injures, but the focus here will be on the following: Knee Injury and Osteoarthritis Outcome Score (KOOS), Lysholm Knee Scale, and the single-leg hop test.

 The KOOS is a condition specific tool that covers 5 subscales: Pain, Other Symptoms, ADLs, Sports/Recreation, and Quality of Life (see Appendix A)43. It is a free outcome measure and can be used with a wide range population (13-72)43. The total scale runs from 0-100, with 100 being symptom free. The MCID for the scale is 8-10 points43. The scale has good test-retest reliability, construct validity, and is responsive to change43.

 The Lysholm Knee Scale is an 8-question, self-report measure that evaluates pain, stairs, swelling, squatting, instability, limp, locking, and support (see Appendix B)44. This would be an appropriate measure for lower-level patients, not athletes. The Lysholm has acceptable internal consistency and test-retest reliability, however, several of the questions have unacceptable ceiling effects45. Criterion and construct validity were also acceptable, and correlation with the WOMAC, Tegner Activity Scale, and SF-12 were found45.

 The single-leg hop test is frequently used to measure function and symmetry between unaffected and affected limbs. Research has shown reliability to be 0.82 to 0.93 for hop tests46. The single-leg hop test is also sensitive to change, as was seen in a study of 42 post-ACL reconstruction patients46. The test is easy to administer, requires no extra equipment, and can show increases in dynamic stability46.

**Summary**

 The anterior cruciate ligament plays a significant role in our profession and in lives of everyone, and without it many of the everyday activities that we participant in would not be possible. Injury to the ACL produces an expensive recovery and time lost to full activity. Our job as physical therapists is to maximize recovery and return the individual back to participation. The above paper reviewed critical components of the ACL including: anatomy, MOI, risk factors, examination, prevention, recovery/surgical options, rehabilitation, and outcome measures. This is just a fraction of the information available but I hope it gives you an idea of where to start with these patients.

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**Figure 1.** Training examples from the 2 training programs that had a positive influence on anterior cruciate ligament injury reduction and athletic performance test results in female athletes: Sportsmetrics and Prevent Injury and Enhance Performance. A, barrier hop forward-backward; B, barrier hop side-to-side; C, walking lunge; and D, agility reaction–instructor cued25.



**Appendix A**

**KOOS KNEE SURVEY43**







Today’s date: \_\_\_\_\_/\_\_\_\_\_\_/\_\_\_\_\_\_ Date of birth: \_\_\_\_\_/\_\_\_\_\_\_/\_\_\_\_\_\_ Name: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**INSTRUCTIONS:** This survey asks for your view about your knee. This information will help us keep track of how you feel about your knee and how well you are able to perform your usual activities. Answer every question by ticking the appropriate box, only one box for each question. If you are unsure about how to answer a question, please give the best answer you can.

**Symptoms**

These questions should be answered thinking of your knee symptoms during the **last week.**

S1. Do you have swelling in your knee?

Never Rarely Sometimes Often Always

S2. Do you feel grinding, hear clicking or any other type of noise when your knee moves?

Never Rarely Sometimes Often Always

S3. Does your knee catch or hang up when moving?

Never Rarely Sometimes Often Always

S4. Can you straighten your knee fully?

Always Often Sometimes Rarely Never

S5. Can you bend your knee fully?

Always Often Sometimes Rarely Never

**Stiffness**

The following questions concern the amount of joint stiffness you have experienced during the **last week** in your knee. Stiffness is a sensation of restriction or slowness in the ease with which you move your knee joint.

S6. How severe is your knee joint stiffness after first wakening in the morning?

None Mild Moderate Severe Extreme

S7. How severe is your knee stiffness after sitting, lying or resting **later in the day?**

None Mild Moderate Severe Extreme

**Pain**

P1. How often do you experience knee pain?

Never Monthly Weekly Daily Always

What amount of knee pain have you experienced the **last week** during the following activities?

P2. Twisting/pivoting on your knee

None Mild Moderate Severe Extreme

P3. Straightening knee fully

None Mild Moderate Severe Extreme

P4. Bending knee fully

None Mild Moderate Severe Extreme

P5. Walking on flat surface

None Mild Moderate Severe Extreme

P6. Going up or down stairs

None Mild Moderate Severe Extreme

P7. At night while in bed

None Mild Moderate Severe Extreme

P8. Sitting or lying

None Mild Moderate Severe Extreme

P9. Standing upright

None Mild Moderate Severe Extreme

**Function, daily living**

The following questions concern your physical function. By this we mean your ability to move around and to look after yourself. For each of the following activities please indicate the degree of difficulty you have experienced in the **last week** due to your knee.

A1. Descending stairs

None Mild Moderate Severe Extreme

A2. Ascending stairs

None Mild Moderate Severe Extreme

For each of the following activities please indicate the degree of difficulty you have experienced in the **last week** due to your knee.

A3. Rising from sitting

None Mild Moderate Severe Extreme

A4. Standing

None Mild Moderate Severe Extreme

A5. Bending to floor/pick up an object

None Mild Moderate Severe Extreme

A6. Walking on flat surface

None Mild Moderate Severe Extreme

A7. Getting in/out of car

None Mild Moderate Severe Extreme

A8. Going shopping

None Mild Moderate Severe Extreme

A9. Putting on socks/stockings

None Mild Moderate Severe Extreme

A10. Rising from bed

None Mild Moderate Severe Extreme

A11. Taking off socks/stockings

None Mild Moderate Severe Extreme

A12. Lying in bed (turning over, maintaining knee position)

None Mild Moderate Severe Extreme

A13. Getting in/out of bath

None Mild Moderate Severe Extreme

A14. Sitting

None Mild Moderate Severe Extreme

A15. Getting on/off toilet

None Mild Moderate Severe Extreme

For each of the following activities please indicate the degree of difficulty you have experienced in the **last week** due to your knee.

A16. Heavy domestic duties (moving heavy boxes, scrubbing floors, etc)

None Mild Moderate Severe Extreme

A17. Light domestic duties (cooking, dusting, etc)

None Mild Moderate Severe Extreme

**Function, sports and recreational activities**

The following questions concern your physical function when being active on a higher level. The questions should be answered thinking of what degree of difficulty you have experienced during the **last week** due to your knee.

SP1. Squatting

None Mild Moderate Severe Extreme

SP2. Running

None Mild Moderate Severe Extreme

SP3. Jumping

None Mild Moderate Severe Extreme

SP4. Twisting/pivoting on your injured knee

None Mild Moderate Severe Extreme

SP5. Kneeling

None Mild Moderate Severe Extreme

**Quality of Life**

Q1. How often are you aware of your knee problem?

Never Monthly Weekly Daily Constantly

Q2. Have you modified your life style to avoid potentially damaging activities to your knee?

Not at all Mildly Moderately Severely Totally

Q3. How much are you troubled with lack of confidence in your knee?

Not at all Mildly Moderately Severely Extremely

Q4. In general, how much difficulty do you have with your knee?

None Mild Moderate Severe Extreme

***Thank you very much for completing all the questions in this questionnaire.***

**Appednix B**



**Appendix C46**

