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The comparison of graft types in anterior cruciate ligament (ACL) reconstruction in athletes: a literature review

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Abstract

Background. Rupture of the anterior cruciate ligament (ACL) is one of the most common and devastating injuries in sports orthopaedics. Its incidence rate is approximately 68.6 per 100 000 person-years and it represents over 50% of all knee injuries. The risk is exceptionally high among athletic populations, with female athletes facing disproportionately higher injury rates. As nearly 75% of these injuries occur via non-contact mechanisms during high-risk dynamic movements, surgical intervention is frequently required. Given the high and increasing volume of ACL reconstructions performed annually, optimizing surgical strategies is critical for successful athletic recovery.

Aim. The aim of this literature review is to compare graft choices in anterior cruciate ligament reconstruction to guide the clinical decision-making process in athletic populations.

Material and methods. A comprehensive literature search was conducted in the PubMed database for articles published between 2021 and 2026. The search strategy used combinations of keywords including "anterior cruciate ligament reconstruction", "graft choice", and "athletes" to identify relevant clinical studies and reviews published on ACL reconstruction in athletes. Studies comparing various graft options and reporting on functional outcomes and return to sport rates were selected for analysis.

Results. The literature indicates that autografts provide superior clinical outcomes compared to allografts, which exhibit unacceptably high failure rates in young athletes. Bone-patellar tendon-bone (BPTB) autografts are characterized by biomechanical strength and rapid bone-to-bone healing and low rates of graft failure. On the other hand, it is associated with high donor-site morbidity, knee pain and the risk of patellar fracture or patellar tendon rupture. Hamstring tendon (HT) grafts minimize knee pain but are linked to prolonged flexor weakness, and a significantly higher risk of graft rupture in young, active athletes compared to BPTB.

Quadriceps tendon (QT) autografts provide comparable knee stability to BPTB and HT grafts, but with lower donor-site morbidity than BPTB and lower re-rupture rates than HT. Peroneus longus tendon (PLT) provides an excellent tensile strength, good functional outcome however it may be associated with postoperative donor-site pain and diminished ankle eversion strength.

Conclusions. Graft selection in ACL reconstruction cannot be a universal approach and must be highly individualized through shared decision-making. Orthopedic surgeons must consider multiple variables including the athlete's age, specific sport demands and concomitant injuries. Individualized and patient-centered approach in ACL reconstruction is essential for achieving a successful return to play and maintaining long-term postoperative quality of life.

Keywords: Anterior cruciate ligament, ACL reconstruction, Graft choice, Return to play, Quality of life

1. Introduction

1.1. Epidemiology of ACL injuries in general population and among athletes.

Rupture of the anterior cruciate ligament (ACL) is recognized as one of the most common and devastating ligamentous injuries in sports orthopedics. It represents more than 50% of all knee injuries. The overall incidence rate in the general population is approximately 68.6 per 100,000 person-years. (1,2). ACL reconstruction (ACLR) is one of the most frequently performed orthopedic procedures, with estimates indicating that between 100,000 and 300,000 surgeries are conducted each year in the USA (3). Over a 12- year period in the USA, rates of ACLR increased from 10.36 to 18.06 and from 22.58 to 25.42 per 100 000 person- years for women and men, respectively (4). The risk is remarkably high among athletic populations, with data showing that greater than 3% of athletes will sustain an ACL tear within a four-year window of sports participation (5). What's more female athletes face a disproportionately higher risk of sustaining an ACL tear, with injury rates ranging from 2 to 8 times higher than their male counterparts in similar sports (6). While American football accounts for the highest absolute number of ACL injuries, women's gymnastics, women's soccer, and women's basketball demonstrate the highest injury rates per athletic exposure. This heightened risk in females is attributed to a combination of anatomical differences, higher baseline ligament laxity, and hormonal fluctuations that affect collagen elasticity and neuromuscular control (6,7).

1.2. Mechanisms of ACL injury

Most ACL injuries do not involve direct trauma. Nearly 75% of ACL tears occur via non-contact mechanisms. These injuries typically happen during dynamic, high-risk movements involving a combination of valgus stress, external tibial rotation, and sudden deceleration during cutting, pivoting, or awkward landings. They can be observed in the high rates of ACL injuries in American football, soccer, basketball, and gymnastics (5,6). ACL tears frequently occur with other injuries, such as damage to the medial collateral ligament (MCL) or menisci, which can complicate treatment and recovery (8). Interestingly, the setting in which athletes sustain these injuries is highly skewed toward official competitions. High-level athletes are significantly more likely to suffer an ACL tear during a match or game than during practice. For example, in European professional soccer, the ACL injury rate during matches is reported to be 20-fold higher than during practice sessions, a trend that is consistently mirrored in professional and collegiate American football (4,5). On the other hand, contact sports that involve limited pivoting and jumping, such as professional ice hockey, demonstrate much lower rates of ACL injury (6).

1.3. Return to Sport after ACL Injuries

For the general population, the primary goal of ACL reconstruction (ACLR) is to restore basic knee stability for daily living. In elite and professional athletes, the surgical and rehabilitative management must account for extreme biomechanical loads and sport-specific demands. An ACL injury threatens not only the athlete's physical health but also their career longevity, contract and scholastic obligations, sponsorships, and revenue-generating potential (4). Surgical reconstruction of the torn ACL is the golden standard to restore anteroposterior and rotatory knee stability for athletes intending to return to pivoting sports (9). Overall return to sport (RTS) rates are generally high for elite athletes with studies showing that approximately 82% to 83% successfully return to sports participation (10,11). Data reveals that only about 63% to 65% of athletes manage to return to their exact pre-injury level of play or competitive performance. Moreover, only 55% of athletes resume competitive-level performance (10). Even among those who do return to the top level, many experience a measurable decline in performance (10,11). Studies on professional soccer players, for example, have shown that athletes often exhibit poorer statistical performance, fewer starts per season, and fewer goals scored in the seasons following their ACLR. Similar outcomes are seen in the National Football League, where defensive players often retire sooner and record fewer tackles post-injury (4).

2. Comparative analysis of graft types

The selection of an appropriate graft is one of the most critical and modifiable variables in ACL reconstruction (ACLR), significantly influencing biomechanical properties, clinical outcomes, and the risk of graft failure (12). The primary options include autografts, allografts and synthetic ligaments (8,13). The detailed information on primary advantages and limitations of ACL grafts is shown in Table 1.

2.1. Autografts versus allografts

Allografts offer the distinct advantage of eliminating donor-site morbidity, reducing surgical time, and decreasing immediate postoperative pain (4,12). However, they undergo a slower biological incorporation process and have been shown to have an unacceptably high failure rate in young, active athletes with rupture rates up to four times higher than autografts in patients under 25 years old. Some studies report that active patients under 25 years of age had a 9.6% graft rupture rate with autograft versus 25.0% with allograft. Consequently, allografts are generally not recommended for primary ACLR in elite athletes (4,9). Among autografts, the bone-patellar tendon-bone (BPTB), hamstring tendon (HT), and quadriceps tendon (QT) are the most extensively utilized worldwide (1,8).

2.2. Bone-Patellar Tendon-Bone (BPTB) Autografts

Historically considered the gold standard for high-level athletes, the BPTB graft offers exceptional biomechanical strength and enables rapid bone-to-bone healing within the tunnels, functioning similarly to fracture healing (4,14,15). It consistently demonstrates the lowest rates of graft failure. It has also been shown that bone grafts can be healed to the host bone within 6 weeks, whereas soft-tissue grafts take 8–12 weeks to fully incorporate (4). However, BPTB is associated with the highest donor-site morbidity, anterior knee pain, difficulty kneeling, and the risk of patellar fracture or patellar tendon rupture. These complications are almost exclusively related to the graft harvesting technique. BPTB autografts had an incidence of anterior knee pain of 17.4% vs 11.5% in HS autografts. However, it has been suggested that anterior knee pain after ACL surgery may be related to loss of motion and poor rehabilitation rather than graft choice (4,8,14,16).

2.3. Hamstring Tendon (HT) Autografts

HT autografts minimize anterior knee pain and provide better cosmetic results, making them an appealing alternative to BPTB (6,8). However, they rely on soft-tissue-to-bone healing, which is slower and more prone to tunnel widening (15). They also result in prolonged knee flexor weakness, which can impair performance (12). Most importantly, multiple registry studies highlight a significantly higher risk of graft rupture and revision surgery associated with HT autografts compared to BPTB, particularly in young and active athletes. There is 2.1-times higher odds of graft failure with HT autograft compared to BPTB autograft (11,15).

2.4. Quadriceps Tendon (QT) Autografts

The QT autograft is rapidly gaining popularity as a highly versatile as it can be harvested as a full or partial-thickness graft, with or without a bone block (4). QT graft is an option that merges the benefits of BPTB and HT grafts. QT grafts have a larger cross-sectional area and more collagen mass than the BPTB graft. Studies consistently show that QT autografts provide comparable knee stability and patient-reported outcomes to BPTB and HT grafts, but with significantly lower donor-site morbidity than BPTB and lower re-rupture rates than HT (4,12,14,15). The main disadvantage is the risk of postoperative quadriceps muscle weakness and potential rectus femoris retraction (6).

2.5. Peroneus Longus Tendon (PLT) Autografts

The PLT is an emerging autograft choice that provides excellent tensile strength, good functional outcome, minimal donor-site morbidity and a significantly larger graft diameter than the HT autograft. Harvesting the PLT is faster due to its superficial location and preserves the knee's extensor and flexor mechanisms, minimizing thigh weakness. However, it can be associated with postoperative donor-site pain and diminished ankle eversion strength. Clinical studies show that ankle function remains preserved post-harvest, and patients receiving PLT grafts may return to sport significantly earlier than those with HT grafts (17).

2.6. Synthetic Ligaments

Advanced synthetic grafts, for example the Ligament Advanced Reinforcement System (LARS) device have been designed allow a rapid rehabilitation. However, their use remains controversial. While some mid-term studies show satisfactory outcomes, systematic reviews

indicate that autografts still provide superior objective stability and lower long-term complication rates (13,15).

3. Factors Influencing Graft Selection in Clinical Practice

There is no single perfect graft that suits all athlete patients. Therefore, graft selection must be highly individualized based on multiple clinical factors. A patient-centered approach utilizing shared decision-making (SDM) is widely recognized as essential in modern ACL reconstruction. During this collaborative process, the orthopedic surgeon and the athlete must carefully weigh the surgical options, integrating the athlete's specific sport demands and career expectations. Psychological preparation is another factor in recovery process. Fear of reinjury, low self-efficacy, and poor motivation are associated with delayed return to sport and not optimal functional outcomes. Implementing SDM has been shown to improve treatment satisfaction, enhance adherence to rigorous rehabilitation protocols, and ultimately lead to better surgical outcomes (7). Surgeons must take into consideration multiple patient-specific and injury-specific variables such as age, gender, sport-specific demands, concomitant injuries. The detailed information on the optimal patient profile for each ACL graft is placed in Table 1.

Age is a dominant predictor of graft success. In young, highly active athletes especially those under 25, the risk of allograft and HT graft failure is remarkably high (1,9). In skeletally immature athletes - children and adolescents with open growth plates, HT or all-soft-tissue QT autografts are favored to prevent growth arrest (14). Once skeletal maturity is reached, young athletes (under 25) are strongly advised to receive BPTB or QT autografts (1).

For young women aged 25 and under, evidence shows a significantly lower graft failure rate with BPTB autografts ($6.13\% \pm 2.58\%$) compared to HT autografts ($17.35\% \pm 8.19\%$) (18). Additionally, few studies have established that there is an increase in objective knee stability and a lower incidence of graft rupture in primary ACLRs with PT compared with HT autografts among young females (19).

The athlete's specific sport heavily dictates the choice. BPTB grafts are contraindicated for sports requiring frequent kneeling, such as wrestling or judo, due to the high incidence of harvest-site pain. HT grafts are discouraged for athletes who rely heavily on explosive hamstring power and knee flexion, such as sprinters, gymnasts, and soccer players, due to lingering flexor weakness. For those patients who kneel or in those who rely on hamstrings quadriceps tendon autografts are preferred (4).

In cases of concomitant knee injuries, the ACL graft selection is also crucial. If an athlete has a combined ACL and MCL injury, harvesting the hamstring tendons is highly discouraged.

The hamstring complex provides vital dynamic support against valgus stress compromising it in an MCL-deficient knee significantly increases the risk of ACL graft failure. Expert opinions suggest the use of allograft-only reconstructions to limit donor-site morbidity or using at least one allograft and one autograft (20). In cases where multiple ligaments are torn, the demand for graft tissue is high. In these scenarios, allografts are frequently utilized to prevent extreme donor-site morbidity and excessive surgical trauma that would result from harvesting multiple autografts (4).

The surgeon's technical proficiency and clinical volume are massive, yet often under-discussed, determinants of graft selection. HT autograft was used in the vast majority of cases, however experienced surgeons significantly more likely to use PT and QT autografts and tailor their approach to the specific athlete (19).

Table 1. Summary of Graft Choices in Anterior Cruciate Ligament Reconstruction.

Graft Type	Ideal patient Profile	Primary Advantages	Primary Limitations	Time to return to play in different studies
Bone- Patellar Tendon- Bone (BPTB) Autograft	High-demanding athletes; High-level pivoting sports; Patients < 35 years old;	Lower graft failure and rupture rates; Time-tested; Bone-to-bone healing allows for rapid biological integration; High return to sport rates	Highest rate of donor site morbidity and anterior knee pain; Risk of patellar fracture or patella tendon rupture; No option for skeletally immature patients; Extensor mechanism dysfunction	9.6 ± 2.2 months; 9.45 months (6.69- 11.98)

Hamstring Tendon (HT) Autograft	Moderate sport activity; Patient activity that requires kneeling; Skeletally immature patients; Prioritized lower donor-site morbidity	Less anterior knee pain; Lower donor site morbidity compared to BPTB; Possibility of individualized graft size	Possible increased laxity; Slower graft integration; Hamstring muscles weakness; Higher graft rupture rates compared to QT and BPTB	10.5 $\pm$ 2.1 months; 5.84 months (5.35-6.43)
Quadriceps Tendon (QT) Autograft	Patients < 35 years old; High-level pivoting sport; Activity that requires kneeling; Skeletally immature patients; Revision cases and patients with previous graft issues;	Possibility of individualized graft size; Reduced harvest site pain; Strong biomechanical properties Comparable graft rupture rates to BPTB; Lower donor site morbidity than BPTB but comparable to HT; Less flexion strength loss compared to HT	Less studied in long-term period; Decreased extensor strength; Risk of patellar fracture or quadriceps tendon rupture	8.1 $\pm$ 2.6 months; 8.64 months (7.63-9.47)

Peroneus Longus Tendon (PLT) Autograft	Athletes requiring a large graft diameter where preservation of thigh musculature is prioritized	Tensile strength; Good functional outcome; Minimal donor-site morbidity	Diminished ankle eversion strength; Localized donor-site pain	6.61months (5.38-7.91)
Allografts	Patients > 40 years old; Low activity level; Multiligament Knee Injury	No donor site morbidity; Shorter operation time; More predictable graft size	Higher failure rates in young athletes; Delayed incorporation	Recommended return to play is at least 12 months after surgery

Source: (3,7,11,17,21,22)

4. Return to sport (RTS) and long-term quality of life (QoL)

Setting appropriate expectations regarding the recovery timeline is critical for the high-level athlete. Failure to establish realistic timelines for return to sport (RTS), which typically require 9 to 12 months for elite athletes can lead to rushed rehabilitation, graft failure, and suboptimal career outcomes (4). Returning an athlete to the play must be viewed as a process. It should rely on a shared decision-making platform within a multidisciplinary biopsychosocial framework (23).

The influence of specific graft choice on RTS timelines shows varying results in the literature. While overall RTS rates are often comparable between BPTB, HT, and QT autografts, the time to clearance can differ (14). One study noted that athletes treated with HT autografts were cleared for sports much earlier after 25.4 weeks compared to QT - 37.6 weeks and BPTB autografts - 41.1 weeks-, though this faster clearance with HT came at the cost of a significantly higher ACL graft retear rate - 38.6% for HT versus roughly 9.6% for BPTB autografts, and 10.7% for QT autografts (3). Conversely, another cohort study demonstrated that athletes receiving QT autografts returned to sport significantly faster – after 8.1 months compared to those with BPTB - 9.6 months and HT grafts 10.5 months (21). What's more the PLT autografts are characterized by the mean time to return to sports of 218.6 ± 26.61 days.

Patients in the PLT autograft group returned to sports 34 days earlier than those in the HT group. The detailed data on time needed to return to sport is placed in Table 1.

Emerging evidence also suggests that augmenting an HT or peroneus longus graft with a Lateral Extra-Articular Procedure (LEAP) dramatically enhances return to play. Adding a LEAP resulted in a 94% RTS rate overall, and an exceptional 98.9% RTS rate among athletes engaged in high-impact pivoting sports (10). Even with a mechanically intact graft, the inability to RTS is predominantly driven by psychological factors. Fear of reinjury, lack of confidence, and shifting lifestyle interests are consistently primary reasons athletes fail to return to the field (24). The ACL-Return to Sport after Injury (ACL-RSI) scale is a critical tool for quantifying this mental state. Studies indicate that graft choice may actively influence psychological readiness. Athletes treated with QT autografts have demonstrated significantly higher ACL-RSI scores at 6 months postoperatively and at the time of RTS clearance compared to athletes with BPTB or HT autografts. Furthermore, the QT group was significantly more likely to achieve an ACL-RSI score of 65 or higher—the threshold highly predictive of successfully returning to preinjury sports at 2 years—highlighting a distinct psychological advantage during the recovery and return-to-play phases (21).

Postoperative quality of life and clinical satisfaction are evaluated using Patient-Reported Outcome Measures (PROMs) such as the International Knee Documentation Committee (IKDC) subjective score. When looking at long-term QoL a significant improvement in IKDC scores is highly sustainable over time. After 8 years, 87% of patients reported that their knee felt stable during daily and athletic activities. Importantly, long-term QoL is significantly impaired by concomitant joint damage. The presence of a cartilage lesion larger than 2 cm² identified during surgery is the strongest predictor for a poorer long-term IKDC score (24).

4. Discussion

The present literature review underscores that while anterior cruciate ligament reconstruction successfully restores knee stability in athletes, the choice of graft is correlated with the postoperative outcomes and time needed to return to play. The conclusion the modern sports medicine is that there is no universal graft, that's why a highly individualized approach is necessary (1). Historically, the bone-patellar tendon-bone autograft has been recognized as the gold standard for high-demand elite athletes due to its superior static stability, rapid bone-to-bone healing, and the lowest re-rupture rates (8,10). However, this comes at the cost of high donor-site morbidity, particularly anterior knee pain, kneeling difficulty, and extensor

mechanism dysfunction (10). On the other hand, the hamstring tendon autograft minimizes anterior knee pain but relies on slower soft-tissue-to-bone healing and is associated with a significantly higher risk of graft failure. This makes HT grafts less suitable for young or those, who rely on hamstring muscle, such as sprinters and soccer players. The quadriceps tendon autograft has emerged as an alternative for BPTB and HT grafts. Current evidence demonstrates that the QT provides a larger cross-sectional area and biomechanical strength comparable to BPTB, but with significantly less harvest-site pain and functional outcomes (4). Returning an athlete to their pre-injury level of play is the ultimate measure of ACLR clinical success. Overall return to sport rates is generally high for elite athletes - 82% to 83%. However, only about 63% to 65% of athletes manage to return to their exact pre-injury level of play and only 55% of athletes resume competitive-level performance (10). What's more some studies indicate that graft choice dictates time needed to return to play. Some data suggest that, athletes with HT grafts might return to play faster due to preserved quadriceps strength, however it comes often with a significantly higher risk of subsequent ACL re-tear (3). Fear of reinjury and a lack of psychological readiness are consistently identified as the primary barriers to RTS, even in athletes with mechanically stable knees (21). Interestingly, emerging evidence suggests that graft choice directly influences this psychological recovery. Athletes receiving a QT autograft have demonstrated significantly higher psychological readiness to return to sport compared to those with BPTB or HT autografts (21). Furthermore, newer alternatives like the peroneus longus tendon (PLT) autograft have shown promising results in accelerating RTS timelines. In average athletes return to sport 34 days earlier than after HT graft (17). Moreover, augmenting an ACL reconstruction with a Lateral Extra-articular Procedure (LEAP), such as a Lateral Extra-articular Tenodesis (LET), significantly reduces graft rupture rates and residual rotatory laxity (10). On top of that, the shift toward patient-centered ACLR is crucial for postoperative outcomes. It requires integrating the athlete's specific sport, age, sex, and anatomical factors into the decision-making process (1).

5. Limitations of Current Literature and Future Directions

Despite significant advancements, the current literature exhibits several limitations. There is profound heterogeneity in surgical techniques, rehabilitation protocols, and RTS clearance criteria across studies, which complicates direct meta-analytical comparisons between grafts. Future research must prioritize large, prospective randomized controlled trials with extended follow-ups to solidify the indications for newer grafts and adjunctive procedures.

5. Conclusions

In the modern era of sports medicine, optimizing ACL reconstruction outcomes in elite athletes requires an individualized shared decision-making approach. By carefully weighing the athlete's specific sport demands, anatomy, age, gender and concomitant injuries against the biomechanical profiles of ACL grafts, surgeons can improve the time needed to return to play, maintain the low risk of reinjury, protect long-term joint health, and maximize athletic career longevity.

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