Anterior Cruciate Ligament and Meniscus Repair Rehabilitation For the Collegiate Athlete

The Collegiate "Sports Medicine" Environment

Orthopedic rehabilitation at the collegiate level is encompassed under the healthcare discipline of "Sports Medicine". Sports Medicine is defined as the management of medical problems of active individuals at all ages and all levels of participation, it deals with pathophysiology, biomechanics and optimization of human performance[1]. Exercise is used as a therapeutic modality in the prevention and treatment of disease and injury; sports medicine professionals promote health and disease prevention not only in athletes, but also within the entire community and population[1]. When working in a collegiate sports medicine environment compared to the outpatient orthopedic rehabilitation clinic, there are several similarities and differences. Post-surgical rehabilitation is surgeon directed in both environments, but in the outpatient setting physical therapists are the primary rehabilitation specialists with all other personnel (athletic trainers, physical therapy assistants, strength coaches) working under the therapist. In the athletic training room environment, athletic trainers may be the primary rehabilitation specialist, or work alongside physical therapists while rehabilitating athletes. Outpatient physical therapy visits generally are limited to 2-3 times a week based on insurance benefits and therapists schedules, where in the collegiate setting, athletes usually rehab 5-7 times a week, sometimes multiple sessions a day. Finally, while rehabilitation timelines play a vital role in all rehabilitation settings, collegiate rehab specialist may feel increased pressure from coaches, athletic directors or the athlete for quicker clearance to return to play.

Common Sports Medicine Injuries

The anterior cruciate ligament (ACL) is the most commonly injured knee ligament with approximately 100,000 to 200,000 ruptures a year in the United States[23]. The majority of ACL injuries are non-contact, especially in the female population, which has a higher predisposition to the injury[23]. Risk factors that increase female's susceptibility to ACL injuries are increased quad dominance and Q-angle, static valgus positioning of the knees, and the presence of female sex hormones that increase tissue elasticity[23]. Though females have a higher risk of ACL injury, the NCAA injury surveillance system states that American men's football has the highest ACL injury rate among collegiate athletes (33%)[23]. The meniscus is the most commonly injured tissue in the knee, and accounts for approximately 750,000 surgeries a year in the United States[24]. Acute tears to the meniscus often occur during dynamic twisting motions, but degenerative injuries can also happen in older adults[24]. Since these injuries are prevalent in collegiate sports medicine settings, and have a similar rehabilitation process and timeline, this paper and additional presentation will focus on injury, repair and rehabilitation of ACL reconstructions (ACL-R) and meniscus repairs.

The goal of this Capstone project is to introduce and increase the understanding of tissue composition and healing properties of both injuries, as well as present evidenced based information on the rehabilitation timeline. The individuals in attendance at the presentation and those that read this paper will ultimately be exposed to interventions and therapeutic exercise techniques for rehabilitation for these specific injuries of the knee. Key factors the clinician must consider when working in a collegiate sports medicine setting are the differences between the elite collegiate athlete and the injured non-athlete. The collegiate athlete's diet must be considered, as well as the psychological and social impact of college sports combined with athletics[22]. The elite athlete generally will require caloric intake greater than the non-athlete. The college athlete must also deal with the stresses of collegiate academics such as tests, grades and being away from home. When appropriate, the clinician must be confident and responsible enough to refer the athlete to other healthcare practitioners such as counselors, dieticians, strength coaches etc.

ACL Anatomy and Biomechanics

The ACL is a band of dense connective tissue that is situated intra-articularly within the knee joint[1]. The ligament's proximal attachment is at the posterior part of the inner surface of the lateral femoral condyle, while the distal attachment is at the fossa located anterior and lateral to the medial tibial spine[1]. The tibial attachment is somewhat wider and stronger than the femoral attachment, and also sends a variable amount of fibers anteriorly beneath the transverse intermeniscal ligament, in some cases blending with the attachment of the anterior or posterior horn of the lateral meniscus[1]. The ACL ligament like most ligaments is composed primarily of collagen fibrils, these fibrils make up approximately 94% of the ligament and give the ligament it's high tensile stress resistance and three-dimensional orientation[1].

The ACL is innervated by nerve fibers of the posterior articular branches of the tibial nerve[1]. The ligament also contains multiple mechanoreceptors such as Ruffini receptors that are sensitive to stretching, Pacini receptors that are sensitive to rapid movement, as well as Golgi-tension receptors and free nerve endings that serve as nociceptors (pain receptors)[1]. These mechanoreceptors play an important role in the "ACL reflex", which is a motor program reflex that activates hamstring contraction to prevent ACL injury during a strong quadriceps contraction[2]. The blood supply to this cruciate ligament is primarily provided by the middle genicular artery, with synovial sheath vessels also supplying vasculature to the ligament[1].

The ACL is divided into two parts; the anteromedial bundle (AMB) and the posterolateral bundle (PLB), with the PLB containing a larger amount of fascicles compared to the AMB[1]. The ACL plays a vital role in knee joint stability, as it is the primary restraint against anterior translation of the tibia relative to the femur[1]. When the knee is in extension the ACL bundles run in a fairly parallel fashion, during knee flexion the AMB tightens and lengthens while the PMB shortens and becomes slack [1]. As such, the AMB is the primary restraint to anterior tibial displacement during knee flexion, while the PLB is the dominant restraining force in knee extension[1]. The ACL provides an average restraint of 82-89% of the applied anterior load at 30^{o} degrees of flexion, but slightly decreases to 74-85% restraint at 90^{o} of knee flexion[1]. The ACL is also a secondary restraint to internal rotation when the knee is extended, and varus-valgus knee angulation in closed chain (CKC) situations[1].

ACL Injury and Healing/Repair

Studies reveal that 70% of ACL injuries are non-contact, with the body positioned with the femur internally rotated, the knee close to full extension, the foot planted and the individual decelerating which causes a dynamic valgus force to the knee[5]. ACL injuries also occur when the body's center of mass is behind and away from the base of support[5]. Risk factors for ACL injury include poor neuromuscular control of the hip and knee as well as postural stability deficits [5]. When ligaments are loaded over an extended period of time, or exposed to tensions greater than the structure can withstand, disruption of collagen fibers with tissue failure occurs[6]. After injury, the ligament goes through the normal stages of healing (inflammation, proliferation and remodeling), but evidence suggests that the injured ligament tissue is replaced with tissue that is grossly histologically and biomechanically more similar to scar tissue[6]. Scar tissue is vastly inferior to natural ligament tissue in that it has less plasticity and strength[6]. Therefore, a partially torn ACL in an athletic individual may not be able to provide adequate joint stability due to it's weakened state[6]. A grade III sprained or "ruptured" ACL will not heal (or scar) due to the inability of the injured ligament to form a fibrin-plate clot, which acts as scaffolding to repair the ligament[7]. The inability to form this fibrin-platelet clot is due to the synovial fluid in the joint dispersing the blood as a haemarthrosis[7]. For all these reasons, interventions for injured ACL's usually require surgical interventions[6,7].

Since an injured ACL cannot readily heal, ruptures are repaired using autologous or heterologous tissue called "grafts". It is the surgeon's preference on which graft to use. A patellar tendon autograft (bone-patella-tendon-bone) can lead to anterior knee pain, patellar tendonitis, increased crepitus and discomfort with kneeling[8,9]. Hamstring musculature may take longer to strengthen during rehabilitation when a hamstring autograft is used. Hamstring grafts use the semitendinosus and gracilis muscle tendons, some evidence suggest there is a decreased risk of extension loss when using this graft[8,9]. ACL allografts using the harvested tissue of a cadaver have many advantages, such as the possibility to treat patients with multiple ligament injuries or revisions, reduced operation times, reduced post-operative pain and a lower risk of arthrofibrosis[10]. Disadvantages of allografts include risk of donor to recipient disease transmission, and decreased integrity of the graft after radiation sterilization[10]. The use of xenografts, or allografts using non-human species tissue require more investigation with high rated systematic reviews and controlled trials.

ACL-R Rehabilitation

These timeframes are based on multiple evidence-based resources, and are not the protocols of any orthopedic surgeon. They are meant for educational use, and are general recommendations for stand-alone post-operative ACL rehabilitation.

Pre-surgery Phase

Time Frame[11]	After ligament injury, prior to surgery
Goal(s)[11]	Prevent arthrofibrosis, decrease swelling, minimize pain, obtain full range of motion (ROM), and neuromuscular control.
Tissue	Haemarthrosis (blood in joint), longer inflammatory phase due to increase presence of pro-inflammatory cytokines[12].
Interventions[11]	• Gait training with assistive device • Cryotherapy • Quad sets • Heel slides • Passive (PROM) stretching
Notes[11]	Pre-rehabilitation is also used to discuss surgical procedure, post-surgical recovery expectations and rehabilitation goals. A clear expectation of what to expect post surgery has demonstrated improved post-surgical outcomes and a decrease in acute surgical pain.

Phase I

Time Frame[11]	1-day to 4-weeks post-surgery
Goal(s)[11]	Protect graft and control pain, swelling, and inflammation. Recovery of active and passive ROM and neuromuscular control (decrease/prevent further quad inhibition).

Tissue	• Early graft healing phase
	  o Strength of graft is not optimal; mineralization of the graft bone interface is the primary site of weakness in tendon-bone graft[13].
	  o Graft heals with fibrovascular scar at the graft-tunnel interface and forms perpendicular collagen bundles that resemble Sharpey fibers on an indirect insertion[14].
	  o Formation of scar tissue at bone-tendon graft interface results in mechanically inferior strength[14].

Interventions[11]	• Isometrics (Quad sets) • Heel slides • Terminal knee extensions (TKE) in closed chain • PROM stretching • Patellar mobilizations • Neuromuscular control of gluteal muscles • Weight bearing as tolerated (WBAT) gait training (per surgeon's orders) • Compression
Precautions[11]	• Open chain (OKC) exercises performed in $90^o – 40^o$ movement range (no weight), avoid OKC exercises from $30^o – 0^o$ movement range. (ACL is primary restraint against anterior tibial translation, especially in OKC quad extension, weighted quad extensions stress new graft. • Overly aggressive activities can loosen graft attachments, cause inflammation and lead to graft failure[12] • Flexion ROM $\leq 90^o$ • Wear knee brace when not in PT, discuss unlocking brace with physician.
Notes[11]	Full knee extension to advance to phase II; failure to get full knee extension may result in arthrofibrosis in the anterior intercondylar notch (cyclops lesion). Control of pain, swelling and inflammation prevents quadriceps inhibition, maintains full knee extension and makes immediate weight bearing possible. Quadriceps atrophy, persistent quad lag with straight leg raise (SLR), incomplete extension and gait impairments in week 5 are predisposing factors for quadriceps weakness after 6-months.

Phase II

Time Frame[11]	4-weeks to 10-weeks post surgery
Goal(s)[11]	Flexion ROM ≥ 90, restore normal gate, maintain full extension and work towards full flexion ROM, increase proprioception, increase lower extremity (LE) muscle strength, protect graft[12].

Tissue[15]	• Proliferation phase
	    ○ Maximum cellular activity
	    ○ Revascularization of graft 6-8 weeks
	    ○ Loss of collagen orientation and crimp pattern
	    ○ Decreased collagen fiber density
	    ○ Graft is at its weakest mechanical strength

Interventions[11]	• All interventions from phase I • Dynamic balance • CKC exercises • Functional movement training • OKC isokinetic and isotonic weighted exercises at 8-weeks
Precautions[11]	Graft is at it's mechanical weakest.
Notes[11]	Minimal knee pain and swelling, full knee extension, ≥ 90^o of knee flexion and normalized gate to advance to phase III. Training of functional movement patterns improves the interaction between stabilizing structures of the kinetic chain (trunk, hip, knee and ankle). Wait for physician orders to discharge (d/c) knee brace.

Phase III

Time Frame[11]	10-weeks to 16 weeks post surgery
Goal(s)[11]	Full knee flexion ROM, no pain, minimal swelling, protect graft, quadriceps and hamstring strength ≥ 75% of contralateral side. Begin light impact and running activities with surgeon's clearance.

Tissue[14, 15]	• Ligamentization phase
	    ○ Collagen fibers began to organize
	    ○ Parallel alignment of collagen fibers never fully restores
	    ○ Vascularity decreases and returns to values of intact ACL

Interventions[11]	• Isokinetic testing • Running • Light agility • Begin Olympic lifts • Cardiovascular endurance training • Strength training for power
Precautions[11]	Wait for clearance from surgeon to begin running and plyometrics.
Notes[11]	To stimulate coordination and control through afferent and efferent information processing, exercises should be enhanced by variation in visible input, surface stability, speed of exercise performance, complexity of the task, resistance, one or two-legged performance etc.

Phase IV

Time Frame[11]	16-24 months post surgery
Goal(s)[11]	Maximize strength and endurance of knee stabilizers; improve arthokinetic reflexes, increase strength of operative leg ≥ 85% of contralateral leg, functional tests on surgical leg within ≥ 85% of contralateral leg. Begins sports specific activities such as plyometrics, and aggressive agility. Acceleration and deceleration exercises are important.

Tissue[14,15]	Ligamentization phase

Interventions[11]	• Aggressive agility
	  o Cutting, pivoting, accelerating and decelerating
	• Isokinetic Testing
	• Plyometric jumps
	• Increased running distances (sprinting)
	• Functional testing
	  o Hop test
	  o T-test

Precautions[11]	Between phases III-IV is generally when the athlete will attempt to do activities they are not cleared for.
Notes[11]	Plyometric exercises are an appropriate preparation for increased agility training because they improve the concentric contraction power of the muscle so that quicker changes in direction are possible. No pain or swelling, full ROM and strength of surgical leg within ≥85% of contralateral leg to advance to phase V.

Phase V

Time Frame[11]	≥ 6-months post surgery
Goal(s)[11]	Safe return to athletics, no pain, full ROM, maintenance of strength and endurance for return to athletics.
Tissue[14,15]	Ligamentization phase
Interventions[11]	• Position specific sports drills • Lower extremity strengthening continues • Functional clearance tests
Precautions[14,15]	Graft may take up to 12-18 months to reach morphology and mechanical strength of intact non-surgical ACL[13].
Notes[11]	Bracing per surgeon's recommendation

Meniscus Anatomy and Biomechanics

The knee contains two menisci, the medial and lateral meniscus. The menisci are wedged shaped (when viewed in cross section) semi-lunar fibro-cartilage structures that are attached to the tibial plateau along the periphery by the coronary ligaments and to the femur by the ligaments of Humphrey and Wrisberg[3]. The menisci are attached to the patella by patellomeniscal ligaments, which are thickenings of the anterior joint capsule[3]. When viewed from above the medial meniscus appears C-shaped while the lateral meniscus is O-shaped[3]. The medial meniscus is less mobile than the lateral meniscus during joint motion due to its attachment to the medial collateral ligament (MCL)[3].

The menisci are largely composed of type-I collagen arranged primarily in a circumferential orientation, which provides "hoop stress" and allows the structures to withstand anterior and posterior tension forces such as those caused by straight line jogging. Decreased radially oriented fibers make the meniscus susceptible to medial and lateral tension forces such as those caused by aggressive lateral cuts[4]. The menisci blood supply comes primarily from the inferior and lateral geniculate arteries, which form a peripheral plexus within the synovium and capsule of the knee. Small branching capillaries from the genicular plexus that penetrate the knee capsule provide nourishment to the outer third or "red zone" of the meniscus[3]. The middle third or "red/white zone" has a very limited blood supply, while the inner "white zone" has no blood supply and must rely on diffusion of synovial fluid for nutrients[3]. The poor healing properties of the menisci are directly related to the poor blood supply[3].

The menisci primary functions are transmitting weight-bearing forces, providing shock absorption, increasing knee joint stability, facilitating nutrients, providing lubrication for the articular cartilage and promoting knee proprioception[3]. Biomechanical studies demonstrate that in CKC knee extension, approximately 50% of axial knee forces are transmitted through the menisci, while with CKC knee flexion 85-90% of axial forces are transmitted through the menisci[3].

Meniscus Injury and Repair

As previously mentioned, the primary mechanism of meniscal injuries are torsional and medial/lateral axial loads applied during CKC activities while the knee is extending out of a flexed position[3]. Activities with movements performed in the transverse or coronal plane load the meniscus tissue in a way it is not structurally built to handle. Meniscus injuries are classified by complexity, plane of rupture, direction and overall shape[3]. Specifically they are identified as vertical longitudinal, oblique, horizontal cleavage, radial and complex[3]. The most common type being the vertical longitudinal tear commonly referred to as a "bucket handle"[4]. Additionally, during knee flexion, the main loading of the often-injured medial meniscus occurs at the posterior region[16]. As the posterior horn slides slightly over the posterior rim of the tibial plateau, significant stress is placed on the structure[16]. This is why knee flexion ROM restrictions are common in post-surgical meniscus.

There are multiple surgical techniques for meniscus repair, such as inside out or outside in suturing. It is the surgeon's choice on where to begin the suture(s) during repair, but strong evidence suggests that double vertical oriented suture repair in longitudinal meniscus injuries is the strongest and most durable[4]. During a meniscus repair "trephination" or debridement of the vascular portion may be performed to encourage bleeding for increased healing of the repair. The surgeon may also debride the meniscus flaps so that they approximate better during suturing[17].

Meniscal repair rehab

These timeframes are based off multiple evidence-based resources, and are not the protocols of any orthopedic surgeon. They are meant for educational use, and are general recommendations for stand-alone post-operative meniscus repair rehabilitation.

*Pre-rehabilitation phase same as ACL-R. **

Phase I

Time Frame[18,19]	1-day post surgery to 6-weeks
Goal(s)[18,19]	Control pain, swelling, minimize effects of immobilization and protect meniscus
Tissue	In animal study: at 6-weeks post-op meniscus repair, meniscus had reached 50-100% of healing in avascular zone, (peripheral repairs heal quicker than centralized

	repairs)[20].
Interventions	• Quad sets • Heel slides • Gait training with assistive device (AD) • PROM Flexion • Patella mobilization • Cryotherapy
Precautions[3]	• Brace locked in extension from 1-6 weeks OR per surgeon orders • Knee flexion ROM limited to 90^{o} for approximately 4-weeks • Non-weight bearing (NWB) to touch down weight bearing (TDWB) with crutches and knee brace locked in extension.
Notes[18,19]	Criteria for advancement to phase II: Full knee extension, SLR without quad lag, 90^{o} of flexion.

Phase II

Time Frame[18,19]	6-weeks to 12-weeks
Goal(s)[18,19]	Increase flexion ROM, increase quad strength, restore normal gait, protect repaired meniscus.
Tissue	• In animal study, meniscus was approximately 50-100% healed in avascular zone at 6-weeks post-repair[20]. • Other animal study: tensile strength of the healed (non-surgical) lesion in vascular zone did not reach the strength of normal meniscus even by 12 to 16-weeks[21]. • Take away message: Be carful!
Interventions[18,19]	• Cryotherapy • Proprioceptive balance exercises • TKE • Bike • Leg press • Calf raises • Knee flexion ROM > 90^{o}. • Squats (limit to 60^{o}) • OKC exercises
Precautions[18,19]	d/c brace per surgeon's orders, avoid deep knee flexion with CKC activities.
Notes[18,19]	Functional movements without posterior knee pain criteria for advancement to phase III.

Phase III

Time Frame[18,19]	12-20 weeks post surgery
Goal(s) [18,19]	Restore full ROM, no inflammation, no knee pain.
Tissue	Animal studies indicate complete meniscus healing at ≥ 6-16 weeks post-injury and/or repair[20,21].
Interventions[18,19]	• Jogging • Double leg jumps advancing to single leg • Jump Rope • Begin Olympic lifts • Light agility
Precautions[3]	Begin CKC exercises with knee bend > 60^{o} when cleared by surgeon in this phase.
Notes[18,19]	Wait for surgeon clearance to initiate sports specific drills

Phase IV

Time Frame[18,19]	≥ 6-months post surgery
Goal(s) [18,19]	Sports specific training, maintenance of strength and ROM
Tissue	Animal studies indicate complete meniscus healing at ≥ 6-16 weeks post-injury and/or repair[20,21].

Interventions[18,19]	• Sprinting
	• Aggressive cutting
	• Sports specific and position specific drills
	• Functional testing
	    o Hop test
	    o Excursion test
	    o Isokinetic training and testing

Precautions[18,19]	Athletic/ functional bracing if ordered by surgeon.
Notes[18,19]	Clearances from surgeon, meeting functional goals/outcomes as well as isokinetic testing are all criteria for returning to sport. Surgical knee should be ≥ 85% strength and function of non-surgical knee.

Conclusion

Rehabilitation of the surgically reconstructed ACL and repaired meniscus takes a skilled healthcare professional with a high level understanding of musculoskeletal anatomy, biomechanics, and tissue composition. The rehab specialist must also be adept in therapeutic rehab with a knowledge base in aerobic and anaerobic exercises, with some proficiency in manual techniques. The practitioner will be spending a great deal of time with the athlete and must gain their respect and trust to facilitate more effective and efficient rehabilitation. Care must be taken to challenge and progress the athlete towards their pre-injury competitive level, without causing further damage to the healing tissue(s).

It must be disclaimed that the timelines and exercise ideas included in this paper and the associative PowerPoint presentation are steeped in evidence-based practice, but may differ dramatically from the protocols used by other surgeons. It should also be noted that when working with post-surgical individuals with multiple ligament injuries, a combined ACL-R with meniscus repair, or cartilage damage, the protocols are vastly different than the ones used within this paper and presentation. Generally speaking, the more traumatic the number of injuries that must be repaired surgically or left alone to heal in-situ, the less aggressive the protocol; with aggressive and sports related activities pushed further out in the rehabilitation timeline. When applying this information in the training room or orthopedic clinic, it is imperative that the surgeon's protocol be followed and that practitioners use their best clinical judgment.

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