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Review Article

Anterior Cruciate Ligament Reconstruction with Quadriceps Tendon Autograft: A Comprehensive Review

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Abstract

Traditionally, first-line graft options for ACL reconstruction have been Bone-Patellar Tendon-Bone (BPTB) and Hamstring Tendon (HT) autografts. However, over the past two decades a growing body of literature has demonstrated Quadriceps Tendon (QT) autografts are an excellent option in comparison to the BPTB and HT autografts. Biomechanical data has shown QT autografts offer excellent load to failure, and clinical outcome studies have shown a low rate of postoperative complications. This paper aims to provide a comprehensive literature review on the use of QT autograft in ACL reconstruction.

Introduction

In the United States alone, there are approximately 200,000 Anterior Cruciate Ligament (ACL) ruptures each year with the majority of these occurring in high-school and college-age athletes [1]. Due to the relatively high activity level of the individuals sustaining ACL injuries, operative management is frequently recommended making ACL reconstruction one of the top 10 most common orthopedic procedures performed [2]. Females are more likely to sustain these injuries, as female athletes competing in basketball and soccer across all age groups are two to eight times more likely to suffer an ACL injury compared to males. Furthermore, data from the National Collegiate Athletic Association (NCAA) shows the rate of ACL injury per athletic exposure was found to be most common in female athletes competing in gymnastics, basketball, and soccer [3]. There are multiple risk factors which predispose female athletes to sustain an ACL injury. Anatomical risk factors such as smaller ligament size, increased knee laxity, and increased Body Mass Index (BMI) all increase the risk of an ACL injury. In addition to these anatomic risk factors, differences in neuromuscular control between males and females show that females have a higher quadriceps-to-hamstring ratio and are more likely to have an increased valgus moment of the knee upon landing, placing them at higher risk for injury. Sex hormones such as estrogen and relaxin, which affect collagen cross-linking, have also been shown to be at increased levels at the time of ACL injuries [3].

In the current literature, the most frequently used techniques of ACL reconstruction involve using either Bone-Patellar Tendon-Bone (BPTB) autograft, quadruple Hamstring Tendon (HT) autograft, or Quadriceps Tendon (QT) autograft. Traditionally, BPTB autograft has been the gold standard graft selected with HT autograft becoming more common, therefore studies involving ACL reconstruction with QT autograft are limited compared to the BPTB and HT autograft methods. This paper will investigate the literature involving the biomechanics and outcomes of QT autografts compared to BPTB and HT autografts for ACL reconstruction.

Historical Perspective: ACL Reconstruction

The treatment of ACL ruptures has evolved greatly over the past 50 years. In the 1960s, the main way to clinically diagnose an ACL rupture was the anterior drawer test at 90 degrees of flexion with various degrees of internal and external rotation of the tibia which led to positive tests predominantly when menisci or capsulo-ligamentous damage was involved. As a result, the goal of treatment was to restore adequate tension to the medial capsuloligamentous structures, rather than restoring the ACL itself, which was followed by cast immobilization. The benefits from this treatment were mainly derived from the stiffness of the knee causing reduced instability. Later in the 1970s as journal publications became more widespread, the diagnosis of ACL ruptures became more common as physical exam maneuvers such as the Pivot shift and Lachman test allowed surgeons to more accurately diagnose ACL ruptures.

At that time, various techniques involving anterolateral tenodesis using the fascia lata were commonly used followed by cast immobilization. Though initial results were promising, the long-term outcomes of these patients were poor, and surgeons began to direct their attention toward reconstructing the ACL [4]. Attempts such as the Marshall-MacIntosh technique became more popular in the late 1970s and was aimed at reconstructing the ACL. Using this technique, a continuous strip of patellar tendon, pre-patellar fascia, and a tubularized strip of quadriceps tendon was used. This was then passed through a tibial tunnel and then fixed to the femur and a synthetic ligament was added to the pre-patellar aspect to support the repair. During this same time period, attention was turned towards using a free patellar tendon graft and by the 1980s, harvesting the middle third of the patellar tendon and using it as a free graft secured by interference screws became the gold standard. As this technique became more reliable, the anterolateral tenodesis techniques became less necessary and decreased in popularity. Due to difficulties with passage of the bone block portion of the patellar tendon graft and concerns over patellar fracture, surgeons began looking toward the quadriceps and hamstrings as a replacement for the patellar tendon. The quadriceps tendon graft was first presented in 1979 by Marshall, et al. and the first publication discussing a hamstring graft for ACL reconstruction was by Lipscomb in 1982 [4]. A biomechanical analysis of the quadriceps tendon by Noyes, et al. in 1984 demonstrated that the quadriceps tendon had 14-21% of the load to failure of a native ACL [2]. Though the graft used in this analysis was a suboptimal graft composed of partial thickness quadriceps tendon, patellar tendon, and prepatellar tissue, the results of this study caused the QT autografts to fall out of favor among surgeons for primary ACL reconstructions [2]. As more studies on the quadriceps tendon have been performed, the traditional idea of the QT graft being biomechanically weaker as diminished, and it has been steadily gaining popularity [2].

ACL Reconstruction versus ACL Repair

The conventional surgical management of the ACL tear is ACL reconstruction. Traditionally, primary repair of the ACL has had poor outcomes due to synovial fluid creating a suboptimal biological healing environment in addition to frequent stresses placed on the repair during knee movement preventing adequate fibrin-platelet scaffolding for healing leading to re-rupture [5]. Techniques for ACL repair include direct repair, internal bracing with ligament augmentation, bridge-enhanced ACL repair, and dynamic intraligamentary stabilization [6]. A systematic review of primary repairs of the ACL showed only 41% with final KT-1000 measurements of less than 3 mm difference compared to contralateral side [7]. A study of 28 patients undergoing ACL repair with the internal brace with augmentation showed a failure rate at 15%, while a study of 59 patients undergoing repair with the dynamic intraligamentary stabilization had a failure rate of 17.5% [6,8]. By comparison, 76.3% of patients undergoing ACL reconstruction with the QT autograft had KT-1000 measurements of less than 3 mm difference compared to their contralateral side and had a graft failure rate of 2.1%, showing a more consistently superior result compared to ACL repair [9].

Comparison of Graft Properties

Although the historical gold standard graft was BPTB autograft, this still remains a controversial topic as the use of other graft options have increased. The QT autograft was once thought to be biomechanically inferior to the BPTB autograft due to a study showing that it had a maximum load to failure of 14-21% of the native ACL, though as previously discussed, this study used a suboptimal graft leading to poorer outcomes. More contemporary studies show a maximum load to failure of the quadriceps tendon graft to be closer to 2200 N with a stiffness of 466 N/mm [10]. In comparison, the average ultimate load to failure of the native ACL has been determined to be 1725 ± 269 N [11]. A study by Stäubli, et al. showed that a 10 mm wide quadriceps tendon graft had a cross-sectional area of 64.6 mm^2, which is nearly double that of a BPTB graft of the same width (Figures 1,2).

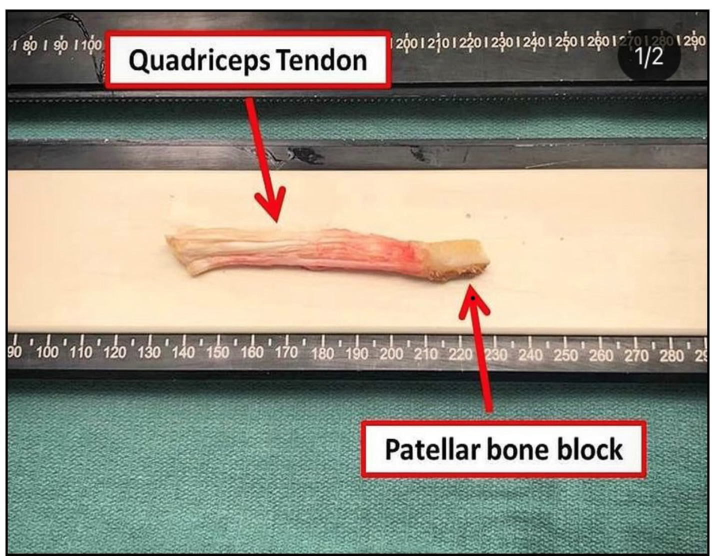

Figure 1: Quadriceps Tendon Bone Autograft after Graft Harvest.

Figure 2: Quadriceps Tendon Bone Graft Preparation for ACL Reconstruction.

This increased cross-sectional area is preferred in order to reduce the likelihood of windshield wiper effects as well as tunnel-graft mismatch [12]. Harris et al showed the load to failure was 1.36 times that of a comparable-width patellar tendon graft [13]. The optimal graft harvest dimension of BPTB autografts is 10 mm to maximize the graft strength while reducing the risk of patella fracture. Biomechanical studies show that BPTB grafts that are 10 mm wide have an ultimate load to failure of 2977 N in a young individual [14]. Ultimate load to failure of these grafts decreases as patients age [15]. A study of cadavers shows that BPTB grafts of a 41.5-year-old have an average maximum load to failure of 1580 N [10], while the BPTB graft of a 28-year-old has a load to failure of 2977 [14].

The standard hamstring tendon harvest involves either doubling the harvested semitendinosus and gracilis tendons or if only harvesting semitendinosus, quadrupling the semitendinosus. When quadrupled, the final graft diameter should have a final diameter of at least 8 mm, resulting in a maximum load to failure of 4590 N [16]. Studies show increased rates of graft failures with graft diameters less than 8 mm [17].

Patient History, Physical Examination, & Imaging

Similar to many other orthopedic injuries, the history and physical examination play a key role in directing the physician toward the correct diagnosis. Mechanism of injury frequently involves a decelerating, landing, or cutting movement combined with a valgus load to the knee. Patients will often describe a mechanism of injury involving an acceleration/deceleration and hearing a pop followed by difficulty weight bearing and knee swelling with an aspiration showing a large hemarthrosis. This hemarthrosis often develops within a few hours after an ACL injury and makes physical examination difficult due to pain and muscle guarding [1,11]. There are multiple physical examination tests that can aid with diagnosis of an ACL injury. The Lachman test is an accurate test for both acute and chronic ACL ruptures with a sensitivity of 85% and specificity of 94%. The Pivot shift test is a useful examination with a high specificity of 98%, however it has a low sensitivity at 32% for acute tears, therefore cannot be used solely to rule out an ACL tear. The anterior drawer test is perhaps the most recognizable of all ACL physical examination tests and is useful in chronic ACL ruptures, however it is an unreliable test in acute ACL ruptures with a sensitivity and specificity of 49% and 58% respectively. In chronic ACL ruptures, the sensitivity and specificity increase to 92% and 91% respectively and can be a useful tool [18]. Though the diagnosis of an ACL rupture can many times be made based on history and physical exam, imaging studies are commonly obtained to help confirm a diagnosis and also provide more information regarding concomitant injuries, such as meniscal tears. Plain radiographs are often normal, though occasionally an avulsion fracture of the proximal lateral tibia (Second fracture) can be seen which is pathognomonic for an ACL tear. An MRI is the gold standard imaging study to confirm an ACL rupture with accuracy rates as high as 95-100% [11].

Pre-operative Considerations

Not all patients who sustain ACL tears necessarily require surgical intervention. Surgical intervention is generally best suited for athletes, individuals under the age of forty or individuals over the age of forty who are highly active. Though young patients and athletes can certainly do well without surgical intervention, gait biomechanics in those who are treated with nonoperative rehabilitation show higher contact forces in the medial compartment when measured five years after injury compared to those who are treated surgically [19]. This change in loading of the knee joint raises the concern for increased rates of future development of osteoarthritis compared to those who undergo ACL reconstruction. Patients should be counseled that 50% of individuals sustaining ACL injuries develop osteoarthritis in the injured knee within 10 to 20 years after injury [19]. Patients who spend a substantial amount of time kneeling would benefit from QT autograft instead of BPTB autograft as there would be less donor site pain. Of those patients who pursue ACL reconstruction, QT autograft is only contraindicated in those with a history of prior quadriceps rupture and chronic quadriceps tendinopathy [20]. Multiple studies now show that pre-operative rehabilitation leads to better long-term outcomes in those who undergo ACL reconstruction [21]. Pre-operative rehabilitation specifically focuses passive knee extension range-of-motion and quadriceps strengthening using neuromuscular training and muscle strength training in order to improve post-operative outcomes [1]. Individuals participating in pre-operative rehabilitation experience higher Knee injury and Osteoarthritis Outcome Score (KOOS) and Return-To-Sport (RTS) rates 2 years after injury [22].

Complications

The most common complication of QT autograft is donor site pain, with 6.1% of patients reporting anterior knee pain. The rate of graft rupture for patients undergoing QT autograft is roughly 2.1% [9]. It is important to note that when compared to studies involving HT autograft and BPTB autograft there was no significant difference in these rates of re-rupture [9]. In addition to potential complications such as donor site pain and risk of re-rupture, patients should also be informed of peri-incisional numbness as well as quadriceps strength deficits. Compared to their non-operative leg, the patients' operative leg would have an 11.6% decrease in peak torque and 18.4% decrease in isometric average torque, though this is similar to the results found in BPTB autograft patients [20]. Risk of infection after undergoing a QT autograft is extremely low. Infection rates across all types of ACL reconstruction is 0.6%, with allografts having a higher likelihood of infection compared to autografts (odds ratio, 6.8) [23].

Clinical Outcomes

A meta-analysis conducted by Mouarbes, et al. [9] examined 2166 QT autografts used in ACL reconstruction. In their analysis, a Lachman test grade 0 was found in 81.2 % of 926 patients and a grade 0 Pivot shift in 84.8% of 918 patients who underwent QT autograft. A weighted mean side-to-side difference in anterior tibial translation was 1.72 mm, with side-to-side difference greater than 3 mm found in 23.7% of patients. The weighted mean Lysholm score was 90.7 in the 1482 patients analyzed, and an objective International Knee Documentation Committee (IKDC) grade A or B in 87.1% of 1414 patients analyzed [9]. Donor-site pain was present in 6.1% of 1448 patients and the graft failure rate was found to be 2.1% of 1554 patients studied. When patients undergoing QT autograft were compared to patients undergoing BPTB autograft, no significant difference was noted in their stability, grade of Lachman test, Pivot-shift test, Lysholm score, objective IKDC score, or graft survival rates. There was a significant difference found in donor-site pain, as patients undergoing QT autograft experienced less pain compared to those undergoing BPTB autograft (risk ratio for QT versus BPTB, 0.25) [9]. When comparing 17 patients undergoing QT autograft versus 17 BPTB autograft, electromyography and isometric torque data from the patients showed similar isometric quadriceps strength and no difference in quadriceps EMG ratios between the two groups [20]. Similarly, when comparing QT autograft with HT autograft, no significant differences were found in stability, grade of Lachman test, Pivot-shift test, objective IKDC score, or graft survival rates. No significant differences in anterior knee pain between the two groups were found in regard to donor-site pain. However, significant differences were found when comparing mean Lysholm scores between the two groups, as patients undergoing QT autografts had better functional outcomes with a mean difference of 3.81 [9].

Discussion

Although the QT autograft has traditionally been overlooked as a first-line graft choice for ACL reconstructions due to original studies using suboptimal QT autografts, studies published in the past two decades have begun to demonstrate its efficacy compared to the BPTB and HT autografts. As more studies show the QT autograft to be a reasonable graft option, the rate of use of this graft has increased from 2.5% in 2010 up to 11% of graft selection as of 2014, though it still trails the BPTB autograft (23%) and HT autograft (33-53%) [2]. The QT autograft is a biomechanically thicker and more robust graft choice with a 1.8 times greater thickness, 20% more collagen, and 1.36 times higher load to failure when compared to BPTB autografts of the same width [9,13]. The use of the QT autograft with bone plug also accelerates the recovery similar to BPTB autograft as it achieves bone-to-bone healing. The QT autograft has similar functional outcomes but also has less donor site pain and numbness compared to the BPTB autograft and is a worthwhile option in patients who spend a substantial amount of time kneeling. In comparison to the HT autograft, the QT autograft has similar stability and donor site morbidity while having slightly better functional outcomes. QT autograft also has the advantage of preserving hamstring strength. This is a potentially important difference as hamstring weakness is associated with ACL injuries, especially in the female athlete population [24]. Because the QT autograft has not always been a first-line choice for ACL reconstruction, there are limited studies comparing outcomes between the QT autografts and the BPTB and HT autografts. Further high-quality research delineating the differences in outcomes between these graft choices is needed.

Conclusion

The objective and functional scores of the QT autograft compared to the BPTB and HT autografts illustrate similar outcomes with less donor site pain than the BPTB autograft and superior functional outcomes when compared to the HT autograft. As a result, the use of the QT autograft has steadily been gaining popularity and is an excellent option for autograft choice in patients undergoing ACL reconstruction.

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