©Journal of Sports Science and Medicine (2002) **1**, 63-71
http://www.jssm.org

Review article

ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION: CLINICAL OUTCOMES OF PATELLA TENDON AND HAMSTRING TENDON GRAFTS

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Received: 1 May 2002 / Accepted: 09 July 2002 / Published (online): 1 September 2002

ABSTRACT
An injury to the ACL can result in significant functional impairment. It has been estimated that more than 100,000 new ACL injuries occur each year. Surgeons employ numerous techniques for reconstruction of the ACL. Of critical importance is the source of the graft to replace the damaged ACL. The graft choices include autografts (the patient's own tissue), allografts (donor tendon), and synthetic/prosthetic ligaments. Tissue harvest sites for autografting include the middle third of the patella tendon, the quadriceps tendon, semitendinosus tendon, gracilis tendon, iliotibial band, tensor fascia lata, and the Achilles tendon. Selection of the type of graft material is predicated upon the tissue's ability to tolerate high levels of stress. Likewise, the clinical presentation and functional outcome is related to the graft material selected. This manuscript specifically examined the patella tendon and hamstring tendon grafts. Numerous manuscripts that studied the outcomes of these graft materials were compiled to help the clinician appreciate the advantages and disadvantages of each of the graft materials. Outcome measures such as thigh circumference, knee range of motion, isokinetic strength, knee stability, pain, and vertical jump/1-leg hop were incorporated. The purpose of this manuscript was to compare and contrast the clinical presentation of patients who underwent an ACL reconstruction using the patella tendon versus the hamstring tendons. This information can be valuable to the clinician when considering the rehabilitation protocol after ACL reconstruction.

KEY WORDS: ACL, ligament reconstruction, functional outcome.

ÖN ÇAPRAZ BAĞ TAMİRİ: PATELLA VE HAMSTRING TENDON DOKULARIN KLİNİK SONUÇLARI

ÖZET
Bir ACL yaralanması önemli fonksiyonel kayıplar ile sonuçlanabilir. Her yıl 100 000'den fazla yeni ACL yaralanmaları olduğu tahmin edilmektedir. ACL tamiri için cerrahlar çeşitli teknikler kullanır. Hasarlanmış ACL yerine konacak dokunun kaynağı kritik önemdedir. Doku seçimleri sentetik/prosthetik, allograft (donör tendon) ve autograf (hastanın kendi dokusu) ligamanları içerir. Autograf için doku alınan yerler patellar tendonun orta 1/3'ü, kuadriseps tendonu, semitendinous tendonu, grasilis tendonu, iliotibial bant, tensor fasia lata ve Aşil tendonunu içerir. Doku materyalinin seçimi dokunun yüksek düzeyde stresi kaldırabilme gücü üzerinde belirlenmektedir. Ayrıca, klinik olarak tanınması ve fonksiyonel sonuç seçilen doku materyali ile ilişkilendirilir. Bu yazıda özellikle patella ve hamstring dokularını incelendi. Bu doku materyallerinin sonuçlarının incelendiği değişik yazılar klinisyenlerin doku materyallerinin her birinin avantaj ve dezavantajlarını anlamalarına yardım etmek için derlendi. Uyluk çevre ölçümü, diz hareket açıklığı, izokinetik kuvvet, diz stabilitesi, ağrı ve dikey sıçrama/1 bacak sıçrama gibi ölçüm sonuçları dahil edildi. Bu

yazının amacı patella ve hamstring tendonları kullanılan ACL tamiri yapılmış hastaların klinik sonuçlarını karşılaştırmakdı. Bu bilgiler ACL tamiri sonrası rehabilitasyon açısından klinisyenler için değerli olabilir.

ANAHTAR KELİMELER: ACL, ligaman tamiri, fonksiyonel sonuçlar.

INTRODUCTION

Physical therapists are frequently called upon to rehabilitate individuals who have undergone anterior cruciate ligament (ACL) reconstruction. To ensure optimal outcomes, it is important to understand the surgical options and techniques employed. The purpose of this manuscript is to provide an overview of the literature on ACL reconstructive surgery with an attempt to correlate surgical graft selection with functional outcomes. Finding limited information on this topic from a physical therapy perspective, we believe this would be a valuable contribution to the literature.

The ACL is an important component for normal kinematics of the knee joint. The primary function of the ACL is to restrain anterior translation of the tibia on the femur in open chain activities and perhaps more importantly, restrain posterior translation of the femur when the tibia is fixed, i.e. closed chain activity (Hiemstra et al., 2000). The mechanism of injury for an ACL tear is usually associated with a deceleration or a change of direction on the planted lower extremity i.e. pivoting (Bach and Boonos, 2001; Hiemstra et al., 2000). Factors that may contribute to injury of the ACL can be classified as intrinsic or extrinsic (Matava et al., 2002). Intrinsic factors include Q angle, femoral notch size, joint laxity, and hormonal influences (Barrett et al., 2002; Matava et al., 2002). Whereas, extrinsic factors include muscle strength, neuromuscular activation patterns of the hamstrings, and abnormal biomechanical forces (Barrett et al., 2002; Matava et al., 2002).

ACL RECONSTRUCTION

The ACL is the most commonly reconstructed ligament of the knee (Bach and Boonos, 2001). It has been estimated that more than 100,000 new ACL injuries occur each year (Bach and Boonos, 2001). An injury to the ACL can result in significant functional impairment (Lephart et al., 1993). Although reconstruction of the acutely torn ACL (<3 weeks after injury) has fallen out of favor (Ramsdell and Tietjen, 1994; Saperstein and Hershman, 1994; Shaieb et al., 2002), failure to reconstruct the ligament at all can lead to recurrent bouts of instability, damage to the meniscus and articular cartilage, and may accelerate the progression of osteoarthritis for the active individual (Brown and Sklar, 1998; Corry et al., 1999; Delay et al., 2001; Lephart et al., 1993). Diagnostic tests used to confirm trauma to the ACL include the Lachman test (Bach and Boonos, 2001; Barrett et al., 2002; Bartolozzi, 1993; Corry et al., 1999; Eriksson et al., 2001), the prone Lachman test (Norkus et al., 2002), the pivot shift test (Bach and Boonos, 2001; Barrett et al., 2002; Bartolozzi, 1993; Corry et al., 1999), and the KT1000/2000 arthrometer (Aglietti et al., 1994; Anderson et al., 2001; Bach and Boonos, 2001; Barrett et al., 2002; Corry et al., 1999; Feller et al., 2001, Ferrari et al., 2001). Magnetic Resonance Imaging (MRI) is also used because it provides the fine soft tissue detail necessary for a definitive diagnosis (Bartolozzi, 1993).

Once damage to the ACL has been confirmed, indications for the reconstruction of the ACL include (Bach and Boonos, 2001; Bartolozzi, 1993; Francis et al., 2001):

- the high performance athlete;
- the young/healthy active individual;
- the individual involved in sports that require pivoting and jumping;
- the individual involved in recreational activities > 5 hours/week;
- the individual with 3 or more episodes of instability per year;
- the individual with an arthrometer assessment of 5mm more displacement than the uninvolved knee;
- the individual that failed a conservative rehabilitation program.

In contrast, the predictors of a less than optimal surgical outcome may include (Bartolozzi, 1993):

- sedentary lifestyle;
- obesity;
- open growth plates;
- degenerative joint disease;
- coexisting medial meniscus tear;
- failure to comply with pre-operative rehabilitation.

Surgeons employ numerous techniques for reconstruction of the ACL (Aune et al., 2001; Bach and Boonos, 2001; Bartolozzi, 1993; Brown and Sklar, 1998; Carter and Edinger, 1999; Corry et al., 1999; Keays et al., 2001; Ramsdell and Tietjen, 1994; Shaieb et al., 2002; Yunes et al., 2001). Of critical importance is the source of the graft to replace the damaged ACL. The graft choices include autografts (the patient's own tissue), allografts (donor tendon), and synthetic/prosthetic ligaments. Tissue harvest sites for autografting include the middle third of the patella tendon, the quadriceps tendon, semitendinosus tendon, gracilis tendon, iliotibial band, tensor fascia lata, and the Achilles tendon. Despite the publication of numerous manuscripts, there is not consensus in the literature on the optimal choice for the graft source (Anderson et al., 2001; Brown and Sklar, 1998; Delay et al., 2001; Francis et al., 2001; Keays et al., 2001; Lephart et al., 1993). However, the most common choices for ACL replacement are the patella tendon or double-stranded hamstring tendons (Aglietti et al., 1994; Anderson et al., 2001; Aune et al., 2001; Shaieb et al., 2002). Another confounding factor is the surgical technique chosen. Many surgeons perform the reconstruction procedure via arthroscopy, while others prefer an open arthrotomy (Anderson et al., 2001; Bach and Boonos, 2001; Bartolozzi, 1993; Corry et al., 1999; Eriksson et al., 2001). Regardless of the technique, the goal of ACL reconstructive surgery is to eliminate the pivot shift phenomenon (the anterior subluxation of the tibia), restore normal knee kinematics, regain as much pain-free movement as possible, and resume optimal function (Lephart et al., 1993; Mologne and Friedman, 2000).

There are several critical factors that must be considered when deciding on the most appropriate type of graft to utilize. The ideal graft selection should match the strength and stiffness of the ACL as closely as possible (Lephart et al., 1993; Mologne and Friedman, 2000; Saperstein and Hershman, 1994). Immediate rigid fixation, rapid ligamentization, and healing of the graft fixation sites are optimal (Brown and Sklar, 1998). The graft should also be accessible for harvesting to minimize damage or weakness of a patient's tissue (Brown and Sklar, 1998; Mologne and Friedman, 2000). In reality, there is currently no single graft source that meets all of these criteria (Mologne and Friedman, 2000).

The ACL is a complex structure that attaches to the posterolateral aspect of the intercondylar notch and the anteromedial aspect of the central tibial eminence (Mologne and Friedman, 2000). The length of the ACL is 31-38mm and the width is 11mm, on average (Mologne and Friedman, 2000). Most authors believe that the anteromedial and posterolateral bundles tighten in flexion and extension, respectively (Mologne and Friedman, 2000). The tensile strength of the ACL has been reported to range from 1725 to 2195 N (Mologne and Friedman, 2000; Saperstein and Hershman, 1994). Tensile strength is defined as the force the tissue can tolerate before failure (Brown and Sklar, 1998). Stiffness has been reported to range from 242 to 306 $N.mm^{-1}$ and represents the rigidity of the tissue (Brown and Sklar, 1998; Mologne and Friedman, 2000). During normal daily activities, forces have been reported as high as 823 N for a 70kg person to descend a ramp (Mologne and Friedman, 2000). Forces produced during athletic activities could be considerably higher. An additional consideration is that the post-operative ACL load may even exceed the normal knee forces. This may be due to a loss of muscular control and/or a less than optimal anatomic graft placement (Saperstein and Hershman, 1994).

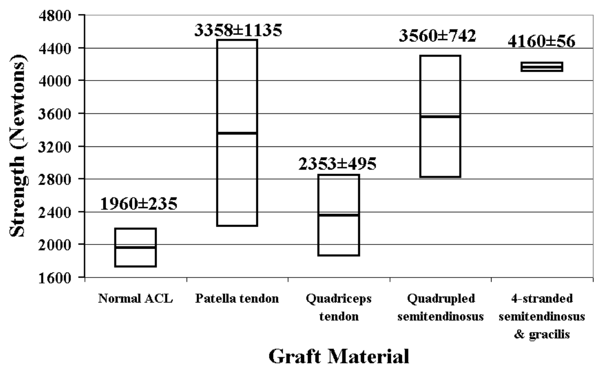

Figure 1. Mean strength of graft materials compared to the normal Anterior Cruciate Ligament (ACL).

Selection of the type of graft material is predicated upon the tissues ability to tolerate these high levels of stress. Various authors have reported the patella tendon graft to be 138 - 170% stronger and 125% stiffer than the original ACL (Brown and Sklar, 1998; Mologne and Friedman, 2000; Noyes et al., 1984; Noyes et al., 1983). The semitendinosus/gracilis combination is said to be 200% stronger and 300% stiffer than the original ACL (Brown and Sklar, 1998; Mologne and Friedman, 2000). Figures 1 and 2 provide a graphical representation of the strength and stiffness of materials used to replace a damaged ACL. These are the mean values of the tissue based upon a comprehensive review of the literature (Brown and Sklar, 1998; Butler et al., 1985; Corry et al., 1999; Grana and Hines, 1992; Hecker et al., 1997; Mologne and Friedman, 2000; Noyes et al., 1983; Noyes et al, 1984; Woo et al, 1991). The high initial tensile strength and stiffness and the rigid bone-to-bone fixation techniques have made the patella tendon a desirable choice for ACL replacement (Brown and Sklar, 1998). Whereas, the single-stranded hamstring tendon grafts have been found to be inferior in strength and stiffness to the normal ACL (Brown and Sklar, 1998). Thus, 4-stranded hamstring grafts (double-stranded gracilis and semitendinosus) with greater strength and stiffness have been an accepted alternative (Noyes et al., 1984). However, caution should be taken not to adopt the philosophy that more is always better. If a graft is too stiff, a patient may be overconstrained. This can result in difficulty obtaining full range of motion and may contribute to patellofemoral pain (Sachs et al., 1989; Shaieb et al., 2002).

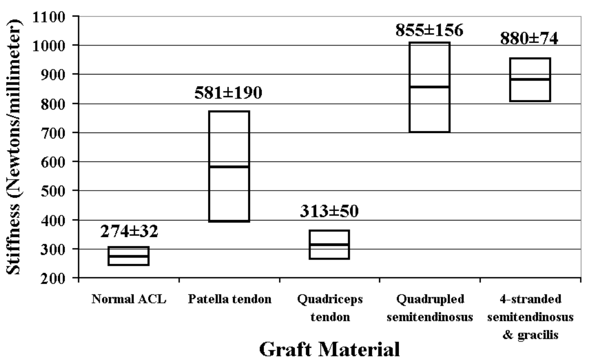

Figure 2. Mean stiffness of graft materials compared to the normal Anterior Cruciate Ligament (ACL).

FUNCTIONAL OUTCOMES

Strength and stiffness of the graft are important components. However, functional outcomes are what determine the success or failure of the surgical intervention (Hiemstra et al., 2000). The following data represents the use of a variety of assessment tools to determine functional outcomes. Data from over 40 studies (1983 - 2002) were reviewed for the two most commonly used graft materials: the patellar tendon and the hamstring tendons.

Patella tendon grafts:

For patella tendon grafts, numerous studies have looked at various aspects of recovery (Aglietti et al., 1994; Anderson et al., 2001; Aune et al., 2001; Barrett et al., 2002; Bartlett et al., 2001; Carter and Edinger, 1999; Corry et al., 1999; Eriksson et al., 2001; Feller et al., 2001; Hiemstra et al., 2000; Lephart et al., 1993; Osternig et al., 1996; Peterson et al., 2001; Shaieb et al., 2002; Witvrouw et al., 2001). Thigh circumference, knee range of motion (ROM), isokinetic strength, knee stability, pain, and vertical jump/1-leg hop are among the components addressed. Previous research has reported a positive correlation between knee extension strength and functional outcomes (Hiemstra et al., 2000). Although the use of the patella tendon for the graft tissue has been reported to result in greater initial atrophy of the quadriceps muscle, there was no significant difference in thigh circumference in any of the studies reviewed (Corry et al., 1999; Eriksson et al., 2001; Feller et al., 2001; Shaieb et al., 2002; Witvrouw et al., 2001). Only two studies (Aglietti et al., 1994; Shaieb et al., 2002), reported a significant loss of ROM. Aglietti et al. (1994) found that 47% of the patella tendon graft patients had a 1-3° knee extension loss at 28 months post-operatively. Shaieb et al. (2002) found that 52% of the patella tendon grafts, versus 27% of the hamstring tendon grafts, had a loss of knee flexion. The average loss of the patella tendon graft group was 3.4°. The lack of full knee extension can compromise knee stability during functional activities. Even the slightest of knee flexion contractures will result in a flexion moment at the knee during weightbearing. This will require the quadriceps muscle to contract to maintain extension even when the line of gravity falls anterior to the knee joint line. The quadriceps muscle is known to contribute to anterior translation of the tibia (relative to the femur) and tension the ACL (O'Connor, 1993; Osternig et al., 1996).

Isokinetic testing has focused primarily on concentric quadriceps and hamstring strength. Both low and high concentric velocities were examined but there is a notable absence of eccentric data. Patients with patella tendon grafts demonstrated quadriceps deficits that ranged from 15-41% of the uninvolved lower extremity (Aune et al., 2001; Bartlett et al., 2001; Feller et al., 2001; Hiemstra et al., 2000; Keays et al., 2001; Natri et al., 1996; Sachs et al., 1989; Wilk et al., 1994; Witvrouw et al., 2001). Quadriceps deficits tended to be greater at the lower end of the velocity spectrum (Shelbourne and Nitz, 1990; Witvrouw et al., 2001). Whereas, a 2-10% hamstring deficit was reported at six and twelve months post-operatively by Witvrouw et al. (2001). Clinicians have argued that open chain isokinetic testing is not a functional activity. However, Wilk et al. (1994) found a statistically significant positive correlation between isokinetic knee extension strength at 180 and 300°.s^{-1} and the hop-for-time and distance test and the cross-over triple hop test. No such correlation has been identified with the hamstrings. However, Osternig et al. (1996) examined eccentric knee flexion torque at least one year after arthroscopic ACL reconstruction with the patellar tendon. The post-surgical limb was found to produce significantly less (13%) eccentric knee flexion torque than the uninjured knee at $60°.s^{-1}$. EMG activity revealed that the gastrocnemius muscle exhibited a significant reduction in the reconstructed knee. Prior research by Osternig et al. (1995) reported significant decreases in eccentric hamstring EMG activity as the velocity of movement increased from 100 to $300°.s^{-1}$. Thus, the ability to restrain knee extensor torque may be velocity dependent. O'Connor (1993) recognized the importance of the capacity of the hamstrings and gastrocnemius to counter the forceful extensor torque and unload the cruciate ligaments. As for knee joint stability, two (Anderson et al., 2001; Witvrouw et al., 2001) of the five (Aglietti et al., 1994; Anderson et al., 2001; Bach and Boonos, 2001; Eriksson et al., 2001; Witvrouw et al., 2001) studies reported better joint stability with patella tendon grafts then hamstring grafts as measured with an arthrometer from 26 weeks to more than two years post-operatively. On average, the side-to-side differences in anterior translation of the tibia was 0.9 to 1.2 mm greater for the hamstring tendon groups (Anderson et al., 2001; Witvrouw et al., 2001).

Pain was often related to function and was measured with a variety of tools. The Lysholm Knee Score (ICC = 0.90), the Tegner Activity Scale (ICC = 0.97), the Kujala Test, the International Knee Documentation Committee (IKDC) Scale (ICC = 0.99), and the Cincinnati Sports Activity Score were used as outcome measures (AOSSM, 2002; Aune et al., 2001; Bach and Boonos, 2001; Barrett et al., 2002; Corry et al., 1999; Eriksson et al., 2001; Feller et al., 2001; Tegner and Lysholm, 1985; Witvrouw et al., 2001). These assessment tools evaluated symptoms/activities such as numbness, locking, stair climbing, squatting, and patella-femoral crepitis, to name a few. Seven studies (Aune et al., 2001; Bach and Boonos, 2001; Bartlett et al., 2001; Corry et al., 1999; Feller et al., 2001; Kartus et al., 1997; Shaieb et al., 2002) reported a significantly higher incidence of anterior knee pain or pain with kneeling among the patella tendon graft recipients. This symptom was reported to be problematic from 4 – 24 months post-reconstruction by various authors (Aune et al., 2001; Bartlett et al., 2001; Corry et al., 1999; Feller et al., 2001; Kartus et al., 1997; Shaieb et al., 2002). Sensitivity of the operative area may contribute to the discomfort of kneeling (Aune et al., 2001) but it has been theorized that the anterior knee discomfort is related to the donor graft site at the inferior pole of the patella. Yet serial MRI studies by Avery (2002) at the Orthopedic Associates of Portland found that within 3 - 4 months after the tissue harvest, the patella tendon regenerates. In fact, it initially overgrows into a thicker tissue that then undergoes remodeling to a more normal contour by 12 - 18 months. Aglietti et al. (1994) used the percentage of patients who returned to agility sports 28 months post-operatively as the measure of success. In this study, 80% of the patella tendon grafts versus 43% of the hamstring tendon graft patients returned to this high level of function. In a meta-analysis of ACL reconstruction techniques, Yunes et al. (2001) reported that patients reconstructed with patellar tendon grafts have an 18% greater chance of returning to their pre-injury level of activity than their hamstring tendon counterparts.

Hamstring tendon grafts:

When addressing the use of hamstring tendon(s) for the replacement of the ACL, the variations in the surgical protocols must be acknowledged. Although autografting of the gracilis or semitendinosus alone are performed (Carter and Edinger, 1999; Hiemstra et al., 2000), the technique of coupling/doubling the semitendinosus and gracilis tendons is a more commonly published procedure (Aglietti et al., 1994; Anderson et al., 2001; Aune et al., 2001; Barrett et al., 2002; Carter and Edinger, 1999; Corry et al., 1999; Feller et al., 2001; Hiemstra et al., 2000; Keays et al., 2001; Witvrouw et al., 2001). Once again, thigh circumference, knee ROM, isokinetic strength, knee stability, pain and vertical jump/1-leg hop were the outcome measures examined.

There was no significant difference in thigh circumference or knee ROM in any of the studies reviewed (Aglietti et al., 1994; Anderson et al., 2001; Barrett et al., 2002; Carter and Edinger, 1999; Corry et al., 1999; Eriksson et al., 2001; Feller et al., 2001; Hiemstra et al., 2000; Witvrouw et al., 2001). However, isokinetic strength deficits were found. Again, the paucity of data regarding eccentric force production is striking. Hiemstra et al. (2000) mapped both concentric and eccentric strength of the knee flexors and extensors across the velocity spectrum (50 to $250°.s^{-1}$). The authors identified eccentric knee flexion deficits at high velocities for the hamstring graft group. These deficits were most notable through the 60 to 95° arc of knee motion. This is consistent with the work of Coombs and Cochrane (2001) who reported an eccentric hamstring deficit (18% average) at 60, 120, and $180°.s^{-1}$ across patents reconstructed three, six, and twelve months prior. The significance of the hamstrings as dynamic stabilizers of the knee has been eluded to earlier. One might relate the presence of flexor deficits to the tissue harvest site but the recent work of Cross et al. (2002) revealed that the semitendinosus and gracilis tendons did, in fact, regenerate. The regrowth from the distal cut of the muscle belly was found to be attached to the medial popliteal fascia (not the usual site). Palpation, MRI, and EMG confirmed this regrowth. Thus, 6-months post-operatively, the hamstrings were deemed functionally intact (Cross et al., 2002). So it is puzzling that in follow-up studies 30 months post-operatively, to find that significant strength deficits persist (Coombs and Cochrane, 2001; Hiemstra et al., 2000). To make matters worse, it has been suggested that the deficits may even be an underestimation when the contralateral limb is used for comparison. Given a period of reduced activity due to the ACL injury, the contralateral limb may be subjected to a deconditioning effect, thereby lowering the baseline values.

With respect to knee stability, three individual studies (Anderson et al., 2001; Feller et al., 2001; Witvrouw et al., 2001) and the meta-analysis by Yunes et al. (2001) reported that the hamstring graft groups demonstrated greater laxity when compared to the patellar tendon groups. All studies used the KT1000 to assess laxity. Feller et al. (2001) found the laxity at four months status post ACL replacement. Mean anterior tibial displacement for the hamstring group was 1.2 ± 1.1 mm versus 0.5 ± 1.1 mm for the patella tendon group at 67N. This was consistent with the results of Witvrouw et al. (2001) who found laxity at 67N in a hamstring graft group as compared to a patellar tendon group at six weeks (1.4 vs. 0.5 mm), three months (1.6 vs. 0.6 mm), and six months (2.1 vs. 0.9 mm) but no significant difference existed one year after surgery (1.4 vs. 1.1 mm). Other researchers (Anderson et al., 2001; Corry et al., 1999) found more laxity in the hamstring graft group 24-months after surgery than in the patella tendon group. Yunes et al. (2001) reported that the hamstring grafts were 12.5 and 13% more likely than the patella tendon graft to display ligamentous laxity greater than 3 mm with 20 pounds and maximal force, respectively. Similar reports were reported for the pivot shift test (Yunes et al., 2001). Although not statistically significant, Shaieb et al. (2002) reported that 55% of the hamstring tendon group (compared to 21% of the patella tendon group) had three or more millimeters of anterior displacement with a KT1000 at the two-year follow-up examination. Avery (2002) has suggested that hamstring tendon grafts may be subjected to a bit of laxity due to the "bungee cord" effect. He indicated that the sutures used to fixate the hamstring tendon at each end of the graft might add length and elasticity. Recent improvements in the fixation technique may be instrumental in maintaining graft stiffness.

Reports of pain and function are variable across the studies reviewed (Aglietti et al., 1994; Barrett et al., 2002; Corry et al., 1999; Feller et al., 2001; Hiemstra et al., 2000; Witvrouw et al., 2001). In some instances, the hamstring graft patients had a higher self-reported level of function via the IKDC (Feller et al., 2001; Hiemstra et al., 2000). Whereas, another study (Barrett et al., 2002) found that the hamstring group did not return to the prior level of function. While the patellar tendon graft group surpassed their pre-injury activity level (Barrett et al., 2002).

CLINICAL IMPLICATIONS

It is beyond the scope of this manuscript and the authors' expertise to elaborate on graft fixation techniques. Suffice it to say that in the early phases of rehabilitation, the strength and stiffness of the fixation is as important as the graft site itself (Mologne and Friedman, 2000). However, after 8-12 weeks when biological healing is complete, the fixation method is of lesser importance. With new modifications in fixation techniques such as bioresorbable screws impregnated with hydroxyapetite and the closed loop Endobutton, functional outcomes may improve. To date, when comparing the various types of graft selections with regard to the functional outcome, the primary factors that have surfaced from the literature are the graft harvest site, the knee joint stability, isokinetic force production, and anterior knee pain. Because of strength deficits and anterior knee pain, Bartlett et al. (2001) has suggested considering the activity or occupation of the ACL reconstructed individual. Sports such as gymnastics and wrestling that require hamstring strength, as well as sports like football and sprinting that experience frequent hamstring injuries may opt for patellar tendon reconstruction. Whereas, occupations such as carpet layers and tilers that require sustained kneeling, as well as basketball and tennis players that rely on the extensor mechanism of the knee may opt for a hamstring tendon graft.

However, little work has been done in the area of eccentric muscle activity (Coombs and Cochrane, 2001; Hiemstra et al., 2000; Osternig et al., 1996). We have all read numerous articles about the quadriceps to hamstring ratios using both the concentric and eccentric modes. However, for proper dynamic knee stabilization, the ratio of interest may be the force couple of concentric quadriceps to eccentric hamstrings. This concept was briefly mentioned by Osternig et al. (1996). The eccentric activity of the hamstrings may be very important in checking the anterior translation of the tibia. Thus eccentric knee flexors can provide dynamic knee stabilization. Furthermore, hamstring activation patterns have been reported to be different between the genders (Matava et al., 2002). It has been suggested that women may be more dependent on the hamstring musculature for proprioceptive feedback than males (Ferrari et al., 2001). With this information in mind, the examination of eccentric hamstring force may be important for both genders, but for females it may be even more important. What has become increasingly clearer to the authors is the need for much more aggressive rehabilitation strategies. Neither concentric nor eccentric strength deficits should exist at 12-months post-operatively. If ACL-reconstructed individuals are permitted to return to recreational and competitive athletics 6-months after surgery, then more attention needs to be given to eccentric rehabilitation techniques. Aune et al. (2001) suggested that aggressive strengthening programs for the knee flexors continue even after the resumption of athletic activities.

In conclusion, the purpose of this manuscript was to provide the clinician with an impression of how each of the graft site patients would present. Through this comprehensive review of the literature, the reader should understand the strengths and weaknesses of each procedure. In addition, we hope that this manuscript will prompt clinicians to explore the dynamic force ratio of concentric quadriceps to eccentric hamstrings to continue our quest to maximize functional outcomes with our patients.

ACKNOWLEDGMENTS

The authors would like to thank Paula Geigle, PhD, PT, Jack Waters, Jr., MSPT, ATC, CSCS, and Chris Wise, PT, MTC, OCS, ATC for their input into the development of this manuscript.

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