EXAMINING ACL REVISION SURGERY OF A FEMALE COLLEGIATE ATHLETE

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ABSTRACT

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Anterior cruciate ligament (ACL) reconstruction surgeries have become very common in the athletic population. With the increasing numbers of opportunities for physical activity, physical education, and sports participation, more competitive and amateur athletes are being treated for sports-related musculoskeletal injuries such as ACL sprain and rupture. High school and collegiate athletes, specifically, are at a higher risk for ACL injury than their weekend warrior counterparts are. Due to the prevalence of this injury in the younger, more active population, the medical community has been motivated to find the most appropriate treatment for this season-ending injury.

Orthopedic surgeons have been able to identify successful reconstructive methods using tissue grafts that aid in the full recovery of their patients. Gone are the
days where the athlete is told that he or she can no longer participate in their sport due to ACL injuries; athletes now have the opportunity to return safely to participation as soon as 6 months after reconstructive surgery. Unfortunately, the different grafts that are available for reconstruction have both positive and negative outcomes, thus there is yet to be a true medical “gold standard” among surgeons. This fact is troubling for the collegiate athlete looking for an accelerated return-to-play timeline.

The purpose of this study was to chronicle the recovery of a female collegiate athlete who suffered an ACL injury and progressed through reconstructive surgery, rehabilitation, and return to full competition after two ACL reconstructions in the same knee. The athlete suffered an initial ACL rupture, as diagnosed by her orthopedic surgeon, during her first collegiate basketball season. Reconstructive surgery was performed using cadaveric tissue. At 11 months after the operation, the graft ruptured during basketball practice while performing a routine lay-up. An autogenic hamstring graft was used for the revision surgery. After receiving two different types of grafts, this athlete’s case presents an opportunity for the medical community to question and further examine the optimal type of graft for young athletes who are looking to continue athletic competition after surgery.
CHAPTER I

INTRODUCTION

Overview

The high school football star attempts to evade the oncoming defensive linebacker as he pivots out of the pocket, but sadly, the linebacker reaches his target and the quarterback hears a loud “pop” as his leg gets twisted between the 260-pound lineman and the ground. An amateur ice-skater lands her double axel a fraction of a second too late as her knee buckles under her before she falls to the hard ice. The collegiate soccer player has been noticing that his knee gives way simply as he is walking around campus after a bad side tackle in last week’s match. All of these athletic individuals are suffering from a similar problem: instability of the knee joint. What is possibly causing this feeling of “giving way” or instability is more than likely due to an injury that plagues approximately 350,000 recreational and competitive athletes each year: rupture of the anterior cruciate ligament (ACL).

The ACL is the main stabilizing structure of the knee that helps to limit anterior translation of the tibia. It originates superiorly in the posterolateral portion of the femoral notch and projects inferiorly where it inserts on the anteromedial portion of the tibial eminence. It is housed in between the medial and lateral condyles of the femur, also known at the intercondylar notch. The ACL is made up of two distinct bands, the anteromedial and the posterolateral portion. In full flexion, the anteromedial band of the...
ACL is taught while the posterolateral band is taught in full extension. This ligament, along with the help of the medial collateral ligament (MCL), aids in the restraint of tibial rotation and excessive valgus motion within the knee joint (Perrin & Shutlz 2005). Without proper function of the ACL, it would be very hard, if not impossible, to remain an active and high performing athlete. Sadly, due to improper mechanics and accidents that affect the knee, the incidence of ACL injury is on the rise within high school and college-aged athletes.

Traumatic knee injuries, of which ACL injury is a main culprit, are seriously disabling injuries in sports, with prevalent short- and long-term disabilities that may end an athlete’s season or even career (Vaunik, Morrissey, Rutherford, Turk, Pilih, & Perme, 2011). There is practically a nation-wide epidemic of ACL rupture, with approximately 350,000 new cases in the United States each year; it is also one of the most common sports injuries of the active population diagnosed by orthopedic surgeons (Marrale, Morrissey, & Haddud, 2007; Wojtys & Brower, 2010). This injury is most likely to occur mainly between the ages of 15 and 44 years, the time when sports and physical activity are encouraged and more demanding (Childs, 2002). As the level of competition increases and sports activities become more rigorous, the potential of ACL injury increases, especially if bad habits such as poor body positioning are not corrected at an early age. Research has shown that ACL injuries are more common in immature boys, specifically those beginning more competitive sports at a younger age, but the risk and incidence of injuries increase after maturation for females and decrease in males (Wojtys & Brower, 2010). High school athletes with poor body mechanics progress to collegiate athletes with an increased risk of ACL injury. Rates of ACL injury are 2-8 times greater
in females than males (Childs, 2002). This statistic can be unnerving for female athletes. It will be important for more research to be done in the future as female athletics become more prominent and education toward injury prevention becomes more available.

When the ACL becomes damaged or sustains a complete rupture, reconstructive surgery is the most likely option. Unlike other soft tissues in the body, the ACL cannot regenerate on its own; conservative treatment in lieu of surgery may help strengthen the knee joint and its surrounding structures, but it will not replace the stabilization of the native, or original, ACL. This is another reason why reconstructive surgeries have become more prevalent among this active age group. One can survive without a fully functional ACL, but one would be very hard-pressed to perform athletic maneuvers without one. The drive to continue being a competitive athlete fuels the need to get back to the court or field as soon as possible. Also, injured athletes retire sooner from sports than those who remain healthy throughout their athletic careers. Athletes who sustain ACL injuries, regardless of whether they have had reconstructive surgery, are likely to develop degenerative knee disorders that may cause ongoing problems. If reconstruction is successful, the athlete will lessen the chances of developing osteoarthritis, but the injury increases the lifetime arthritis risk by 105 times (Parkkari, Pasanen, Mattila, Kannus, & Rimpela, 2008). Understanding this, athletes should opt for reconstructive surgery so that they can continue participation in athletics and suffer fewer degenerative knee conditions later in life.

Reconstruction of the ACL happens to be the sixth most common orthopedic procedure that is performed in the United States that grosses approximately $2 billion in medical costs (Fu, Christel, Miller, & Johnson, 2009; Wojtys & Brower, 2010). This
number has grown over the past few decades as surgeons have come to realize the success that they have had with ACL reconstruction (ACLR). Currently, the cost of a single surgery to reconstruct the ACL is roughly $17,000 depending on graft type (Childs, 2002). Due to inflation and insurance issues, this number continues to increase year by year. Almost $2 billion for ACLR, $646 million is specifically spent on repair for ACL deficient female athletes playing sports in the high school and college setting (Childs, 2002). Treating ACL injuries is extremely expensive and puts a heavy strain on the health care system in the United States. With this in mind, the focus of ACL injury should shift from treatment to prevention.

Due to such a high incidence of ACL injury in the past 25 years, it is not surprising that there have been well over 2,000 research articles that have been published addressing the occurrence, pathology, and prevention (Marrale et al., 2007). Few medical subjects in current surgery techniques have elicited as much controversy as that of how to best reconstruct the ACL (Tibor et al., 2010). Further, there are numerous published case studies. Some consider case studies to be inferior to objective studies. However, the high number of case studies should assist researchers, clinicians, and athletic trainers identify effective methods of clinical examination that would best identify risk factors for ACL injury.

The prospective cohort design is considered to be the strongest method of identification for testing prospective ACL risk factors (Padua, 2010). This specific design would require testing of athletes before any injury occurs to allow for a preinjury baseline profile of each athlete (Padua, 2010). There are only two studies that are prospective cohorts that have investigated biomechanical and neuromuscular ACL injury
characteristics (Hewett et al., 2005; Zazulak, Hewett, Reeves, Goldberg, & Cholewicki, 2007). These types of studies are very important because they can aid researchers in giving a more accurate and concrete explanation to what factors may cause ACL injury. Also, it would be important for research to continue to extend toward examining the best type of graft to be used in ACLR, especially when considering a competitive athlete. While excellent results have been reported for the different types of graft types that can be used for ACLR, there has not been concrete proof that one type of graft is superior than another in all aspects of healing, rehabilitation, and return to full participation for the competitive athlete.

There are several different mechanisms of injury in which an athlete can rupture his or her ACL. Typical mechanisms of injury to the ACL include deceleration with twisting, pivoting, or a quick change of direction (Wilk, Arrigo, Andrews, & Clancy, 1999). These mechanisms are normal motions that can be seen in sports and explain the abnormally high incidences of ACL injury in athletics. Additionally, injury to this ligament is the result of an outside force that would cause an anterior displacement of the tibia on the femur (Starkey & Ryan, 2002). This could also occur if the femur was driven in a posterior direction in relation to the tibia. It may also be injured due to non-contact mechanisms, rotational stresses, or hyperextension of the knee (Starkey & Ryan, 2002). These mechanisms of injury are classified as non-contact because the knee is not subjected to external forces. They occur when the athlete pivots or cuts and changes direction quickly. There have also been some suggestions in prospective risk factors to ACL injury. Increased external knee abduction, or valgus, moments during drop-landing activities as well as increased trunk motion after a quick force release have demonstrated
prospective risk factors for sustaining an ACL injury (Hewett et al., 2005; Zazulak et al., 2007). Interestingly, these force energy moments are common during female movement patterns.

Daily activities apply around 454 Newtons (N) of stress to the ACL; the ligament is able to tolerate up to 1,730 N before it fails, yet the ACL may still be ruptured due to a non-contact injury (Houglum, 2005). While external contact with a player or other object plays a role in ACL injuries, most ACL injuries do not involve direct contact. Up to 70% of ACL injuries in elite female athletes occur without direct contact (Wojtys & Brower, 2010). The injury and secondary injury of the athlete studied in this investigation did not involve contact. During routine lay-ups the athlete came down without any external forces acting on her knee when the ligament ruptured. This is consistent with the clinical findings that female athletes involved in jumping sports have significantly more severe knee injuries than males (Wilk et al., 1999). It is unclear whether injuries that the athlete in question suffered were due to prospective risk factors, injury predispositions, dangerous movement or moment patterns, or a combination of elements. It is possible that the similar ACL injuries suffered by the female basketball player, characteristic to ACL rupture and graft failure, was multifactorial.

Athletes often hear an audible “pop” or feel a popping sensation and will feel immediate pain deep within his or her knee joint upon rupture of the ligament. Within a few minutes, the pain may decrease or completely disappear, but some swelling will proliferate, usually in the medial aspect of the knee joint. The athlete may complain of the knee giving way or feeling instable if he or she tries walking on the affected leg without assistance. They will also notice an increased feeling of instability while walking
downhill or down the stairs as the ACL cannot control the anterior translation of the tibia during these activities. Injury to the ACL alone without damage to surrounding structures in the knee is unlikely, as it is common to have concomitant injuries to the medial meniscus or medial collateral ligament (MCL). The athlete’s feeling of instability is also increased when the initial injury causes further damage to these or other structures in the knee (Starkey & Ryan, 2002). If structures such as the menisci can be preserved or are unaffected after trauma to the ACL, the potential risk of osteoarthritis later in life is reduced (Roos, 2005). Improperly diagnosed and left untreated, the knee joint has an increased risk of damage to other soft tissues in the knee.

Athletes that suffer ACL ruptures face a host of problems aside from the general instability of the knee joint. Further problems and complications include a decrease in physical performance, an increased risk of meniscal injury (if it has not already been damaged during the initial trauma), and an increased risk of potential degenerative knee disorders later in life (Soon, Chang, Neo, Mitra, & Tay, 2004). Other problems that the athlete may face are withdrawal and even depression due to the athlete being removed from the playing field or court. Athletes may feel a sense of lost or changed identity that can hinder them emotionally and potentially hamper their athletic careers. All of these issues should be address during the athlete’s rehabilitation. While the athlete may only be concerned with the immediate consequences following trauma, i.e. restriction from competition, if left untreated, he or she will face long-term complications that will not only limit their capability to participate in sports, but potentially hinder their physical activity completely. A ruptured ACL is capable of some vascular response after an injury; however, spontaneous repair of the ligament does not occur (Marrale et al.,
2007). This is an important fact when considering reconstructive surgery versus conservative management.

With conservative management (rest and progressive strength training exercises) the outcome of spontaneous repair to the ligament is inferior to the results following a reconstructive surgery (Marrale et al., 2007). The athlete’s knee will continue to “give way” and feel unstable since the structure responsible for the restriction of anterior tibial translation is absent. If the athlete competes in a sport that involves quick cutting motions, pivoting, or jumping, the knee will continue to “give out” and increase the likelihood of secondary injury. The presence of mechanoreceptors within the ACL provides sensory feedback with regard to length and tensional changes in the ligament, which then activates a neuromuscular response that helps to contribute to the knee’s active joint stability (Perrin & Shutlz 2005). Due to this fact, it would be detrimental for an athlete to return to play while lacking an intact or reconstructed ACL. For athletes suffering from this injury, anterior cruciate ligament reconstruction (ACLR) is the best, if not only, option for returning to play competitive sports without any physical restrictions.

Certain mechanisms of injury are termed “high-risk” and are seen in many collegiate sports, specifically basketball (Mihata, Beutler, & Boden, 2006). This was the case with the athlete in the present investigation. For example, mechanisms of ACL injury for non- or minimal-contact include jumping, cutting or pivoting, abrupt deceleration, and body checking, or charging in the case of basketball. Perrin and Shutlz (2005) deem these types of movements as “risky” athletic mechanisms that can lead to what they have coined as the “position of no return.” This is the specific point at which the body loses the ability to control external tibial rotation and valgus stress within the
knee, thus creating the high degree of stress to the ACL that can cause ligamentous failure.

In addition to the aforementioned forces that put the ACL at risk, McLean (2008) has suggested that the “female movement pattern” is riskier than the male movement pattern during sports activities. It is universally accepted that females are more at risk for suffering an ACL injury due to certain extrinsic as well as intrinsic factors that are female specific. Predisposing factors that may lead to ACL injury that are extrinsic in nature to the female body are affected by the way that females move during sport-specific body motions. Many ACL injuries that occur in females are believed to take place upon single-leg landing, for example during the landing of a lay-up, with no direct external blow to the knee itself (Patrek, Kernozek, Willson, Wright, & Doberstein, 2011). Other mechanisms of injury may include females having the tendency of landing in a more extended than flexed leg position (Starkey & Ryan, 2002). This leg position puts more force on the ACL during jumping and landing, and often other structures within the knee must also absorb the additional forces, potentially leading to secondary injury.

Females are also more quadriceps-dominant than their male counterparts; the quadriceps is the dominant muscle group of the thigh and females demonstrate an altered muscle activation and coactivation, which affects overall muscle coordination (McLean, 2008; Starkey & Ryan, 2002). The strength of the quadriceps enables the tibia to be pulled anteriorly during physical activity, and without the antagonistic hamstring activation, this can easily predispose one to an ACL injury. Other extrinsic factors include foot hyperpronation, tibialis posterior weakness, an anterior pelvic tilt, anteverted hips, an increase in knee out-of-plane motions and excessive loading (McLean, 2008;
Starkey & Ryan, 2002). The menstrual cycle is one blatant extrinsic factor that may predispose female athletes to ACL injuries. Several studies found an increased risk of ligamentous damage during the first half of the menstrual cycle (Myer et al., 2009). While research findings have been mixed with regard to the likelihood of ACL rupture during certain times of the menstrual cycle, it is widely accepted that the fluctuation of hormones in the menstrual cycle plays a role in ACL injury.

Predisposed intrinsic factors of female ACL injuries are factors that cannot be adjusted by training or learned behaviors. These more anatomical factors may include an overall increase in joint laxity, disproportionate limb alignment, an inherent smaller intercondylar notch, genu recurvatum, and simply having a smaller ACL than males (Starkey & Ryan, 2002). For the female basketball player being examined in this report, any or all of these factors may have played a part in her subsequent injury and re-injury. It seemed as if her body was inherently working against her and that her secondary injury was inevitable.

Once the initial trauma of the injury subsides and the athlete is diagnosed appropriately, the decision on what type of graft to use to reconstruct the ligament must be made. A few options are available, and most of them are effective and have plenty of research to show positive results for the athlete looking to return to play competitive sports. However, there are still issues that surround which graft type would produce the best possible outcome for these athletes. Although over 100,000 ACLRs are performed each year, approximately 85% of surgeons who conduct primary ACL surgeries perform fewer than 10 procedures annually, and many surgeons conduct only one revision surgery each year (Fu et al., 2009; Duquin, Wind, Fineberg, Smolinski, & Buyea, 2009). With a
large amount of surgeons performing only a few ACLR surgeries each year, the potential for surgical mistakes or issues with lack of experience may arise, leaving an athlete with an inexperienced surgeon at a disadvantage. Also, surgeons may become comfortable with only one type of surgical procedure for ACLR and use it across the board instead of addressing the needs of different athletes. Because a “gold standard” has been hotly debated and the anatomy of every athlete is different, a large amount of variances in surgical techniques and outcomes of ACLR can differ from surgeon to surgeon.

Fu et al. (2009) found that success rates among experts in orthopedics are no better than 85% to 90%, and that these numbers decrease if the determining factor of surgery and graft type is that the athlete desires to return to sport at the preinjury level. While these numbers seem relatively high, the prognosis for ACLR declines if the goal is to return to a pre-injury level of competition. This is an unsettling reality. Ekdahl, Wang, Ronga, and Fu (2008) found that the ability to return to pre-injury activity is as low as 37-75%. The reality that the injured athlete may never be able to reach his or her pre-injury level is daunting, but having ACLR instead of simply undergoing conservative treatment certainly have more favorable outcomes. It is obvious that more research be done to reveal the most effective means of surgery as well as have a high emphasis placed on the prevention of this season-ending injury.

Recent research has, in fact, found many positive outcomes from having primary ACLR, and many people are able to fully recover from this surgery and continue their activities of daily living. The problem that is currently being investigated is the troubling low rates of the athletic population to return to their respective sports at a level that is equal to that of when they had a healthy native ACL. Despite current findings of
relatively high rate of positive outcomes, complete graft failure after ACLR may still occur (Ekdahl et al., 2008). In fact, the incidence of subsequent injury after ACLR has been shown to be 33% of athletes aged 18 to 25 years once they have returned to high level competitive sports (Shelbourne, Gray, & Haro, 2009). The interpretation of failure rates remain high in some studies as “failure” is defined as the patient continuing to suffer from knee laxity and persistent pain or complications after ACLR. Wegrzyn, Chouteau, Philippot, Fessy, and Moyen (2009) reported that 10 to 25% of their patients indeed suffered from failed ACLR. It has been shown that reinjury to a knee that had undergone ACLR to be 4.3% in women. Further, failure rates as high as 6% in similar demographics (Shelbourne et al., 2009). There are many factors that play into graft failure, this failure rate should be as close to zero in order to get an athlete back onto the field or court and out of the operating room.

Many suggestions have been made as to why an ACL graft would fail after the initial reconstruction. Reasons may include graft failure secondary to a repeated trauma to the affected area, poor surgical technique or placement of the graft, undiagnosed concurrent knee injuries that were not properly diagnosed or treated at the time of reconstruction, and a failure for the graft to biologically incorporate (Borchers, Pedroze, & Kaeding, 2009). Due to these incidences of injury and the unfortunate potential for graft failure, the decision on which type of graft to use for ACLR should be a group effort. Athletes should have a highly qualified team to help guide them through the process. This should include an athletic trainer as well as the orthopedic surgeon. Surgical procedures should be based on the specific physical demands and requirements of an athlete’s sport.
Types of Grafts

There are a few well-documented grafts that can be used for surgical reconstruction of the ACL that have surpassed the old techniques that showed poor long-term results. It was only a few decades ago when physicians had the unfortunate task of telling their patients that nothing could be done one the ACL was torn. Medical technology has also come a long way from simply attempting to suture what was left of the superior and inferior portions of the ligament together. The techniques that have become predominant in the past two decades due to the higher incidence of good long-term results include ACLR that utilize synthetic grafts, autograft tissue (the patient’s own tissue), and allograft (cadaveric tissue). This review will specifically focus on the latter two techniques.

The two most common autograft tissues that are used today are the bone-patellar-tendon-bone (BPTB) graft and the hamstring tendon graft. Of these two autografts, clinicians have attempted to regard the BPTB autograft as the “gold standard” to which the effectiveness of all other reconstructive techniques for the ACL are compared (Chouliaras, Ristanis, Moraiti, Stergiou, & Georgoulis, 2007; Marrale et al., 2007; Sherman & Banffy, 2004; Sun, Tian, Zhang, Xia, Zhang, & Yu, 2009b). While this may be the case within past and even some current research, many well-known problems have been documented in medical literature in regards to the negative outcomes of this method of ACLR. These troublesome post-surgery issues include complications from donor- or harvest-site morbidity and consistent anterior knee pain (Liden, Ejerhed, Sernet, Laxdal, & Kartus, 2007). Due to these persistent and relatively common problems
with BPTB ACLR, other techniques and graft types have been explored and have shown positive results.

It is apparent that with ACL injury increasing at a rapid rate, surgeons need to become more practiced and diligent at mastering this specific type of ligamentous reconstruction. Once a surgeon has performed a specific type of ACL surgery on a regular basis, he or she may become more comfortable utilizing one graft over the other. In recent research, it has been noted that 46% of orthopedic surgeons prefer to use BPTB autograft for ACLR, while 32% prefer hamstring tendon autografts, while the remaining 22% prefer the use of allografts for their reconstructions (Duquin et al., 2009). Further studies show that there is a tendency for surgeons to use more BPTB grafts in ACLR for their male patients and for those who are self-reported athletes, whereas hamstring grafts were more commonly used in females undergoing ACLR (Duquin et al., 2009). This may be unrelated to preferential graft type, however it remains imperative that the surgeon be aware of the specific needs of the patient in order to choose the best graft type for reconstruction. The previous statistic does bring up a potentially controversial debate with regard to surgeons using surgical techniques with which they are familiar. The fact that surgeons report using BPTB grafts more in males even though males tend to be more hamstring dominant and thus weaker in their quadriceps, and yet, surgeons prefer harvesting quadriceps tendons. Similarly, females tend to be more hamstrings dominant, so the question of why surgeons prefer harvesting a hamstring tendon, and thus potentially creating more weakness in the hamstring may arise. An argument could be made that there is not an anatomically sound reason for use of the hamstring graft in females as opposed to males.
Reconstruction of the ACL using autogenic tendonous tissues has produced beneficial clinical results over the past few decades (Marrale et al., 2007). However, the one major drawback from using a patient’s own tissue (donor- or harvest-site morbidity) has generated a desire for athletes and surgeons alike to avoid sacrificing the patient’s own tissue. This concern has prompted the arrival of the use of allografts as an alternative graft source within the past 15 years (Marrale et al., 2007). The use of allograft tissue has increased so much so that cumulative tissue bank data in the United States has reported that the Achilles tendon and tibialis anterior tendon allograft tissue have been back ordered (Fu et al., 2009). This type of graft is often more appealing to athletes because after surgery they may experience less pain and he or she may feel as if he or she could get back to full competition more quickly. However, specific grafts have benefits and liabilities for athletes that should be discussed thoroughly before surgery.

The athlete examined in this case study suffered from a non-contact ACL rupture during her first collegiate basketball season. After physical examination from the athletic trainers at CSU, Chico, and the team physician, with resonance imaging confirmation of the rupture, the athlete underwent ACLR with the use of cadaveric tissue. She experience little to no postoperation complications and showed good compliance during an accelerated rehabilitation program. She was cleared to return to sports activities approximately 6 months after surgery. Approximately 11 months after surgery, the athlete re-ruptured the graft in a manner similar to the previous injury during a basketball practice session. The revision surgery was accomplished using autograft hamstring tendon grafts from the ipsilateral leg. Due to complications with the primary surgery, the orthopedic surgeon originally prescribed a 12-month return-to-play protocol in order to
decrease the chances of a third rupture. However, due to the diligence of the athlete and competent supervision of the athletic trainers throughout the rehabilitation process, the surgeon cleared the athlete for full-participation in basketball approximately 8 months after surgery.

Importance of the Study

The appropriate reconstructive graft choice for the ACL remains controversial and is hotly debated; a number of graft options as well as surgical techniques have been identified throughout the literature, both with positive and negative outcomes to each graft type (Liden et al., 2007). This review will examine the use of two different tissue graft types for the use of ACLR of the knee of one athlete, something that has not been examined at length in recent research. By investigating not only the initial ACLR but the subsequent revision ACLR, athletic trainers, physicians, and orthopedic surgeons may be able to better understand which grafts are best for certain athletes based on the physical demands of their sports. This could also better equip orthopedic surgeons in advising their patients on the optimal graft type, especially those patients who happen to be athletes looking to return to competitive sports. Instead of relying on a “gold standard” tissue type, consideration should be taken when choosing a graft that would better yield accelerated return to play results that athletes would expect.

This study has the potential to add to the already increasing knowledge and understanding that ACL injury is plaguing athletes, especially female athletes, and is adding to the already burdened healthcare system. This injury is occurring at epidemic rates, and if prevention is not possible, then creating the optimal ACLR that will offer
positive long-term outcomes is essential. The statistics are daunting. Injury data gathered from 1999 revealed that female high school-aged athletes had a 1 in 100 chance of sustaining an ACL injury; the male athletes had a 1 in 500 chance (Wilk et al., 1999). Wilk et al. (1999) further reveal injury statistics by noting that the collegiate male athlete exhibited a 1 in 50 chance of sustaining an ACL injury while collegiate female athletes had a 1 in 10 chance. These rates are unacceptable. As healthcare professionals, we can do better. These injuries are preventable. This information must be further examined so that these athletes have a better change of completing their athletic careers in the safest and healthiest way possible.

Definitions

Donor- or Harvest-Site Morbidity

For the purpose of this review, donor-site morbidity will refer to pain at the incision sight with use of autograft ACLR. Harvest-site morbidity will refer to the failure, death, or total rejection of the new implanted graft tissue (Starkey & Ryan, 2002). These definitions may also include overall weakness in the tendonous harvested area due to the actual trauma of harvest or lack of regeneration of the tendon. For example, after a BPTB autograft reconstruction, patients may find pain or discomfort at the patellar tendon donor site, especially during the act of kneeling (Kartus, Movin, & Karlsson, 2001). Donor-site morbidity from BPTB ACLR may also include knee extensor mechanism issues. This can range from general quadriceps weakness to patellar fracture or patellar tendon rupture (Lawnhorn, Maj, & Howell, 2003).
Graft Failure

In general, ACLR graft failure may be considered when the restoration of knee joint stability is either diminished or has not been achieved. Graft failure should also be considered when return to physical activity has not been achieved due to pain or inability to restore full range of motion or strength (Menetrey, Duthon, Laumonier, & Fritschy, 2008). Reasons for graft failure are multifactoral. They may include, but are not limited to, graft rupture or elongation attributed to technical errors such as poor graft placement, excessive tensioning or fixation of the graft, traumatic reinjury to the knee, or a failure to address concurrent ligament instability or other structural damage that may place the reconstructed graft under even greater stress (Salmon, Pinczewski, Russell, & Refshauge, 2009). These postoperative complications can occur at any point during an athlete’s rehabilitation, from the day of surgery to the day that they may return to play. It is imperative that the progress of the athlete’s knee is monitored closely to ensure the likelihood of success.

Biological failure of ACL grafts is compounded issue that is not fully understood even to this day. Suggestions from research for this phenomenon include graft failure that may be initiated as early as hours after implantation that may result in extensive graft necrosis, disturbances during the revascularization process, problems with tissue healing at the cellular level, and complications during the healing and ligamentization process, specifically during the proliferation phase (Menetrey et al., 2008).

Other factors that can lead to graft failure may also include the actual use of an allograft instead of an autograft for ACLR, a topic that will be discussed further in this
review. Mechanical failures such as secondary restraint laxity and lack of a well-controlled rehabilitation program also put an athlete at risk for reinjury (Menetrey et al., 2008). Failure may further be considered when an athlete reports instability with functional movements and physical activities during sports. Researchers cite instances such as failing to be able to come to a complete stop after sprinting and the inability to effectively pivot (Menetrey et al., 2008). There may be a significant decrease in frequency or level of physical activity with respect to pre-injury status if a graft has failed, as well as an increased level or pain in the knee, a decrease in range of motion, chronic episodes of the knee “giving way,” and increased anterior laxity or displacement upon physical examination (Menetrey et al., 2008). There are many reasons why an ACL graft may fail after ACRL. It is very important that all aspects of ACLR are considered before choosing the appropriate graft that will hopefully produce the bets long-term goals for the athlete. Subscribing to a well-controlled and extensive accelerated return-to-play rehabilitation is just as important in getting the athlete safely and quickly back to competition.

Incorporation

This term will be used to describe the process of the foreign graft becoming a new living component of the knee. It refers to the body’s ability to not only accept the new graft but also allow it to heal and become vascular through angiogenesis in order to develop into a living tissue. Research shows that ACL incorporation proceeds through 3 different stages. The first stage includes inflammation and graft necrosis, the second stage encompasses revascularization and cell production, and the third stage is comprised of graft remodeling (Fu et al., 2009). Both autograft and allograft tissue go through these
stages of incorporation; however, compared to autograft ACLR, allograft tissue incorporation proceeds in a similar, yet slower, manner (Eagan & McAllister, 2009).
CHAPTER II

REVIEW OF LITERATURE

In 1917, Hey-Groves published the first report of a procedure to reconstruct an ACL using a tethered fascia lata graft (Marrale et al., 2007). Almost a century later, autogenous tissue grafts are the most popular choice for ACLR among surgeons. Luckily, in more recent years, surgeons have discovered new techniques and tissues for this procedure that help to optimize positive long-term outcomes. It is no longer inevitable that ACL ruptures are career-ending injuries. This is particularly important given the elevated incidences of ACL injuries reported in the United States, where over 250,000 new ACL ruptures occur each year (Marrale et al., 2007). While medical procedures and technology continue to evolve, it is evident throughout literature that much can still be learned with regard to how to best prevent, reconstruct, and rehabilitate an injured ACL.

ACL injury can occur with anyone at any age, though rupture is most likely seen in the young, active population, specifically in athletes. Athletes are particularly susceptible to ACL injury if they participate in contact sports where abrupt direction change and pivoting are involved (Borchers et al., 2009). Numerous studies have determined that increased activity, such as high school sports level and participation in collegiate sports, are major risk factors for ACL injuries (Borchers et al., 2009). Muscle weakness may also play a role in ACL injury.
Biomechanical and neuromuscular risk factors including weak hip abductor muscles, such as the gluteus medius, may predispose an athlete to an increase in hip abduction during weight bearing which are commonly seen in sport-specific activities such as jumping and landing (Ireland, 2002; Powers, 2003; Willson, Dougherty, Ireland, & Davis, 2005). This, however, should not deter an athlete from participating in sports, but should encourage players, the coaching staff, and athletic trainers to be familiar with prevention of this season-ending injury. Education of ACL injuries is essential in halting the rise of cases of rupture.

When the unfortunate accident occurs, there are many thoughts that go through the athlete’s mind. Once an athlete understands that this injury may be a stumbling block, it does not have to be the end of his or her athletic career. While an athlete’s return to play is a vital end result, choosing the optimal graft for him or her is just as important as getting back to the playing field. There has been more than two thousand scientific articles published regarding the ACL in the past 25 years, yet little to no research exists regarding ACLR and ACLR revision surgery for athletes in the collegiate setting (Marrale et al., 2007). Because there is little research published, it is imperative that an athlete has an excellent understanding of the costs and benefits of each type of graft that could be used for ACLR and how it could affect their future athletic performance.

The sections of this review are a) graft healing and incorporation, b) the higher incidence of ACL rupture in women as compared to men, c) a discussion of autograft ACLR, d) complications of autograft ACLR, e) a discussion of allograft ACLR,
f) complications of allograft ACLR, g) rehabilitation protocols, and h) ACL injury prevention.

Graft Healing and Incorporation

ACL incorporation proceeds through three different phases that coincides with tissue healing: inflammation and graft necrosis, revascularization and cell population, followed by graft remodeling. Inflammation and necrosis begins immediately after surgery (the graft undergoes immediate necrosis once it is transplanted into the host site) and can continue to undergo cell death for up to two months (Fu et al., 2009; Houglum, 2005). This would constitute the acute phase of tissue healing. During this time, inflammatory mediators are released into the area of trauma. As early as four days after surgery, neutrophils as well as macrophages are seen in the junction of the tendon and the bone, while after ten days, local macrophages are recognized within the graft (Ekdahl et al., 2008). The fibroblasts of the donor tissue undergo cell death during this time, and the remaining collagenous tissue becomes a scaffold for remodeling (Fu et al., 2009). This scaffold, if it has not succumbed to necrosis, graft failure, and bombardment of inflammatory mediators and leukocytes, will become a new living tissue that will hopefully retain the tensile strength of the native ACL. This is called the subacute inflammatory phase, which the graft can be as weak at 11% of its normal strength, and this phase has been noted to last as long as 6 months after surgery (Fu et al., 2009). The findings of the present case study are excellent examples of why it is important for the athlete who suffers an ACL injury to prescribe to a rehabilitation program that closely maintains the safety of the athlete and of the new graft during this precarious time.
Whether an athlete decides to have an autogenic graft or allograft for ACLR, there will be some graft deterioration upon implantation. It may be suggested from the evidence that all tendonous tissue, regardless of which tendon was used for ACLR, may lose a percentage of its original strength during the early healing period (Laxdal et al., 2008). Menetrey et al. (2008) agree that avascular necrosis occurs within the central portion of the graft as early as the first 3-4 weeks after implantation while a vascular invasion occurs on the surface of the graft during 3 to 8 weeks postoperation. Around this time the next phase of healing, the proliferation phase, takes place. This aligns well with the idea that during revascularization, capillary beds form from the outside of the wound, or in this case, the foreign graft tissue, and move toward the center. The avascular center of the transplanted tissue has relatively low numbers of viable cells, and collagen synthesis is relatively inactive in the early postoperative months (Menetrey et al.). In the first eight weeks, the graft is literally racing to become viable tissue before graft necrosis completely destroys the tissue scaffolding. Near the conclusion of this phase, the migration of neovascular cells and fibroblasts that are derived from the synovial membrane of the knee joint is followed by new collagen formation, and maturation of the graft will proceed over time (Muramatsu, Hachiya, & Izawa, 2008). If excessive outside forces are limited during early rehabilitation and if the graft is successfully revascularized, the tissue will pass into the next phase of healing. However, if inadequate graft vascularity occurs, it will leave the graft vulnerable to failure. Graft failure during the revascularization process may be caused by over-tensioning of the graft during surgical implantation, prolonged or excessive postoperative immobilization, infection, and other immunologic responses to the foreign tissue (George, Dunn, & Spindler, 2006).
If these risks are eliminated, the graft may successfully incorporate in its new environment and be able mature into a new viable tissue that could possibly be as strong and stable as the native ACL.

The proliferation phase is the time when new tissue growth occurs; angioneogenesis takes place, and the laying down of new collagen can be seen. In the case of ACLR, this is the time that the new graft is at its weakest. Revascularization of the initially avascular graft occurs around 8 to 10 weeks after surgery and is completed around week 16 (Houglum, 2005). Due to proliferation and remodeling of the tissue, approximately eight weeks will pass before the graft can firmly attach to the bone to which it has been fixed (Houglum, 2005). Again, during this time, the graft is at its highest risk for rupture or failure. Graft tissue remodeling occurs within the new intra-articular environment that once housed the native ACL; it is a complex structure that may lead to a completely incorporated graft, but it does not result in an exact duplicate of the original ACL (Menetrey et al., 2008).

It is widely noted in current research that autograft tissue heals more rapidly that allograft tissue in ACLR. Borchers et al. (2009) used a sheep model to investigate the differences between incorporation times. These authors found that biological healing after ACLR was delayed in allografts at 6 to 12 weeks when compared to that of autografts. At 52 weeks, the difference found between the two grafts was much smaller, however, evidence revealed that there were lower structural and mechanical properties of the allografts as well as increased anterior-posterior laxity in the allograft model (Borchers et al.). It can be suggested from these data that allografts have delayed healing time in terms of tissue remodeling. There also seems to be a decrease in long-term
stability of the allograft, and seen in the increased anterior-posterior laxity. These interesting findings, paired with other detrimental mechanical functions following allograft reconstruction in this model, may lead the athlete to reconsider the use of allografts for ACLR if he or she is determined to have an accelerated return-to-play rehabilitation.

The intent of ACLR is to recreate the native anatomy of the original ACL; however, the physical make-up of a ligament is different from the tendonous grafts that are often used to replace the ruptured ligaments. Although, tendonous tissue may produce tensile strength that often exceeds that of the native ligament. Tendons, which consist of 30% collagen and 2% elastin, are surrounded by an extracellular matrix, which contains 68% water (Menetrey et al., 2008). The dry weight of a tendon is mainly made up of collagen (70%); its breaking point has been found to be similar to that of steel (Menetrey et al.). The initial strength of the tendonous tissue may be a reason why this type of graft is so popular to use in ACLR. For instance, when hamstring tendon is harvested, surgeons often double- or even triple- bundle the graft. This enables the tissue to have as high or even a higher tensile strength that the BPTB graft. It has been suggested that the autogenic BPTB graft may offer the strongest healing capabilities for ACLR. Silva and Sampaio (2009) hypothesize that since the BPTB graft relies mainly on integration between the graft bone plug and the tunnel wall of the tibia or femur, a stronger connection will be made between graft and bone interface.

Ligaments, on the other hand, are fibrous connective tissue that are comprised mainly of basic supportive connective tissue cells, or ground substance, cells, and fibrous elements that are composed mostly of water and type I collagen (Menetrey et al., 2008).
The collagen formation of ligaments and tendons differ from each other but appropriately serve the purpose of their respective functions. Compared to tendons, ligaments are metabolically more active, have higher DNA content, have more type III collagen, less collagen and differing collagen bonds, but are more avascular than tendons (Menetrey et al.). Attempting to use a tendon in the place of a ligament may produce positive outcomes after ACLR, but the end result will still be lacking in some of the initial properties of the native ACL.

Researchers propose the term “ligamentization” to explain the histological and biomechanical changes of the tendonous graft during ACLR (Ekdahl et al., 2008; Marumo, Saito, Yamagishi, & Fujii, 2005). If the implanted tendonous graft were to become revascularized and have no biomechanical changes as the new ACL, the athlete would certainly suffer another rupture as the collagen formation would allow less mechanical movement. The tensile strength of the tendon alone as the ACL would leave an athlete with decreased range of motion if it did not incorporate the flexibility of ligamentous tissue. The process of ligamentization is thought to be a part of graft tissue adaptation; graft necrosis, swelling, revascularization, invasion of fibroblasts, and collagen synthesis with ligament formation occur during this time (Marumo et al., 2005). Essentially, ligamentization may be a part of the body’s tissue healing process responding to the new tissue in the host. Histological analysis suggests that preservation of the peripheral attachments of the ruptured ACL may aid the ligamentization process if portions of the native proprioceptive fibers remain relatively intact (Bradley & Tejwani, 2009). While in theory the process of ligamentization sounds like the ideal process of healing and incorporation, it will still take the graft approximately one year to take on the
structural and mechanical characteristics of a ligament (Marumo et al., 2005). This very
fact is the answer to why athletes that suffer ACL injuries are restricted from athletic
competition for up to a year; it is, in fact, season ending.

Recently, researchers have been utilizing platelet growth factors in order to accelerate ligament and tendon healing. Silva and Sampaio (2009) hypothesize that platelet growth factors directed into the tendon or ligament may allow for an accelerated return-to-play in injured athletes. The high amount of growth factors that are found in blood platelets play an essential role in the regeneration of bone, soft-tissue healing, and tissue maturation, all of which are found in ACLR (Silva & Sampaio, 2009). Using platelet-rich plasma to accelerate healing is currently a trend in baseball where elbow and shoulder injuries are often seen. Platelet-rich plasma is made up of a small volume of plasma that is enriched in platelets; it is extracted from a patient’s own blood and centrifuged in order to separate the plasma that will then be injected into the area of injury (Silva & Sampaio, 2009). Once the platelet concentrate is activated within the injured tissue, a fibrin scaffold forms, and a host of proteins and growth factors are released into a local environment, which aids in the acceleration of tissue repair after surgery (Silva & Sampaio, 2009). This same process that it used in shoulder and elbow surgeries or injuries could hypothetically be used to help accelerate the healing and potentially incorporation of the ACLR scaffolding. If there is a deficiency in the revascularization process, there will be a lack of available oxygen to cells of the new tissue; injecting platelet growth factors in the form of platelet-rich plasma may allow for optimal healing (Menetrey et al., 2008).
One landmark study found that there is a bioactive component of whole blood within platelet-rich plasma that enhances the movement of circulation-derived cells to the area of injection (Mishra, Woodall & Viera, 2009). By injecting platelet-rich plasma, cells that encourage tissue healing will rush to the site of injection, which would then theoretically augment the healing process. It was further noted that platelet-rich plasma induced type I collagen production as well as increased the propagation of macrophages at days 3 and 7 after injection (Mishra et al., 2009). This process of using platelet-rich plasma to promote healing, while not thoroughly researched, could be one more step to accelerating the return-to-play timeline. Further studies are warranted in order to clarify the precise role of the growth factors found in platelet-rich plasma. However, it may be assumed that a lack of these growth factors could possibly lead to a biological failure of an ACL that has been reconstructed (Menetrey et al., 2008). These new advances in medicine may certainly put an athlete at an advantage when it comes to retuning to play in his or her respective sport; however, there is still a need of continued research to find the best possible outcome for tissue healing.

Higher Incidence of ACL Rupture in Women Than Men

It is currently estimated that 1 in 3,500 members of the general population will suffer from ACL injury; the majority of these injuries occur in young adults (Perrin & Shutlz, 2005). The rate of ACL injury in females that are physically active or that participate is sports much greater. Depending on their age and sport, females suffer ACL injuries at a rate of 1.16 to 8.38 times that of males, a shocking statistic for female athletes (Perrin & Shutlz, 2005). These ligamentous injuries are especially elevated in
females that participate in high school and college athletics, especially if the sports is
dominated by cutting, sudden deceleration, pivoting, and jumping. For example, female
athletes playing in soccer and basketball are reported to have injury rates over three times
greater in soccer and four to five times greater in basketball as compared to males (Perrin & Shutlz, 2005). This trend has become so alarming that the National Collegiate Athletic Association (NCAA) tracks these injuries and keeps the statistics in a national database. The NCAA injury reports indicate that the likelihood of sustaining an ACL injury is
between 2 and 8 times greater for females as compared with males participating in similar sports that experience similar extrinsic risk factors such as playing surfaces, footwear, and playing conditions (Bennyon, Johnson, Braun, Sargent, 2006). It is evident that this disparity causes great concern for the female athlete, and more and more research appears in databases the cover this topic. Recently, research has moved from focusing on rehabilitation of females suffering ACL injuries to preventing the injuries from happening in the first place.

The prevalence of ACL injury is so great that there is a specific clinical conference dedicated to ACL injury. Recently, it was agreed on by sport medicine specialists and researchers that the research has been moving away from conducting studies that are purely descriptive comparison models of males versus females in terms of ACL injury disparities (Shultz et al., 2010). Current research has moved toward achieving a better understanding of underlying mechanisms that have been recorded in sex differences that have been associated with ACL risk injury and prevention (Shultz et al., 2010). With the continued rise in ACL injury, however, it is important that more research be done to help promote the best methods for prevention. Also, without adequate
education or an available specialist to teach proper form, mechanics, and preventative strengthening exercises, it is very likely that females will continue to suffer from ACL injury. It seems that while preventative methods in research may continue to become readily available, it is up to the athlete to become educated on preventative measures and implementing them in his or her physical training plan.

This rise in female ACL injury may also owe directly to social advances within the past century. Opportunities for women to engage in sports have increased especially over the past 30 years following the women’s liberation movement. Following Title IX, the amount of females participating in college athletics surpassed 100,000; the number of females participating in high school athletics rose from 300,000 in 1971 to 2.4 million in 1996 (Perrin & Shutlz, 2005). This is a huge jump in population for athletics, and the argument could be made that females, who are often predisposed to ACL injury, could be increasing their risk simply by choosing to be more active. Another argument could be made that ACL injury in females was not well understood until females exploded into the sports scene, and research is just now catching up with these trends. The total number of teams that the NCAA sponsored increased about 20% in 10 years, from 12,447 in 1987-88 to 15,582 in 1997-98 (Perrin & Shutlz, 2005). The rate of females participating in intercollegiate and interscholastic sports continues to grow. As more sports opportunities become available for women to play, so will the rate of female athletes who injure their ACLs.

There are many theories and anatomical differences that may explain why women are more at risk for injuring the ACL than their male counterparts. Females have smaller ACLs than males; this size difference is believed to be another factor in the
disparate injury rates between males and females (Romani, Langenberg, & Belkoff, 2010). Also, females have a much less rounded and much narrow intercondylar notch than males, which increases the risk of impinging the ACL (McLean, 2008). The notch itself, which is the space created between the later and medial condyles of the femur, must be spacious enough to house the ACL during the knee’s full range of motion. If the notch is too narrow, the ACL may easily become injured during pivoting motions as the femur creates excessive external rotation over the tibia; the femoral condyles can literally guillotine the ACL within the notch. In a similar fashion, a notch that is less rounded or too shallow cannot give adequate space for the ACL to slide through during full flexion and extension. Another anatomical disparity is found in knee joint articular surfaces, which are 20 to 35% smaller in females (Perrin & Shultz, 2005). During valgus loading, smaller knee joint surfaces combined with a narrow intercondylar notch may increase vulnerability and compromise the strength of the ACL. This anatomical feature of a female’s knee may also create a much smaller lever arm in the joint; between the large tensile load on the ACL and the compression on the lateral condyle during valgus loading, the point at which mechanical failure occurs is at the ligament itself (McLean, 2008).

Females also seem to favor different muscle groups that their male counterparts. This may contribute to the higher rates in knee injuries during sport-specific activities. Neuromuscular and muscular differences include a decrease in muscular force, the dependence on the quadriceps muscles for knee and hip stability, an increase in time to develop force, as well as a longer electromechanical response time (Wilk et al., 1999). In a clinical example, females favored the use of knee extensors over hip extensors to
absorb impact forces during drop-landing tests, which showed a higher energy absorption in the knee instead of the hip (Powers & Fisher, 2010). In this case, males were able to attenuate the forces equally though the hips and knees (Powers & Fisher, 2010). If this were taken to the basketball court, it would indicated that females would exhibit a high amount of forces through the knee joint instead of through the hips or other musculature to aid with energy absorption during the landing of a lay-up, jump shot, or rebound. This could be an indicator as to why females are increasingly prone to knee injuries. If other musculature such as hip extensors do not help to control the forces from landing, there may be an overcompensation of quadriceps activation, greater knee motions such as valgus loading in the frontal plane, or a combination of both (Pollard, Sigward, & Powers, 2010).

Other anatomical characteristics increase the likelihood of ACL injury in females exist and are well documented. Females demonstrate preferential quadriceps activity and dominance, promote greater valgus angles, and greater valgus/varus movements of the knee joint during functional movements while participating in physical activity and sports (Perrin & Shultz, 2005). Many of these risk factors can be reduced with proper training and muscle reeducation or motor learning. However, issues such as joint laxity are intrinsic factors, which can lead to ligament injury that cannot be altered by a strength training or prevention program. However, issues with joint stability, something that female athletes often lack, may be corrected. Enhancing dynamic joint stability partly depends on neuromuscular response times; high-speed muscle training may be an important tool to correct this particular parameter (Wilk et al., 1999).
Females also have greater joint laxity than males, as well as altered muscle recruitment patterns, muscle force generation delays, and decreased muscle stiffness (Perrin & Shutlz, 2005). It was found that female rats had much lower amounts of mRNA expression of Type 3 collagen as well as higher normalized ACL stiffness and failure loads than the male rats (Romani et al., 2010). This illustrates the difference between female and male ability to withstand tensile loads on the ACL because the structural component of Type 3 collagen is decreased in this rat model. All of these factors are problematic for the ACL of the female athlete, especially when participating in a sport that is dominated by dangerous movements such as pivoting and jumping, such as basketball.

An increase in knee joint laxity may be influenced by hormonal factors that are specific to females and also may prospectively predict ACL injury risk (McLean, 2008). Many studies have attempted to determine a specific point during a female’s menstrual cycle that is the point of heightened risk of ACL injury, but findings have been mixed. Hormonal influences play a key role in the proliferation of fibroblasts and with collagen synthesis of the ACL; sex hormones themselves may have effects on the tensile properties of ligaments (Childs, 2002; Zazulak, Paterno, Myer, Romani, & Hewett, 2006). Fluctuating hormones during the menstrual cycle may, hypothetically, open a window of vulnerability at which time the ACL is more susceptible to injury. The effects of ACL exposure to increased estrogen levels during the late follicular phase (specifically estradiol) include a decrease in fibroblast proliferation (Zazulak et al., 2006). This fluctuation also involves a decrease in procollagen synthesis in cell cultures, and authors have found that there is a decrease in overall load amount before ligamentous failure in
animal models (Zazulak et al., 2006). If this was the only risk factor known that may predispose females in ACL rupture, one way to combat injury would be to adjust training days based off of when the female is ovulating. This would hypothetically be the period time during the late follicular phase where an athlete may be more likely to injury her ACL.

In contrast, ACL exposure to a higher amount of progesterone, as seen during the luteal phase of the menstrual cycle, may be associated with an higher rate of fibroblastic proliferation and collagen formation in cell cultures (Zazulak et al., 2006). With the upswing of progesterone during the days leading up to menses, it can be suggested that this would be the time when female athletes may train and participate in more sport-related activities, such as jumping, cutting (sudden change of direction), and pivoting, since there may be a decreased amount of ligamentous laxity and risk to the ACL. Another factor that is known to contribute to knee laxity in females is the fact that sex-specific hormones have a profound effect on collagen tissue and appear to significantly alter the metabolism and structure of the ACL (Perrin & Shutlz, 2005).

Studies have revealed that estrogen and progesterone receptors are present on human ACLs, this implies that sex hormones directly influence the structure, composition, and integrity of the ACL itself (Childs, 2002; Shultz et al., 2005). While these findings may help the medical community determine when in a female athlete’s cycle that she may be at a higher risk of ACL injury, it is very difficult to track her hormone levels throughout her athletic season.

It is very unlikely that an athlete may be excused from basketball drills that may increase her likelihood of knee injury because she is nearing the end of the follicular
phase of her cycle. Also, every female’s menstrual cycle is different and may fluctuate easily; attempting to accommodate an entire team of females based off of their cycles would be highly improbable. Reports that implicate female sex hormones to be risk factors of ACL rupture point toward an increased rate of injury during the late follicular phase of the menstrual cycle (Perrin & Shutlz, 2005). However, Perrin and Shultz (2005) note that only two studies have measured genuine hormone levels in order to confirm the accurate cycle phase at the time of injury. This is an important concept given the variability of hormone fluctuation from one female to another in that specific phases may be longer or shorter during the 28-day cycle.

The stage of a female athlete’s menstrual cycle is often simply estimated by approximating the athlete’s last day of menses. Shultz, Sander, Kirk and Perrin (2005) gathered actual serum hormone levels from young, active females instead of recording an approximate day of the menstrual cycle in order to better define cycle phase and the times during which knee laxity was likely to be altered within females. The results from this research differ from that of previous research. Once the results were aligned using consistent serum hormone profiles, it was found that knee laxity was at its least around the 3rd day of menses, after progesterone and estradiol were at their lowest (Shultz et al., 2005). After this period of the follicular phase, knee laxity was at its greatest in the days following peak estradiol levels when progesterone levels initially began to rise (Shultz et al., 2005). Interestingly, these authors found that knee laxity was higher when progesterone levels began to rise, which is characteristically in the beginning of the luteal phase, when other authors found collagen formation and fibroblastic proliferation to be at its highest. In theory, this would be the time when the ACL would be structurally more
capable of sustaining greater loads from external forces. It is obvious that more research is needed to determine to what extent increases in knee laxity affect knee function during sport-specific movements and athletic competition.

Shultz et al. (2005) found that researchers had often suggested that the hormone mediator relaxin may affect biological ligamentous behavior, but more recent studies have failed to find a relationship between relaxin and knee laxity in either normally menstruating or even pregnant women. There is also a significant change in hormonal fluctuation between females from week to week of their menstrual cycle, but found no change in knee laxity measures throughout the course of the female menstrual cycle or even a correlation between laxity and relaxin levels (Zazulak et al., 2006). The ability to better understand how the different sex hormones play a part in knee laxity may play an essential role to help researchers and rehabilitation clinicians predict and prevent ACL injury in female athletes.

Beynnon et al. (2006) studied the relationship between cycle phase and ACL injury in recreational female alpine skiers to help determine if a likelihood existed of the ACL being affected by injury during specific menstrual cycle phases. This was done by obtaining serum estrogen and progesterone concentrations at the actual time of injury, something that had not been done in previous literature; data were then used to determine the phase of the females’ cycle when the ACL injury occurred (Bennyon et al.). Once skiers’ experience and ability was taken into account, participants were predicted to be about three times more likely to suffer ACL injury during the preovulatory, or follicular, phase of the menstrual cycle as compared to the postovulatory, or luteal, phase (Bennyon et al.). Differences between these studies could be found in the differences between
subjects. While one study focused on females who were healthy and athletic, they were not necessarily competitive or collegiate athletes. It is important for researchers to take into consideration the environmental differences between school-aged athletes and those females who are self-proclaimed athletes. Great care must be taken when interpreting results from the effects of hormonal contribution to ACL injury due to the increased amount of female athletes that suffer from irregular cycles. Hopefully this will encourage further investigation in order to further outline potential hormonal or cyclical differences in athletes and those whose cycles model average phase time lengths (Bennyon et al.; Zazulak et al., 2006).

The changing levels of hormones during the menstrual cycle as well as sex hormones themselves may not be the only factors that increase the risk of female ACL injury. Due to the ACL’s role as a passive restraint as well as an active stabilizer of the knee, increased laxity may contribute to knee joint neuromechanical patterns that increase anterior shear forces during movements that require a sudden change of direction (e.g., cutting) and one-foot stopping, landing, and jumping (Perrin & Shutlz, 2005). An increase in knee joint laxity during these sport-specific maneuvers would allow for greater out-of-plane knee motions that would place greater stresses to important structures of the knee. In basketball, one-legged landing after a lay-up is a normal maneuver that, under normal circumstances, a female athlete would be able to effectively perform. With an increase in knee joint laxity, an athlete may not be able to compensate for the excessive valgus movement in the knee, thus placing excessive strain on the ACL and even the MCL.
Female subjects in one study were found to have roughly 3 times greater incidence of ACL ruptures in basketball versus their male counterparts (Podromos, Han, Rogowski, Joyce, & Shi, 2007). This would likely be attributed to the specific “risky” female movement patterns, such as quickly changing direction and poor landing mechanisms, which often plague female basketball players. With statistics such this, it is surprising that prevention programs are not put into place for every female basketball player. When comparing a variety of sports in which females participate, it was illustrated that the highest frequency of ACL injury occurs in basketball players; volleyball players had the lowest risk (Vauhnik, Morrissey, Rutherford, Turk, Pilih, & Perme, 2011). This finding may be due to the longer training hours that the basketball players put in, but it is nevertheless disconcerting that the sport of basketball seems to be one of the riskiest sports that a female can play in regards to knee injuries. Tanaka et al. (2010) found a high incidence of ACL graft revision ruptures in competitive female basketball players and went as far as to suggest completely avoiding an early return to play. These findings, while daunting to the female basketball player in particular, should encourage researchers to question these findings and to examine how the injury rate of the ACL can be decreased or even eliminated for these athletes.

**Autograft ACL**

The primary goal of ACLR is to reestablish the biomechanical strength, stiffness, and knee joint kinematics that the native ACL once possessed (Wang et al., 2009). By attaining these goals, an athlete has a greater chance of performing in his or her sport at the same level as he or she did before the injury occurred. The ideal graft for
reconstruction would not only meet these anatomical goals, but would also have strong fixation and rapid incorporation in the knee joint, would have a low or non-existent rate of donor site morbidity, no risk of disease transmission, and would be cost effective for the patient (Fu et al., 2009). Using a patient’s own tissue can meet most if not all of these goals. This may be the reason why autografts were the original and historically most popular graft choice for ACLR. Autograft tissues that are commonly used in ACLR are bone-patellar tendon-bone (BPTB) grafts, quadriceps tendon-bone (QTB) grafts, and hamstring tendon grafts. The BPTB graft is most commonly used in autogenous reconstruction due to its high strength and stiffness (Lo et al., 2009). Initial positive outcomes with BPTB autografts may have led this graft to be termed the “gold standard” of ACLR among surgeons.

It has been demonstrated that the strength of the patellar tendon autograft to be 159-168% of the native ACL (Marrale et al., 2007). The BPTB graft is normally harvested from the central one-third of the patellar tendon and cut in line with the longitudinal fibers (Hospodar & Miller, 2009). By harvesting the graft in this fashion, surgeons decrease the likelihood of tendon rupture. The patellar plug is also commonly harvested in conjunction with the tendon; it is cut in a trapezoidal fashion at the inferior pole of the patella while the tibial plug is cut in a rectangular fashion from the tibial tuberosity (Hospodar & Miller, 2009). Because the BPTB graft is commonly harvested with a bone plug attached at each pole, the bone-to-bone interference screw placement encourages a solid fixation and rapid incorporation of the graft (Sherman & Banffy, 2004). These surgical techniques to harvest and implant the BPTB graft certainly meet the goals for an ideal ACL replacement.
Beneficial results and positive long-term outcomes have been reported using BPTB autografts, and surgeons have been able to improve on surgical techniques over the past few decades. Advantages of this graft include the capability to permit bone-to-bone union and thus promoting earlier fixation strength that other graft types (Marrale et al., 2007). They also include initial high tensile strength of the available tendons around the knee, and its lack of negative affects from sacrificing a significant stabilizer of the knee (Marrale et al., 2007). The BPTB autograft also has the advantage of availability as the surgeon can opt to use the contralateral or ipsilateral BPTB of the affected knee. This graft is also effective in revision procedures; some surgeons have even found that contralateral BPTB grafts can be used for revision surgeries (Fu et al., 2009). ACLR using BPTB autografts have a decreased graft failure rate, less objective knee laxity, and an increase in patient satisfaction as compared to other types of ACLR (Liden et al., 2007). Also, because the BPTB autograft is readily available from the athlete, the graft is cost effective.

In a 2006 survey regarding ACL reconstruction, members of the American Orthopaedic Society for Sports Medicine (AOSSM) were asked to complete questionnaires pertaining to training and experience of ACLR, graft selection, surgical techniques, and postoperative rehabilitation. There is a wide range of experience among surgeons who perform ACL surgeries. It ranges from <1 year to 49 years, with an average of 14 years in practice (Duquin et al., 2009). The graft most frequently used was BPTB autograft (46%), followed by hamstring tendon autograft (32%), and then allograft (22%) (Duquin et al., 2009). Most surgeons (76%) allow their patients to return to full activity at six months for BPTB autografts, and 43% advocate the use of a brace six
months to a year for those looking to return to sports activity (Duquin et al., 2009). This information is an important piece of research for athletes. When discussing ACLR with an athlete, it is important to obtain a good understanding of the surgeon’s history of performing this reconstruction and what his or her success rate has been with past surgeries.

Other benefits exist with using BPTB autografts, especially with regard to the strength of the tendon. One study found that the ultimate tensile load (2,977 N) and stiffness (455 N/mm) of a BPTB autograft was even greater than the native ACL (2,160 N and 243 N/mm, respectively) (Krych, Jackson, Hoskin, & Dahm, 2008). Strength of the graft being used for reconstruction is certainly an important factor of ACLR, especially if the patient understands the extent to which the body will naturally begin to break down the tissue before it goes through the process of incorporation. BPTB graft also have been shown to be better suited for patients with extreme ligamentous laxity, young men involved in competitive sports, and patients in need of an accelerated rehabilitation program, such as the young woman in this study (Krych et al., 2008). While authors have previously suggested that quadriceps strength and functional capacity may be diminished with the use of BPTB autograft, it has been demonstrated that a BPTB allograft has similar success rate as BPTB allograft (Krych et al., 2008). The risk of patellar tendon rupture or quadriceps atrophy may have been a deterrent for the athlete to make the decision with BPTB autograft, but these findings seem to give this graft choice more credibility.

Though not as frequently used as the other types of autografts, some surgeons look to autogenous quadriceps tendon-bone (QTB) for ACLR. Kim, Kumar and Oh
(2009) evaluated and compared the outcomes of ACLR’s by use of BPTB graft and QTB graft; 48 patients (27 with BPTB and 21 with QTB) were examined at a follow-up of 24 months postoperation. The findings indicated that the stability of the reconstructed ACL with QTB was comparable with that of the BPTB reconstruction. Also, 13 BPTB patients reported discomfort while kneeling, whereas only 4 QTB patients had moderate discomfort (Kim et al., 2009). This common complaint among patients is often seen in BPTB ACLR and has led surgeons to look for alternative graft types in order to eliminate this complication. QTB would provide more positive outcomes when it comes to postoperative pain. Due to these outcomes, a case for QTB grafts could be made for those patients looking for an accelerated return-to-play timeline. However, QTB graft has become a less popular graft choice for ACLR due to its overall harvesting difficulty. Surgeons must battle with denser bone at the proximal section of the patella, overcome the difficulty of having to harvest the graft around the curved patellar surface, and fight with the adherent suprapatellar pouch without causing it undue damage (Fu et al., 2009). Other graft choices have produced similar, if not better, results while allowing for a greater ease of harvest.

The second most commonly used graft is the hamstring autograft, which is generally made up of the gracilis (G) and semitendinosus (ST) tendons. It is also commonly combined as a bundle of the two tendons (ST/G) (Sherman & Banffy, 2004). The use of ST/G graft has increased in popularity since the early 1990s due to the similar functional results as compared to the BPTB graft but with a significant decrease in morbidity rates (Chouliaras et al., 2007; Fu et al., 2009). Surgeons are increasingly utilizing the hamstring graft combined in the form of a 3- or 4-strand ST or ST/G during
the last decade (Laxdal et al., 2008). This bundling of tendonous grafts may be done to mirror the tensile strength of the BPTB graft to make the hamstring graft a contender in ACLR. The collagen mass of the hamstring bundle graft has been found to be 65% greater than that of BPTB grafts (Fu et al., 2009). In addition, the ST/G graft is stronger and seems to have a linear stiffness that more closely resembles the native ACL than the BPTB graft where the central one-third was harvested (Chouliaras et al., 2007).

Some surgeons prefer to at least double-loop the ST/G due to its strength and stiffness. The aligned four tendonous strands are the strongest (4304-4590 N) and stiffest (861-954 N/mm) autogenous graft (Lawhorn et al., 2003). Authors note the rapid biomechanical incorporation rate of a double-looped ST/G graft to be a positive outcome of this autogenic tissue type since the tendons do not undergo necrosis, and viability does not depend on the revascularization of the graft (Lawhorn et al., 2003). These postoperative outcomes may be seen in allogenic tissue ACLR but are avoided in this case. Loss of knee extension is minimal in hamstring autograft ACLR, and anterior knee pain is diminished if not completely absent. It has also been hypothesized that hamstring tendons regenerate; the extensor mechanism problems such as anterior knee pain, pain upon kneeling, quadriceps weakness, potential patellar fracture and tendon rupture, are avoided when hamstring grafts are used for ACLR (Lawhorn et al., 2003).

Research outcomes have been mixed, however, with results of the differing ST/G graft bundles when compared to other autografts. It has been found that there is no difference in outcomes (e.g., joint laxity) when comparing ST/G to BPTB graft techniques (Chouliaras et al., 2007; Laxdal et al., 2008). This finding could be used as a positive argument for hamstring autografts since it was found to be equal to BPTB
autograft. No detectable radiographic differences between hamstring and BPTB grafts have been found at 5-year postoperative examinations (Fu et al., 2009). These findings do not necessarily urge athletes to choose hamstring autografts over BPTB autografts; it does show a certain amount of equality among graft types, however. When comparing BPTB grafts and hamstring autografts in general, it is generally agreed upon that hamstring autograft ACLR leads to a decrease in donor site morbidity and provides identical anterior stability and functional results (Fu et al., 2009).

Complications with Autograft ACLR

There are many positive outcomes with an ACLR autograft, but it is vital that the athlete who must undergo reconstructive knee surgery fully understand the costs as well as the benefits of each option. For example, any autograft tissue has the disadvantage of donor or harvest-site morbidity, an increase of time taken during operation, and complete dependence on the integrity of the donor tissue (Edgar, Zimmer, Kakar, Jones, & Schepsis, 2008). One major drawback of using an autograft for reconstruction is just that; the surgeon must damage another portion of the patient’s body in order to create a new viable structure. This cannot only cause added pain and discomfort to an already uncomfortable procedure, but may add to the physical setbacks during the rehabilitation process. If a female athlete, who is already predisposed quadriceps dominance, chooses hamstring tendon tissue for ACLR, she will have to overcome an even weaker hamstring complex during rehabilitation.

Patellofemoral pain has been reported as the most common and persistent complication after ACL reconstruction with autogenic tissue (Kim et al., 2009). In the
case of autogenic BPTB reconstruction, this anterior knee pain would be contributed to the harvest-site incision and actual harvest of the portion of the patellar tendon. In fact, several studies have found a tendency toward increase anterior knee pain and donor site morbidity after BPTB autograft harvest (Fu et al., 2009; Lo et al., 2009; Marrale et al., 2007; Sun et al., 2009b). Harvesting the patellar tendon at its central one-third portion has been linked to degenerative disease such as patellofemoral osteoarthritis, excessive scar tissue formation, a shortening of the patellar tendon itself, a decrease in terminal knee extension, and patellofemoral pain (Krych et al., 2008). These poor results and complications may counter the reported positive aspects of autogenic tissue.

BPTB autograft is associated with bothersome disturbances in anterior knee sensitivity as well as creates the inability to fully kneel in roughly 40-60% of patients following a short-term follow-up (Marrale et al., 2007). This inability to kneel or bring the knee through the full range of motion in flexion can negatively affect athletic performance and may even cause further injury to the knee or other related structures. It has also been reported that patients who suffer from an accelerated progression of patellofemoral osteoarthritis after BPTB ACLR (Krych et al., 2008; Vairo, McBrier, Miller, Buckley, 2010). This shows that autogenic harvesting may produce both short-and long-term postoperative complications that can plague an athlete far beyond his or her athletic career. If not managed or treated correctly, these obstacles can greatly affect an athlete’s ability to perform and may have the potential of completely ending some athletic endeavors.

Recorded complication of autograft ACLR do not end with troublesome pain and some loss of range of motion. Serious secondary injuries can occur as a result from
compromised structures after harvesting. A current literature review of autograft ACLR found cases of rupture of the remaining patellar tendon after BPTB graft harvesting at three-and-a-half months and eight months after surgery (Marrale et al., 2007). There were also reports of patellar fracture up to six months after reconstruction using the central one-third of the patellar tendon (Marrale et al., 2007). The rate of fracture of the patella after harvest of BPTB autograft is 0.23% to 2.3% and can be attributed to squared bone cuts and a large bone plug harvest (Matava et al., 2009). This potential postoperative risk, while relatively rare, can still occur and could cause serious damage to the already compromised knee.

The patellar tendon, while not a main stabilizer of the knee joint, still plays a key role in normal knee joint kinematics. When harvested at the central one-third, the patellar tendon has been found to have significant clinical, radiographic, and histological abnormalities up to two years after it has been harvested (Kartus et al., 2001). Other studies noted patellar tendon shortening following the use of BPTB grafts (Marrale et al., 2007). Shortening of the tendon can seriously alter the normal kinematics of the knee joint and can cause further injury either up or down the kinetic chain. This shortening can be caused by the increase of scar tissue laying down over the incision of the tendon and may even increase the possibility of tendon rupture.

Another complication of using BPTB autografts can be found if the incision is poorly placed over the anterior portion of the knee. When standard anterior incisions are used to harvest the central third of the patellar tendon, the surgeon endangers the infrapatellar branch of the saphenous nerve that runs close to the tibial tubercle in the
knee (Marrale et al., 2007). This can cause prolonged anterior knee sensitivity after surgery. Due to these dangers, the use allografts have risen in popularity.

Autogenic complications are not limited to the BPTB graft. Some authors have considered the single bundle hamstring tendon autograft to be inferior to the BPTB autograft in regard to strength at the fixation site (Sherman & Banffy, 2004). Because the hamstring graft does not have bone plugs, the surgeon is required to surgically fix the soft tissue to the bone (Sherman & Banffy, 2004). While there are several different fixation techniques from which to choose, this added variable creates more opportunity for mixed or poor results. Since the surgeon must fix the soft tissue to bone, the patient’s recovery may be prolonged in order to allow adequate time for proper soft tissue to bone fixation. It is hypothesized that the graft’s tensile strength may not be adequate in achieving proper postoperative stability (Marrale et al., 2007). Hamstring grafts have also been shown to incorporate slower (8 to 12 weeks) than BPTB grafts (4 to 6 weeks) (Hospodar & Miller, 2009).

If the ACL is compromised due to an injury, the secondary restraints of anterior tibial translation are the hamstring tendons. Donor-site morbidity is lessened with hamstring autografts; however, there are also negative long-term effects from weakening the knee stabilizers and hip extensors (Marrale et al., 2007). If the hamstring is not properly strengthened to preoperative levels during the rehabilitative process, it is logical that there may be a decrease in knee stabilization. Hamstring harvesting for ACLR has also been found to cause persistent weakness in high angles of flexion (Fu et al., 2009). A lack of proper rehabilitative protocols will leave the harvested tissue weak, thus causing secondary problems such as muscle weakness. Donor-site morbidity at the hamstring
incision site was also found to be higher in females, although activity-related soreness at
the donor site may be resolved by 3 months after surgery (Fu et al., 2009). Also, the risk
of nerve neuroma and neuralgia following harvest is present with hamstring harvesting;
the reported incidence of injury to the infrapatellar or main branch of the saphenous nerve
during harvesting of the hamstring is as high as 55% (Fu et al., 2009; Marrale et al.,
2007). Risks must be discussed and well understood before an educated decision can be
made on what graft type to choose for ACLR. It is imperative that the surgeon
understands the physical needs of the athlete and directs the patient to make a decision
that best suits them.

Allograft ACLR

The popularity of using allograft tissue, or tissue taken from cadavers, has
risen over the past 15 years in response to surgeons and researchers attempting to find a
graft that would decrease the potential risks of harvesting a patient’s own tissue. Of the
reported 350,000 ACLR that are performed annually in the United States, approximately
60,000 of those are done with the use of allograft tissue (Wojtys & Brower, 2010). The
use of allograft tissue in primary and revision ACLR continues to expand due to the
elimination of donor-site morbidity and a decrease in surgical time as compared to
autograft ACLR (Edgar et al., 2008; Fu et al., 2009). Surgeons who prefer to use allograft
tissue over autograft tissue site comparable knee stability, a decrease in overall
postoperative pain, as well as positive aesthetic outcomes due to smaller incisions (Fu et
al., 2009). It would seem that every worry that was seen in using autograft tissue was
eliminated by the use of allograft tissue. As this graft choice rises in popularity, so does the amount of scientific literature based on allograft tissue and its use in ACLR.

In animal models, allograft tendons have been shown to heal directly to the bone tunnel and, in clinical models, has been shown to be as effective as autografts (Caborn & Selby, 2002). Allograft remodeling seems to also be similar to autograft remodeling. One author found that an allograft tissue was viable by 6 months after ACLR, and at 12 months, the graft resembled the control ACL (Fu et al., 2009). Further examination has revealed that between 18 and 55 months, allografts appear to have well-arranged collagen bundles that reveal good crimp pattern, have spindle-shaped nuclei, and exhibit normal cellularity (Fu et al., 2009). It may be concluded that allograft tissue exhibits the same biological results as autograft tissue after incorporation and ligamentization. Proponents of allografts have suggested that athletes can return to play sooner due to the lack of donor site morbidity (Fu et al., 2009). The theory is that if the athlete is in less pain, he or she may be able to progress through the stages of rehabilitation at a faster rate, especially if there is a complete lack of pain or sensitivity either in the hamstring or patellar tendon.

There is a range of allograft tissue choices that are available to the injured athlete for ACLR. These tissue choices include anterior and posterior tibial tendons, semitendinosus, gracilis, Achilles, quadriceps, and BTPB tendons (Fu et al., 2009). The most commonly used of these tissues are the patellar, Achilles, and anterior tibial tendons (Matava et al., 2009). Many surgeons prefer soft tissue grafts with a bone plug at each end; other surgeons actually prefer allograft tissues that lack a bone plug. Lawhorn et al. (2003) found that some surgeons are in favor of this type of soft tissue allograft because it
is less time-consuming during the harvesting process. These authors cite contrary problems to previous literature in that a graft with a bone plug is slow to incorporate, may weaken with age, and compromises the fixation with the interference screw when it extends beyond the tibial and femoral tunnel (Lawhorn et al.).

In essence, the allograft would be used as basic scaffolding for ligamentization to take place, not all harvested allografts are created equal. One important factor to having a successful allograft ACLR may be determined by how long the tissue has gone without fresh blood supply from its host. In order to assure the best results of the allograft, the American Association of Tissue Banks specifies that graft harvest from the cadaver host should occur within 15 hours of death, or 24 hours if the body was refrigerated (Matava et al., 2009). Allograft tissue efficacy improves with the elimination or reduction of an immune response (Cartmell & Dunn, 2004). It is important that extensive screening be done of the cadaveric tissue before the graft is harvested to ensure that the graft is free from disease or other issues that may impede the incorporation process.

Another main benefit and selling point for allograft tissue ACLR is the fact that the surgeon does not have to harvest living tissue from another area of the patient’s body. This would decrease postoperative pain and eliminate issues that would be associated with knee extensor or flexor lag. Some data suggest that ACLR with allograft tissue allows for a more aggressive rehabilitation protocol (Edgar et al., 2008). A main factor in determining whether an athlete may progress to the next phase of rehabilitation is pain level. If an athlete experiences less pain due with having an allograft ACLR, the argument can be made that the athlete can progress at a faster rate than an athlete who
had autograft ACLR. These potential positive short-term results may be tempting for the injured athlete and persuade him or her to choose allograft tissue. It certainly could have also been a deciding factor for the athlete involved in this present study.

Complications with Allograft ACLR

Allograft tissue certainly has many benefits for athletes; however, there are still complications that may rise with utilizing this graft for reconstruction. The most notable complication is the potential for disease transmission, both viral and bacterial, such as the human immunodeficiency virus (HIV) (Sun, Tian, Zhang, Xia, Zhang, & Yu, 2009a). This is why having adequate screening of the cadaveric tissue is so important. In 2001, one patient who underwent ACLR died 48 hours after reconstruction of Clostridium sordellii septic shock once the patient received an infected allograft (Sherman & Banffy, 2004). With autograft reconstruction, the need to extensively sterilize the tissue is nonexistent. With allograft tissue, however, it is almost impossible to completely rid the tissue of foreign contaminants or diseases and still have the graft be viable for surgery. Researchers have yet to find a satisfactory method of sterilization for allograft tissue that does not weaken the tissue’s mechanical properties (Barber, McGuire, & Johnson, 2003). Gamma radiation, which is used to destroy viruses, can significantly weaken the ACLR graft at 4 Mrad of radiation (Barber et al., 2003). Lowering the power of the radiation would potentially have less effect on the strength of the ACL, but it may not be effective in killing all viruses. It has also been found that 2 Mrad of radiation is not effective in destroying HIV (Sherman & Banffy, 2004). Due to these complications associated with allograft tissues, sterilization techniques are replaced
with extensive donor screening and aseptic harvest in an attempt to stop allogenic disease transmission (Sherman & Banffy, 2004).

When using allograft tissue, the patient should be made aware that incorporation time varies among the types of graft materials. In general, allografts are incorporated less quickly than in autografts (Fu et al., 2009). These new findings may add time to the rehabilitation process that the athlete thought had initially been shaved off in order to get him or her back to competition more quickly. Fu et al. (2009) found incorporation time for autografts tissue to vary: BPTB is incorporated within six weeks; autograft hamstring within 12 weeks; and quadriceps tendon in 6 to 12 weeks. For allografts: BPTB, anterior and posterior tibial, hamstring, and Achilles tendon allografts are incorporated as late as 6 months (Fu et al., 2009). While an athlete may report less pain with allograft ACL, it does not correlate with incorporation time. In fact, knowing that allograft tissue can take as long as 6 months to incorporate, surgeons may prescribe an even longer return-to-play timeline regardless of pain perception.

Allograft ACLR is also plagued by an increase in failure rate as compared to autografts, contrary to the initial belief that allograft tissue incorporated more quickly than autografts. On a study done with 66 revision BPTB allograft ACLR patients, the overall failure rate was 33% (Barber et al., 2003). It has been recommended that patients use autogenic BPTB instead of allograft tissue for reconstruction. Some failed allograft reconstructions have revealed a complete lack of revascularization or simply did not “take” when viewed at the time of a revision procedure (Hospodar & Miller, 2009). Other postoperative problems may arise during the rehabilitation process if the patient is not closely monitored or does not subscribe to a regimented program. Graft failure at the
fixation site may arise before biological graft incorporation of the graft (George et al., 2006). This could be due to the patient being overly confident in the ACLR, as their pain level is lower than might occur with an autograft. Prematurely returning an athlete to sports before restoration of neuromuscular control has taken place may leave the knee incapable of responding to stress and more prone to a repeated injury (George et al., 2006). Again, the healing process takes time and the rehabilitation formula is set for a medical and physiological reason. Athletes are notorious for pushing the envelope in an attempt to get back to the playing field or court. This ambitious drive shows the passion that an athlete has for his or her sport; however, the athlete may be put into greater risk if the new ACL has not had adequate time to incorporate.

Other drawbacks of allogenic tissue in addition to the potential for immune response and longer incorporation time include increased laxity of the graft over time and a possible greater risk of failure in an athletically active patient (Fu et al., 2009). These risks may be related to the patient being allowed to return to activity too soon. Research addressing allogenic grafts is mixed, however, which poses yet another threat to the athlete. When comparing ACLR using allograft and autograft BPTB, one meta-analysis did not find any significant differences between the two types of grafts (Krych et al., 2008). It may be hard for the athlete or even the surgeon to come to an educated decision of which graft type to use for ACLR when studies continue to provide mixed or neutral results.

In order for the athlete to make an educated decision on which graft to choose for ACLR, he or she must be made aware of all of the potential risks and ramifications for each graft tissue type. Consideration should be made when determining which graft
will best suite the needs of each athlete. Due to the various advantages and disadvantages of each tissue, a gold standard should not be set, but rather a graft that would work best for each individual patient. Special care should be taken for the patient who’s goal is to attain an accelerate return-to-play protocol so that he or she may return to athletic competition.

Rehabilitation Protocols

ACL rehabilitation is extensive in both the time that it takes to return-to-play and in attaining the therapeutic goals of rehabilitation. The accelerated rehabilitation program is often used in competitive athletes since it mimics the demands of the knee during sports and is more aggressive in nature. This evolution of ACL rehabilitation has certainly put the injured athlete at an advantage. Before these recent medical advances in reconstruction, several authors had suggested 6 to 8 weeks of knee immobilization after surgery with 8 to 12 weeks of using crutches in order to be mobile (Wilk, Reinold, & Hooks, 2003). Now, athletes can begin gentle weight bearing and passive range of motion exercises within a day after surgery. During this time, the concept of an accelerated return-to-play rehabilitation was nonexistent; return to sports activities were not permitted until 9-12 months postsurgery, while today it can be achieved in 6 months (Wilk et al., 2003).

Tissue healing and the injury’s response to exercise are primary factors that should dictate the rate of progression of a therapeutic exercise program for the knee after ACLR (Houglum, 2005). Parameters of range of motion, strength, endurance, balance, proprioception, agility, and functional performance are advanced in this case since the
rehabilitation clinician is dealing with an athlete (Houglum, 2005). Every aspect found in
the four different phases of rehabilitation have a time and place once sufficient healing of
the graft has occurred. An athlete is placed on an accelerated rehabilitation program
unless extenuating circumstances such as certain secondary injuries exist, such as
meniscal repair, osteochondral complications, or simultaneous collateral or cruciate
ligament repair (Wilk et al., 1999). It is the duty of the rehabilitation specialist and staff
to closely monitor the athlete’s progression through each phase in order to ensure a
positive outcome. It is equally important that the patient provide honest feedback and
practice good communication as his or her body responds to different exercises in the
rehabilitative program.

There are two basic principles that govern the prescription for proper
rehabilitation after ACLR. The first principle is that the effects of immobility must be
minimized in order to reduce or eliminate disuse effects (Chouliaras et al., 2007). This is
a more contemporary principle that has given positive results since the days of placing
the patient in a full leg cast for up to 6 weeks after ACLR. One tool used to enable
motion without recruiting effort from the patient immediately after surgery is the
Continuous Passive Motion (CPM) device. CPM devices are often seen in the immediate
postoperative recovery to negate the effects of immobility (Almqvist, Willaert, De
Brabandere, Criel, & Verdonk, 2009). The leg is strapped into the CPM device and can
be operated while the patient is sleeping. Bradley and Tejwani (2009) began the use of
CPM machines on their patients beginning on postoperative day 1; the CPM device was
set from 0 to 40 degrees, and increased 10 degrees per day, as tolerated, until a maximum
of 120 degrees was achieved in approximately 1 week. These devices enable the patient
to minimize the negative effects that would occur if the knee were kept immobile without having the patient bear weight. However, one survey revealed that only 30% of surgeons prescribe them to patients after ACLR (Duquin et al., 2009).

The second principle during ACLR rehabilitation is that healing tissues must never be overloaded (Chouliaras et al., 2007). Athletes will want instant gratification after ACLR, but each step of each phase is set for a reason. The ultimate goal is to get the athlete healthy enough for full participation in sports, but progressing too quickly or skipping steps may lead them back into the operation room. An overaggressive rehabilitation may result in excessive capsular mobility, graft stretching, or both (Wilk et al., 1999). In order to adhere to these two aforementioned principles, goals for rehabilitation are set and should be followed closely by the patient. There are 4 phases of rehabilitation that coincide with the process of tissue healing. Goals of each phase of rehabilitation should include the following: the attainment of full range of motion as compared to the contralateral knee; full quadriceps and hamstring strength; enhancement of proprioceptive and dynamic stability; full return to function and sport; and prevention of knee instability (Bradley & Tejwani, 2009). Returning to athletic participation before full restoration of neuromuscular control will leave an athlete at a disadvantage in regard to responding to stress and strain of the knee joint and more prone to recurrent injury (George et al., 2006).

It is important that the athletes not progress from one phase to the next without achieving all of their rehabilitative goals from the previous phase. It is often that an athlete may need to extend the normal timeframe of one phase if setbacks such as consistent pain or issues with a loss of range of motion occur. Also, athletes may have to
regress to a previous phase if they are not physically ready to keep up with the demands of the next phase. A case control study that assessed risk factors for ACL graft failure based on activity level and graft type based patients’ rehabilitative progression on goal achievement rather than weeks after surgery (Borchers et al., 2009). This is an important concept when dealing with an athlete that is either ready to progress or needs more time to achieve the rehabilitative goals. Other return-to-play guidelines for accelerated rehabilitation is based off of good quadriceps control, a lack of complaints during functional activities, increased confidence when running, the ability to cut and pivot, jumping at full strength, and at least an 85% strength score on a single-leg hop test as compared to the contralateral leg (Borchers et al., 2009). These functional considerations play a pivotal role in the rehabilitative process and may be safely achieved earlier or later than by a preset number of weeks after surgery. However, it is important to consider the length of time that elapses after surgery so that the patient does not return to full activity too soon, regardless of how confident the patient feels. In the same case control study, the authors found that allograft patients felt significantly better than autograft patients after ACLR in the early months after surgery and thus returned more quickly to a high level of activity (Borchers et al., 2009). Unfortunately, these patients who exhibited a high level of activity with allograft ACLR had increased odds of graft failure (Borchers et al., 2009). Again, the phases of rehabilitation should cater to the capabilities and needs of the athlete, but they should not allow the athlete to prematurely advance without proper healing time.

An athlete that has sustained an ACL injury will face having to be held from competition for the duration of his or her athletic season, it would be their goal to get
back to playing as soon as possible. An accelerated rehabilitative program would ideally have the athlete safely returning to full sports participation in approximately 6 months. Once the injury has occurred and the athlete has been scheduled for surgery, a “pre-habilitation” program can begin to ensure the best results for the athlete. This program would include such goals as swelling and edema control, pain control, and exercises to restore full range of motion. One great way of achieving all of these goals is by having the athlete begin performing workouts on a stationary or recumbent bike once full rotations are tolerated. These workouts would aid in edema removal from the knee joint and would aid in pain reduction. Also, once the athlete is comfortable, he or she can progress to a more strenuous exercise program, which would help to maintain the muscle tone of the hamstrings and quadriceps without putting excessive strain on the knee joint.

Education is also essential during this time as the athlete may have numerous questions and concerns. Also, injury can be very damaging to the mental and emotional stability of the athlete; keeping an open line of communication with the athlete is important in case there is appears to be a need for referral.

In an accelerated program, rehabilitation would begin immediately following surgery. The time from immediate postoperative care would mark the beginning of Phase I of rehabilitation. The patient would be able ambulate with crutches while weight bearing to tolerance with full knee extension immediately following surgery (Houglum, 2005). The use of a CPM machine could be used to aid with the elimination of range of motion discrepancies that may occur immediately following surgery. Exercises such as straight-leg raises and isometric quadriceps sets can begin as early as the first day after surgery. Two days after surgery, exercises such as passive knee extension to 0°, active
hip exercises, and ankle range of motion should begin (Hougulum, 2005). Weight shifting with the aid of the crutches to enable the athlete to become comfortable partially weight bearing would also be beneficial during the first week of postoperative rehabilitation.

Throughout the entire rehabilitation period, the athlete can maintain core stability by performing abdominal exercises either on the ground or on a stability ball. Also, upper body strength can also be maintained by continuing to weight lift or use an upper body ergometer, which would also help to increase cardiovascular fitness. At the beginning of the second week, active knee range of motion exercises would begin and by the end of the week the patient should be ambulating without the use of crutches (Hougulum, 2005). Standing hamstring curls, some proprioceptive training, and light leg press exercises can begin to help the athlete minimize muscle atrophy.

During the first two weeks of postoperative rehabilitation, it is important that the athlete work to control pain and swelling. This can be done, and should continue throughout the rehabilitation process by utilizing ice for swelling and pain and any prescribed analgesic and inflammatory medication from the surgeon. By the third week, the rehabilitation specialist may introduce pool exercises such as pool walking as well as leg presses that press through a $60^\circ$ range of motion (Hougulum, 2005). Lunges may also be incorporated into the exercise regiment as long as they can be performed without pain. It is important that range of motion be assessed throughout the rehabilitative process so that the athlete does not end up with an extension or flexion lag. Even a few degrees of discrepancy could pose potential risk of further injuring the knee once an athlete has been cleared to play. At the end of the first month, a patient should have full extension and flexion to at least $115^\circ$ (Hougulum, 2005). All previous exercises should be continued with
the progression of more difficult strengthening exercises. This can include lateral lunges, wall squats, vertical squat, and more difficult calisthenics in the pool. This would be near the end of the first phase and begin the transition into Phase II of rehabilitation.

Rehabilitation may progress to Phase II providing that there has been a full restoration of knee range of motion, that strength improvements continue to be made, and that the athlete continues to become as confident on the injured leg as the non-injured leg. During weeks 6 through 8, assuming that there has been no increase in swelling and the patient is progressing with range of motion exercises, the athlete may begin ambulation without the use of a brace (Houglum, 2005). If extension lag, or a lack of full extension of the knee joint, is a problem during this time, prolonged extension stretches can be performed. For these stretches, the athlete can lie prone with the affected leg hanging off of the table so that gravity will cause the knee joint to creep into full extension. Also, it may be necessary to perform joint mobilizations to the patella to help aid in knee flexion. Exercises may continue to progress in difficulty as the athlete becomes stronger and as the atrophied quadriceps increases in girth. Because closed kinetic chain (e.g., squats) exercises put less shear forces on the ACL, it would be appropriate to progress from mini-squats to deeper squatting exercises, box dips, pliés, step-ups, and multi-directional lunges. Also, walking on an inclined treadmill will help prepare the athlete to begin jogging. Around the end of the eighth week after surgery, the athlete would typically be able to progress to the beginning of Phase III of rehabilitation.

By the third or fourth month, the athlete can begin straight-ahead jogging. Once jogging is comfortable, the athlete can confidently but gradually progress to running and sprinting (Houglum, 2005). The athlete may advance to agility drills,
plyometrics, and activity-specific drills during this time as long as full range of motion is present, strength is about 80% of the uninvolved knee, and if proprioception is good in balance activities (Houglum, 2005). A hop test determining the athlete’s ability to perform and correctly land a single-legged hop should also be taken during this time to determine the strength of the involved leg versus the uninvolved leg as well as the confidence of the athlete. During this time, the hop test should be 80% of the contralateral leg (Wilk et al., 1999). Phase III of rehabilitation is characterized by strength and agility training to prepare the athlete to perform sport-specific activities during Phase IV and on into full unrestricted sports participation. Hopping on both legs and progressing to hopping on the injured leg are important exercises to help instill confidence for the athlete. Lateral jumping is also important, especially in basketball athletes. This is also the time when the athlete may return to performing some supervised sport-specific drills that can be done on the athlete’s playing ground. For the instance of the athlete in the present investigation, playing around the world, HORSE, and practicing lay-ups can begin. This is often the athlete’s favorite phase of rehabilitation as they are not only back on the court or the field, but they are often back practicing certain skills with their teammates. This psychological aspect of rehabilitation is also very pivotal in the healing process. During this time, the athlete may progress into the final stage of rehabilitation, Phase IV.

Phase IV of rehabilitation is marked by the unrestricted return to play of the injured athlete at the end of the phase. The fifth and sixth months involve continued strengthening and flexibility exercise and advances to more functional activities that will enable an athlete to participate in full athletic activities with full contact (Houglum,
Emphasis is placed on the advancement of strengthening and neuromuscular control drills as well as proprioception and sport-specific exercises. An appropriate assessment from the athletic trainers and surgeons is necessary at this time to determine the readiness of the athlete to participate in unrestricted activities, and the athlete must pass all aspects of functional examination before returning to play (Houglum, 2005). This includes attaining full range of motion of the knee, equal strength assessments between the affected and unaffected leg and normal proprioception. The athlete must be pain-free during exercise and must be free from diffuse edema after activities. Phase IV of rehabilitation often goes beyond return-to-play; maintenance checks of the athlete’s knee are often called for, and specific rehabilitation exercises or stretches may be needed as time goes on.

The most common time period for return to full sports activity was at five to six months for all graft types (Duquin et al., 2009). Laxdal et al. (2008) performed a study on ACLR patients and compared BPTB and hamstring autografts for knee reconstructions; they had all patients undergo the same rehabilitation protocol. In this study, patients were permitted to fully weight-bear and were allowed full range of motion without the use of a brace. Closed-chain exercises began immediately once surgery was performed; at three months, running was permitted and full contact sports were allowed at six months post-surgery at the very earliest (Laxdal et al.). Short-term results for this study were good and could be used to illustrate an effective accelerated rehabilitation program.

Returning to full competitive participation for an athlete is allowed around six months for ACLR in recent research; returning to activities before six months after
surgery, however, has been found to not increase the risk of subsequent ACL injury (Shelbourne et al., 2009). The rehabilitative program designed by these researchers was designed to take patients through phases that were not defined by time. Instead, they were defined by each patient’s ability to achieve the set rehabilitative goals. Patients were required to (1) attain full range of motion with knee extension and flexion with limited swelling, (2) increase the leg strength of the affected knee to match that of the unaffected knee, (3) complete sport-specific drills individually, (4) perform controlled drills with an athlete’s team, (5) participate part-time in competition, and (6) participate in full competition (Shelbourne et al., 2009). In this case, time guidelines were not necessarily factors in return-to-play. Only when patients could attain rehabilitative goals could they progress to the next phase. Wilk et al. (1999) emphasized eight special considerations that are important to consider when implementing a rehabilitation program designed for female athletes; these included (1) hip musculature in regard to stabilization of the knee; (2) retraining neuromuscular hamstring control; (3) controlling valgus movement of the knee joint; (4) controlling hyperextension of the knee; (5) high-speed interval and endurance training, especially in regard to the hamstrings; (6) neuromuscular reaction time and ability; (7) strengthening the less-developed thigh musculature; and (8) correcting poor muscular endurance. These authors created a protocol that catered to the specific anatomical and neuromuscular needs of their female patients in order to ensure that they would have the best possible long-term outcomes. These aspects may also be implemented during a prevention or intervention program in order to decrease the incidences of noncontact ACL injury.
Critical milestones such as jogging, running, sprinting, and jumping should be achieved in succession before the next phase of rehabilitation is allowed to commence. While it may take a longer or shorter time for certain athletes, enough time should elapse to allow for sufficient tissue healing before progression is allowed. However, simply because it took two weeks for one athlete to attain one goal does not mean it should take that long for another athlete. Generally, timelines are put into effect to create attainable goals for each athlete. For instance, full passive extension should be gained within one week after surgery, full active extension within two weeks; 90 to 100° of flexion within two weeks; and full extension by 6 weeks (Bradley & Tejwani, 2009). The method of advancing strength should depend on the timing of the program, the patient’s response to the program, availability of equipment, and the rehabilitation specialist’s preference and expertise with rehabilitative exercises (Houglum, 2005). It is important for the rehabilitation specialist to have good communication with the athlete to ensure athlete compliance with an individualized program plan. By doing this, the athlete may feel a personal connection with the goals that are set and become motivated to stay on track and to be an active part in the program.

It has been demonstrated that athletes are able to return to sports as soon as 16 weeks after surgery as long as they were able to successfully meet all of the rehabilitation goals and guidelines (Lawhorn et al., 2003). Many athletes may desire to prescribe to this accelerated rehabilitation program; however, the argument could be made that this return-to-play plan puts the athlete back on the playing field too soon. Again, one of the major rules of rehabilitation is to not overload the ACL, especially only eight weeks after the graft is physiologically at its weakest. To help prevent a potential secondary injury or
recurrent injury to the knee, the surgeons usually prescribe the use of a functional knee brace. This is often seen at sporting competitions; athletes often use them for 6 months to 1 year after being released to participate in unrestricted activity (Duquin et al., 2009). Braces help to provide anterior stability where the new ACL may be lacking as well as give athletes the confidence boost that he or she may need to play to their full athletic abilities. However, while braces provide stability during low-stress loads, they have not been shown to adequately stabilize the knee for more functional athletic load applications (Houglum, 2005). It is interesting, then, that athletes will wear them for “extra protection” or that surgeons will recommend wearing them during competitions up to a year after surgery. It has been illustrated in subjective reports that the value found in a functional knee brace lies in the sense of added security when exercising with a brace as compared to exercising without one (Houglum, 2005). While a brace may offer little to no added functional stability during athletic endeavors, perhaps proprioceptive advantage from wearing the brace can give added confidence to the athlete.

**ACL Injury Prevention**

Surgeons have developed sophisticated techniques for ACLR, and rehabilitation professionals such as athletic trainers have fought to return patients to preinjury levels as quickly as possible. While studies where an increase emphasis has been placed on surgical reconstruction and rehabilitation techniques abound in current literature, efforts toward ACL injury prevention should be highlighted and more carefully examined. There is an overall agreement that ACL injuries are initially linked with an extraordinary loss of function (Bennyon et al., 2006). Even after ACLR, there is a
possibility that the index injury will predispose an injured knee to an early onset of degenerative knee disorders such as osteoarthritis (Bennyon et al., 2006). A greater emphasis should be placed on injury prevention in order to keep athletes, specifically female athletes, active throughout their lives. Prevention programs that integrate elements of ACL injury education, balance training and proprioception, plyometrics, strengthening and endurance, and verbal feedback are known to alter biomechanical and neuromuscular issues that are thought to compound ACL injury (Shultz et al., 2010).

Prevention programs should be put in place in preseason training and conditioning before the actual athletic season begins. The program can continue into the season but should not need to be done with the regularity that it would be done in the preseason training. Just as it is important to gradually progress through the phases of rehabilitation after ACLR, so one must gradually ease into a prevention program so as not to overload the athlete. Fatigue alters factors that contribute to lower limb biomechanical and neuromuscular use and is a factor for increased risk of ACL injury risk (Benjaminse et al., 2008; Chappell et al., 2005; Kernozek, Torry, & Iwasaki, 2008; McLean et al., 2007; Orishimo & Kremenic, 2006). By implementing an ACL injury prevention program that encompasses all of the aspects of prevention at once, athletes may become fatigued, which then may result in a higher risk of ACL injury during the prevention program. The effects of fatigue are most evident when combined with unexpected landings, which compromises central processing and control (Borotikar, Newcomer, Koppes, & McLean, 2008; McLean & Samorezov, 2009). Again, fatigue issues compounded with dangerous or unexpected landings, which are often seen being
performed in basketball, can increase the risk of injury. This is an important concept when implementing an injury prevention or intervention program with athletes.

The first week of an intervention program should address endurance issues, while the next week should encompass correcting strength deficiencies, with proprioception and plyometric exercises following those weeks because they are often more difficult to perform. These interventions can be implemented before an athlete’s team begins practice and can last approximately 20 to 30 minutes. Exercises should be done 3 to 4 days a week during the preseason, and one day a week for approximately 15 minutes once the regular athletic season has begun. Unfortunately, no research has delineated the optimal amount of time spent on prevention or an intervention program that would best reduce the risk of ACL injury.

Because ACL injury is a multifactoral phenomenon, prevention should also be multifactoral. It is well understood that an increase in valgus stresses in the knees (i.e., external forces pushing the knee in a medial direction), weak gluteal muscle control, quadriceps to hamstring ratio disparity, and extended knee postures increase risk of ACL injuries. Just as isolated injury to the ACL is uncommon, so is one isolated risk to be the cause for rupture. Focusing on just one aspect of ACL injury risk may not be enough to prevent an injury. For example, ACL prevention programs may not benefit from exclusive emphasis on hip-abductor strength or endurance (Patrek, Kernozek, Willson, Wright, & Doberstein, 2011). Creating a prevention program that aids in the strengthening of hip-abductors may help reduce injury risk, focusing on just that aspect will not reduce the risk entirely.
The importance of prevention has certainly been introduced and discussed in recent research. It is well understood that by implementing ACL prevention programs that there will in fact be a reduction in the incidences of ACL injury. Unfortunately, this has not necessarily been seen across the board with all female sports. Injury-reduction or prevention programs were found to be effective with female soccer players but not with female basketball players (Podromos et al., 2007). This is an interesting and unsettling phenomenon. Because female basketball players are at the highest risk for ACL injury, it would be important to continue to search for the reason of these troubling predispositions and to find appropriate and effective prevention programs.
CHAPTER III

METHODS

Design

As the graduate assistant athletic trainer working with the women’s basketball team during the second injury of the athlete in question, it was determined that conducting a case study-like review was the best method in which to conduct this research and compile this important and relevant information. A review of ACL injury in general combined with the athlete’s injuries in question provided the best way to bring to light this interesting case, especially because there were no previous data recorded with regard to specific muscle testing, range of motion, or other objective measurements prior to the initial injury or rehabilitative process of this athlete. Also, this is a unique and increasingly relevant topic to the sports health care community. Conducting a case study best highlights the progression of this athlete from injury to recurrent injury to return-to-play status. After reviewing the literature, very few authors have reported on revision surgery of the ACL in the general population, let alone the athletic population. Information on the return-to-play progression of athletes who have persevered through revision ACLR was almost nonexistent. No attempt was made to objectively measure or analyze data regarding the differences found between the two graft types; however, the results from this study are a good guide for the medical community in proper care, treatment, and rehabilitation of revision ACLR.
Participant

One 18 year-old collegiate female basketball player was observed in this study. The player was a freshman in college when the initial injury occurred. There was no previous injury reported by this athlete when the initial ACL injury occurred.

Materials

Materials used in this study included physician’s notes from the athlete’s clinical examination, surgeries, and follow-up appointment notes. Also included were the athlete’s injury reports and other pertinent notes from the California State University, Chico athletic training staff.

Procedures

Informed consent was obtained from the athlete to conduct a case study once her second ACL injury occurred in November 2008. Human Subjects in Review Board approval was also obtained in order to do this research. Notes pertaining to her injuries from her surgeon as well as from the athletic training staff were collected. Her name was concealed from the notes to ensure patient confidentiality.

The athlete underwent ACLR rehabilitation throughout the observation process under the care of the certified athletic trainers at California State University, Chico as prescribed from her surgeon. No outside influence or direction was given from the primary investigator that would affect the prescribed rehabilitation of the athlete.
CHAPTER IV

RESULTS

Initial Injury

The athlete’s initial injury to her left knee occurred on December 12, 2007 during basketball practice. As she jumped up for a rebound during a routine drill, she noticed a loud “pop” that came from deep within her knee. She could not recall if the pop occurred during jump-off or landing of the rebound, but she immediately noticed sharp pain deep within her knee once she landed. Weakness of her knee was immediately reported following the initial trauma, and she was physically unable to return to practice. The athlete reported no previous injury to the affected leg. Slight edema was present in the knee joint after the injury occurred and increased once she was safely brought into the athletic training room for examination. After consulting the university’s athletic training staff, all of which suspected an injury to the ACL, she was referred to the team physician. After his examination, it was recommended that a MRI be taken due to his initial impression that she had, in fact, sprained or completely ruptured the ligament. Once the MRI was obtained, it was confirmed that she had ruptured her ACL.

Initial Surgery

Over winter vacation in December 2007, the athlete was able to go to her home city and schedule an appointment with her orthopedic surgeon. During this
appointment, the surgeon explained that she would be able to return to play basketball successfully if she underwent ACLR. He further went on to explain the different graft options that were available for her for reconstruction. After fully reviewing the risks and ramifications, including possibilities of infection, rejection, and loosening or stiffness of the knee over time, the athlete and her mother elected to have an allograft tissue used for her reconstruction. Her surgery date was set for January 3, 2008 with the use of a frozen double-stranded semitendinosus allograft.

During surgery, the torn ACL and the articular space within the intercondylar notch were débrided. The semitendinosus allograft was thawed prior to surgery. There were no outstanding clinical findings during surgery. Once secured in place, the knee was put through full range of motion to ensure that there was no impingement of the ACL at any point during full flexion and extension. Total surgery time was 52 minutes.

Rehabilitation

One week after surgery, the patient’s initial follow-up examination reportedly went very well. She has some slight effusion in her knee, and her range of motion was 0 to 90°. The sutures were removed at this time, and some formal rehabilitation at the surgeon’s clinic was recommended before the athlete returned to school.

Three weeks after surgery, the athlete continued to show signs of improvement. Her range of motion was 3° of knee extension to 110° of flexion, so while she lost a few degrees of extension, her knee flexion was on track with the traditional time measurements of rehabilitation. The surgeon found negative results after performing a Lachman test, and her incision was benign. She began some physical therapy at the
clinic and then went back to her university near the end of winter break to continue rehabilitation with the athletic training staff. The surgeon gave the athletic trainers a prescription order sheet and precautions regarding specific exercises. Jumping, running, cutting, or twisting was prohibited during this time. She did, however, progress very well in terms of increasing her strength and range of motion by exercising on the stationary bike.

At two months post-operation, her range of motion had increased from 3° of extension to 0° and her flexion was up to 140°. Unfortunately, there was some persistent swelling. The surgeon decided not to remove or aspirate the effusion, and encouraged the athlete to continue the cycling, using an elliptical walker, and strength training that she was performing with the athletic training staff. She followed these instructions well, and around six weeks post-operation box-dips and decline box dips were introduced to her strength-training regimen.

At three months post-operation, the athlete’s surgeon noted that she was doing very well with her rehabilitation and that there were no clinical issues whatsoever. Her exam showed mild disuse thickening of her synovium and soft tissue but no effusion. Her knee flexion decreased during this time by about 10°, but her Lachman test was still negative. The surgeon then added light jogging and rope jumping to her rehabilitation program, and encouraged her to progress with weightlifting. She was also allowed to work on speed workouts on the stationary bike and elliptical machine at this time.

At four months after surgery, the athlete was continuing to do very well. She had practiced some agility drills on the basketball court and was not exhibiting any problems. Her examination at that time showed full range of motion with no tenderness
or effusion in the knee joint. The surgeon encouraged her to work on agility and speed without doing any pivoting motions or quick start or stop drills. The final check-up date was set two months later.

On her final exam 6 months after ACLR surgery, the athlete showed no signs of physical or performance problems with her knee. It was noted by the surgeon that she had an excellent response to the reconstructive surgery. At that time, she was back to most of her sport-specific drills without complaint. The examination exhibited good thigh strength, no gross atrophy of her hamstrings or quadriceps, and no knee effusion. She was told to return to the surgeon on a needs-only basis and was cleared to play in full participation of sports in July of 2008.

Secondary Injury

On November 11, 2008, just prior the Thanksgiving holiday, during another routine lay-up at basketball practice, the athlete noticed a hauntingly loud “pop” upon landing. She immediately fell to the ground and understood what the loud pop may have accompanied. This time, she was able to stand up and walk into the athletic training room unassisted. The athlete complained of pain in her left knee similar to that of her initial ACL injury. She was very emotional at this time since she was suspecting that the pain in her knee indicated a secondary injury to her new ACL. Initial examination by the athletic training staff was inconclusive, however, it was suspected by all involved that the ACL might have been re-injured.

The athlete was able to get a walk-in appointment at her surgeon’s office that very same weekend. She showed no effusion in the knee or joint-line tenderness, and at
the time her surgeon produced a negative Lachman’s test. Radiographs were taken and showed normal postoperative changes. At that time, the surgeon was not convinced that she had re-injured the reconstructed ACL, but was unsure exactly what had happened to her knee. He speculated a possible meniscal tear or a loosening of scar tissue. He instructed the athlete to watch the amount of swelling over the Thanksgiving holiday and to call the following week with a follow-up report from the athlete. During that time, the athlete was permitted to perform remedial exercises such as cycling on a stationary bike. The surgeon noted that a MRI would need to be scheduled if she had persistent pain, swelling, or other related problems.

After several days with no improvement in the athlete’s knee with regard to pain, swelling and an overall feeling of instability, an MRI was scheduled and taken on December 5, 2008. The MRI examination found the postoperative changes from her prior ACLR, but that there was a complete lack of distinct fibers of the ACL graft. It was almost as if the ACL graft was no longer there. The immediate impression was that the ACL graft fibers were indistinct and thus the results compatible with a tear of the ACL graft. It was unknown to the surgeon why the graft failed, but was recommended that the ACL be reconstructed.

The athlete decided to have a second surgery to reconstruct her ACL so that she would be able to return to athletics. After the surgeon explained the risks and ramifications of surgery, the athlete expressed apprehension about having an allograft reconstruction for the revision surgery. The surgeon informed her that he would be much more reluctant to let her go back to sports as quickly as the previous return to play time. He could not find a specific reason why the allograft ACLR failed, but was explicit with
his second longer return-to-play guidelines. At this time, other questions were solicited and answered at length, including the understanding that if the athlete decided to have a revision ACLR that she would be held from competition for up to an entire year. These issues were made clear and the decision was made to continue with revision ACLR and informed consent was obtained. An arthroscopic ACLR using an autograft double-stranded hamstring graft was chosen for the procedure.

Secondary Surgery

Revision surgery was performed on December 29, 2008. Under anesthesia, the athlete’s Lachman test was positive, and the surgeon produced a positive grade 2 pivot shift test. Within the intercondylar notch, the ACL graft had been torn centrally. It was an unusual type of tear, where the surgeon felt that there had not been a synovialization or revascularization of the graft; however, there were some minimally functional strands of the ACL at the attachment of the femoral insertion. The race for revascularization or graft failure certainly may have played a role in this case. Because there was little evidence of synovialization of the central portion of the reconstructed ACL, it was apparent that the new tissue lost the race and succumbed to graft failure.

The surgeon first harvested the medial hamstring tendon of the ipsilateral leg before the remnants of the previous ACL graft fibers were débrided. The new graft was then surgically placed within the intercondylar notch and tested in all ranges of motion to ensure there was no impingement of the graft within the knee. The total surgery time for this autograft reconstruction was 90 minutes.
Secondary Rehabilitation

One week after surgery, the athlete was reported by her surgeon to be doing very well. She had some minor swelling and her range of motion was zero to $90^\circ$. Her sutures were removed at that time.

The surgeon explained to the athlete that an important point of the operation was that it appeared that the initial ACL had synovialized, that there was a distal rupture at the tibia and a longitudinal split, but that there were still some fibers intact. He asked her to proceed with rehabilitation cautiously; she was reminded that return to full activity would not resume until one year after surgery. Some range of motion stretches and exercises were encouraged at this time, as she would return to school the following day. Touch, or toe touch, weight bearing was allowed when she returned to school.

At three weeks postoperation, her range of motion had increased to $100^\circ$ of flexion and her Lachman test was absolutely negative. She was then allowed to begin partial weight bearing and light cycling on a stationary bike. She progressed from doing simple forward and backwards rotations while the bike was in the “off” position to cycling with a low resistance. She was able to deter significant quadriceps atrophy by performing these simple cycling exercises.

At her six-week postoperative examination, the surgeon was impressed with her recovery. Her swelling was almost nonexistent, her range of motion had increased to $130^\circ$ of knee flexion, and she continued her exercise program with the athletic training staff. The surgeon encouraged her to gradually continue strengthening her knee and to increase her range of motion.
Three months after surgery, the athlete had achieved full range of motion. She was cleared to begin to jog at that time. The surgeon again advised the athlete that he did not recommend that she return to play until the full 12 months had passed, if she decided to return at all, because he was still uncertain as to why the previous graft had failed. At six months, the surgeon had a follow-up phone conversation with the athlete and was impressed with her continued progress in her rehabilitation.

Approximately eight months after revision ACLR on August 28, 2009, the athlete was cleared to participate in sports by her surgeon, against his initial time constraint for her return to play. She was fitted for a personalized functional knee brace that inhibited tibial translation during activity that she wore during athletic participation. While she was cleared for sports, the athletic training staff slowly incorporated her into full sport-specific activity instead of allowing her to immediately participate in a full team practice. On October 1, 2009, with continued support from the surgeon, the athlete began unrestricted activity with the collegiate women’s basketball team.

Presentation of Findings

The athlete was able to successfully complete her entire basketball season after revision ACLR with autograft double-stranded semitendinosus tissue. The athlete aided the women’s basketball team in a winning season that lasted far into the post-season.
CHAPTER V

DISCUSSION

Restoration of the anatomy and function of the original ACL is the primary goal of ACLR. However, for the patient who is also a competitive high school or collegiate athlete, return to preinjury levels of activity may be the only goal that he or she may seek. Despite the numerous accounts of ACLR in current scientific literature, there is no clear consensus directed to the best practice of reconstruction (Duquin et al., 2009; Liden et al., 2007). It is important that all graft types are considered, costs and benefits are analyzed, and that open and frank communication is kept between the surgeon and the patient before a replacement graft is chosen. One type of graft should not be considered the gold standard in ACLR surgery, as there is no clear piece of evidence that validates the absolute superiority of one graft type the other for every reconstruction.

ACL reconstruction is the only choice for an athlete with an ACL deficient knee to be able to return to play at a preinjury level. While there are a variety of effective reconstructive techniques and graft choices, graft failure continues to remain a postoperative complication in the athletic population. Indeed, most allografts and autografts that substitute a deficient ACL are structurally and biomechanically different than the native ACL (Menetrey et al., 2008). Mechanisms for graft failure are multifactorial. Graft failure may be due to an error in surgical technique, in which an
incorrect tunnel placement may cause graft impingement, excessive graft tensioning, or incorrect graft fixation (Menetrey et al., 2008). This may have not necessarily have been the case with the athlete in the present case study, but it is interesting to note that the surgeon could not provide a clear explanation as to why the reconstructed graft had failed. Failure could also include mechanical or biomechanical factors that include insufficient graft strength, failure from trauma either from accidental reinjury or too aggressive rehabilitation, or as result of a complete lack of incorporation of the new tissue into the host knee (Menetrey et al., 2008).

More research must be done in regard to recurrent ACL injuries and subsequent revision ACLR. The risk factors that lead to recurrent ACL injury need to be studied more thoroughly and must be better defined. One study found that secondary ACL injuries occurred most often in athletes that participated in basketball, and 90% of all subsequent ACL injuries occurred in sports activities at the high school or collegiate level (Shelbourne et al., 2009). It is possible that the graft failure in this current study was also a part of multifactoral complications. Reports have found that failure rates of revision ACLR may be two to three times that of initial ACLR (Salmon et al., 2009). The fact that this athlete had undergone ACLR would have put her at a high risk for graft failure. Also, while the initial surgery was successful and the athlete’s rehabilitation was extensive, it is possible that the race to become a viable tissue was lost by the graft. Being a female athlete also came with inherent risks. Because there are so many factors that may contribute to graft failure for this athlete, it is important that steps are taken to ensure that there are beneficial preventative measures that can be implemented in the future. This particular athlete was able to return to play after her revision surgery; it is also
plausible that there are still risks of this athlete playing basketball. She may also be susceptible to degenerate knee diseases later on in life. This case should be reviewed by medical professionals not only to help evaluate what graft type would work best for athletes undergoing ACLR, but also to help encourage the education and administration of knee injury prevention.

Conclusion

The purpose of this study was to observe a female athlete going through rehabilitation of two separate ACLR on the same knee using two different grafts for reconstruction. In the case of the athlete in the present study, it is possible that once the native ACL was injured, the allograft was chosen the initial surgery due to the suggested speediness of rehabilitation and an early return to play. Unfortunately, whether it was due to a biological failure or a traumatic injury from the lay-up, the graft did not produce a successful outcome. It has been reported that the maturation process of allogenic tendons is slower than that of autologous tendons and has the possibility to lead to looseness or failure of the graft (Muramatsu et al., 2008). That possible postoperative complication could have been a factor in the subsequent failure of the first ACLR since allogenic tissue was used for reconstruction.

A revision surgery that utilized the athlete’s own viable tissue was successful in terms of incorporation of the graft itself and return to play to full competition for the athlete. It seemed that, for this athlete, the autograft double-stranded semitendinosus was the superior graft choice since she was able to return to a preinjury-level of activity without graft failure. The autograft was so successful that the surgeon who initially
prescribed a 12-month rehabilitation process cleared the athlete for participation approximately 8 months after her operation. It is difficult to determine if autogenic tissues were used for the first ACLR if it would have produced such positive outcomes as the second ACLR as graft failure could have been multifactoral complications. It is important to educate the athlete in the different graft types that are available for ACLR and for the surgeon to determine the best graft for the athlete’s specific return-to-play goals.

Limitations of the Study

This investigation was limited to observational measures instead of numerical and more objective data. It can be argued that obtaining data such as objective muscle atrophy measurements or laxity measurements with the use of a knee arthrometer would have strengthened the validity of this study. Also, all goniometric measurements were taken at the follow-up appointments and were not tracked by the athletic training staff or primary investigator during rehabilitation. However, the nature of the study was meant to expose the lack of current literature and to encourage more research and prevention education with regard to this specific injury.

Most research on ACLR revision surgery that has been carried out is limited by a weak design, low numbers of participants, heterogeneous populations, and a lack of concurrent control groups (George et al., 2006). Current revision ACLR findings can be difficult to interpret. Authors cite problems with interpretation that are due to a lack of fixation methods that are standardized by surgeons, differing surgical techniques, operative procedures that are concurrent with ACLR, and graft types (Salmon et al.,...
There are a number of studies that have explored revision ACLR; most were similar to this study in that they were case studies. Case studies in medical literature may be deemed inferior to other more objective studies such as the prospective cohort study that would take place over time with the researchers deciding which graft to use for reconstruction on athletes. However, prospective cohort studies on this topic are non-existent.

It appears that neither the allograft nor autograft is better than the other in every aspect of reconstruction. A prospective cohort study may be performed to help identify risk factors for graft failure; this would be another tool to aid researchers in understanding predisposing ACL risk factors (George et al., 2006). Every graft type, whether autograft or allograft, has its advantages and disadvantages. This overall lack of superiority should prohibit a general recommendation to be made for the surgical community regarding the use of one graft over another.

No randomized control trial has been conducted that directly compares allograft and autograft reconstruction (Tibor et al., 2010). Conducting such a trail for the general population versus the self-reported athletic population could help the medical community better understand if there is a certain graft type that would better suit a patient with an accelerated return-to-play. However, it must be noted that the logistics and ethics of carrying out such a study would make it prohibitive by implanting a graft into a human subject that would be known to cause less than ideal surgical and postoperative benefits. Only two meta-analyses comparing clinical and allograft results has been reported in current literature. One study within the meta-analysis produced inconclusive results and the other had significant methodological limitations (Tibor et al., 2010). While studies
examining ACLR and the results of ACLR using allograft and autograft issues abound in current literature, a limitation to this study is found in the lack of available research regarding revision ACLR in the athletic population. This includes a lack of randomized controls that compare the two most commonly used graft types. Had this kind of research been available, it is possible that a more appropriate graft choice may have been chosen for the athlete’s revision ACLR.

Future Directions

This case would benefit from a long-term follow-up study to determine if there were benefits or repercussions for the athlete after returning to play with the revision autograft ACLR in collegiate sports. The follow-up would be done at the conclusion of the athlete’s college career and once more at ten years after reconstruction, as is seen in some previous research. This would strengthen the evidence that would suggest that special consideration be taken when determining what tissue type to use for a young, competitive athlete. It would also help to set the stage for other athletes who happen to suffer from multiple ACL injuries.

Another future consideration would be to create an ACL preventative program that would specifically cater to female basketball players. This program would be presented to collegiate coaches and initially administered to the athletes by the athletic trainer. The coach would become educated in the risk factors of ACL injury and become familiar with proper body mechanics in order to help recognize when female athletes perform risky maneuvers. Intervention and prevention programs have been shown to limit the incidences of ACL injuries (Shultz et al., 2010). While the ideal prevention program
has yet to be defined, it seems that there is a reduction of knee injury regardless of the specific program formula.

More research on the prevention of ACL injuries is also necessary in the future. While more and more literature becomes available, there is still an overwhelming realization that there is more to learn about ACL injury, prevention, and rehabilitation. Rehabilitation specialists are still unsure of the exact mechanism that underlies the success of the prevention programs. It is understood that prevention is key, but how the duration of prevention training session and the timing of which still is not well defined. Also, defining what age to implement an ACL prevention program would potentially help reduce future ACL injury risk. There is much more that needs to be evaluated and researched so that the medical community can better understand and implement ways to prevent or at least lessen the risk of ACL injuries to athletes.

Currently, a prospective cohort study is being carried out to investigate the biomechanical and neuromuscular risk factors for ACL injuries. The Joint Undertaking to Monitor and Prevent ACL Injury (JUMP-ACL) will collect data from 5500 volunteers that will involve 3-dimensional motion analysis, strength, as well as postural alignment in the participants (Padua, 2010). This study will help to effectively analyze noncontact/indirect-contact ACL injuries and will place an increased importance on creating prevention programs since we may be able to determine the exact mechanisms of injury that may be preventable if proper strength, balance, and endurance training was put into effect.

More controlled research must be done in order to better understand what surgical procedure will most benefit an athlete looking to return to competitive sports.
Perhaps, for female basketball athletes, an early return to play is contraindicated to the overall health and outcome of the ACLR or revision ACLR. More research must be done, especially on revision ACLR for the female athlete. For instance, to date, there has not been a study performed that specifically examines the results of revision ACLR with the hamstring tendon graft and interference screw fixation (Salmon et al., 2009). It is apparent that more research must be done. If more case studies are published that illustrate a variety of outcomes or complications of ACLR, perhaps more research may be done to examine the results and effectiveness of such surgeries. This may help reduce the risk of ACL injury in the athletic population, create less of a burden on the health care system, and help maintain the health and well-being of athletes.
REFERENCES


