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# The terror of athletes - Anterior Cruciate Ligament Reconstruction, grafts and moden techniques

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## ABSTRACT

### Introduction

The anterior cruciate ligament (ACL) is a prevalent sports-related injury, constituting nearly half of knee injuries. This narrative review explores the evolution of ACL reconstruction surgeries, emphasizing graft types and their pros and cons.

### Current state of knowledge

The ideal ACL graft choice depends on factors like age, lifestyle, and demands. Autografts are the current standard, with the Quadriceps Tendon graft offering similar outcomes and fewer complications. Allografts are a secondary option for older, low-demand patients due to a shorter recovery period. Artificial grafts have limited use, lacking strong evidence for clinical advantages but may be considered for suturing torn ACL stumps and in cases were quick recovery is essential.

### Summary

Contemporary orthopedic practitioners must possess comprehensive knowledge of various ACL reconstruction graft types to tailor interventions precisely to individual patient requirements. The selection of a graft should be rooted in a profound comprehension of patients' lifestyles, medical histories, and specific demands, thereby mitigating the subjective impact of any associated limitations for the patient.

Key words: ACL, arthroscopy, graft types, review, ACL reconstruction

## Introduction

The anterior cruciate ligament is among the most torn ligaments in human bodies. It accounts for nearly 50% of sport-related knee injuries. [1] The number of such events is expected to grow as athletes' bodies face increasing overload caused by the growing demand for high-level performance. As the number of competitions rises, the cycle of regeneration and adaptation of athletes' tissues is significantly impaired, thus making them more susceptible to overstrain and injuries, including the ACL rupture. [2,3]

Over the years, different treatment methods of ACL rupture were proposed by surgeons and manufacturers, including various grafts and fixation methods. At the beginning all surgeries were done in an open manner. The very first method described in the literature was suturing the ligament. Later introduced methods included a silk-made prosthetic ligament or using grafts from fascia lata. In 1934 Galeazzi was the first surgeon to reconstruct the ACL with a hamstring tendons autograft. Soon after, other autografts were proposed- the patellar tendon and the quadriceps tendon grafts. Since the development of the arthroscope in the late 70's, arthroscopic reconstruction became the gold-standard for ACL rupture treatment. [4]

As the engineering capabilities grew, new synthetic grafts were introduced by manufacturers, which led to development of techniques such as internal bracing of the ligament.

The 21st century brought new concepts in ACL reconstruction (ACLR) surgeries such as double boundle or regenerative reconstruction. In addition, the development of orthobiologics introduced injectible therapies, aiming to improve the effect of the surgery. Another area of development derives from deeper understanding of the knee anatomy and biomechanics- it lets surgeons comprehend the role of the anterolateral ligament in ACL injurie and thus develop techniques incorporating reconstruction of thereof. [4]

The literature describing different strategies in treatment of torn anterior cruciate ligament is very broad. Numerous studies were carried out to investigate the biomechanical and clinical results of particular grafts and methods.

This article is a narrative review on graft types in ACL reconstruction surgeries, aiming to highlight the advantages and disadvantages of each and sum-up what we already know.

## Current state of knowledge

*Native ACL anatomy and biomechanics*

In order to develop the optimal graft and its placement method a thorough understanding of ligament anatomy and biomechanics is essential. The anterior cruciate ligament has its femoral attachment at the medial area of the lateral femoral condyle. It is described as oval, with a diameter of 18 mm and a width of approximately 11 mm. [5] However a recent study by Śmigielski et al. questioned these measurements and suggested that its thickness at the femoral insertion site is only 3mm. [6] The tibial origin is at the center of the tibial eminence, next to the anterior horn of the lateral meniscus. Its shape was described by Siebold et al. as a "C-shaped" structure.

The main role of the ACL is providing anteroposterior and rotational stability of the knee. This is accomplished by its dual structure- it is comprised of two functional bundles that work synergistically. The posterolateral bundle is responsible for rotational stability in lower degrees of knee flexion, whereas the anteromedial bundle stabilizes the joint in the sagittal plane in higher degrees of flexion. It is important to mention that Śmigielski et al. in 2015 questioned the double bundle structure of the ACL and suggested that it's rather resembles a ribbon, twisted around its long axis. [7] Nevertheless, the conventional understanding of the ACL anatomy remains the double bundle theory.

*Graft types*

Autografts

There are 3 most common autografts used in ACLR: Hamstring tendon graft (HT), Bone-patella-tendon-bone graft (BPTB) and the most recent concept- the quadriceps tendon graft (QT).

In studies investigating patient reported outcomes (PROMs), the difference in questionaries (subjective IKDC and Lysholm scores) between these three grafts were not significant. [8-14] Other researchers compared the revision rate between the grafts. It was proved that HT grafts are related with significantly higher risk of revision than BPTB. There is still lack of research regarding QT grafts and its failure rates. One registry study concluded that HT is associated with 2,7 times higher risk of revision when compared to QT and that performance athletes are the ones where the difference is especially visible. On the other hand, two randomized studies found no significant difference in short term. [13,15]

Another aspect of ACLR is regaining strength and fitness after the surgery. As expected, short

term weakness (5-8 months) of the quadriceps muscle and extensor mechanism is reported to be significantly increased in QT patients when compared to BPTB and HT. However, in longer perspective no significant difference was observed and quadriceps muscle recovery was similar between QT and BPTB grafts. On the flexors side, hamstring weakness was more prevalent and significant in short term observation of HT patients when compared to others. [16,17]

Yet another important factor to be considered while choosing ACL graft are complication types and rates. The most common morbidity after ACLR is anterior knee pain which was proved to be significantly related with BPTB graft. Among major complications are graft rupture, contralateral ACL injury, fracture of the patella, infection and quadriceps tendon rupture. Patellar fractures regard mainly BPTB patients. Postsurgical infections were reported to occur up to 5 times more often in HT patients when compared to BPTB. The least rate of infections was attributed to QT grafts. [16]

Return-to-sport rate is another widely spread parameter for evaluation of ACLR effectiveness. Up to date all major studies reported no significant difference in the rate between different types of autografts. [18,19]

Allografts

The most common allograft harvest sites are BPTB, HT, Achilles tendon and tibialis anterior tendon. In literature allografts from the IT band and peroneal muscle tendon were also described. The main advantages of using allografts for ACLR are reduced resulting from graft harvesting, shorter surgery time and broader size variety. On the other hand, they are related with slower graft restructuring, higher cost, and increased risk of infection. Allografts are also reported to have up to 4-times higher risk of graft tearing. Among the most significant risk factors of allograft failure is graft preparation method- irradiation and chemical processing weaken the graft's structure. [20] The re-rupture rate is especially high in young active patients (aged <25 years). [21]
Yet another aspect where allografts come short is return to sport rate. Keizer et al. reported the rate for BPTB auto and allografts to be 75 and 43% respectively. [22]
However, there is a population suited for allografts. A study by Maletis et al. proved that patients over 40 y.o. may benefit from allograft usage as in this age group the graft rupture rate is similar for auto and allografts while keeping all the advantages.[23]

Synthetic grafts

Both auto and allografts have their disadvantages. To overcome them surgeons came up with the idea of synthetic grafts. The first synthetic graft was developed in 1949 by a German scientist Ruther. It was named Supramid as it was made of a derivative of polyamide. Along with the development of technology new grafts were engineered from materials such as carbon fiber, Teflon, or Dacron. Unfortunately, none of them provided satisfactory long-term outcomes.

Another type of synthetic implants were augments designed to support autologous grafts in the early phase after the surgery, during the healing process when the graft is the weakest. Disappointingly, long-term observation showed poor results- joint instability and high re-rupture rate.

The most popular synthetic graft currently in use is the Ligament Advanced Reinforcement System (LARS). Studies revealed promising results with no postoperative graft-related complications and very low re-rupture occurrence at 8-year follow-up. Su et al. reported no significant difference in terms of clinical outcomes between LARS and HT autografts at 5-years after the surgery. [24] However it is important to note that, Tiefenboeck et al. reported that in a 10-year perspective only half of patients were satisfied with the effect of the treatment. [25] As a result, the LARS graft is not recommended as a primary ACLR graft and should rather be considered as an alternative for specific cases, for example for elderly, low-demand patients. Parchi et al. showed that the functional outcome was sufficient for this age group and enabled rapid postoperative recovery. [24]

It is important to note that the evidence behind the comparison of synthetic with other graft types is limited. The available RCTs compared the effects of synthetic grafts only with BPTB autografts. Moreover, they mainly incorporated patients around 30 years of age so beyond the synthetic grafts' target group.

A summary of advantages and disadvantages of all described graft types is presented in Table 1.

| Graft type | Pros | Cons | Ref |
|---|---|---|---|
| **Autografts (in general)** | - Higer success rates<br>- Faster graft incorporation<br>- Lower risk of disease transmission | -Limited graft availability<br>-Donor site morbidity<br>-Potential for postoperative pain at donor site | 26,27 |
| **BPTB Autograft** | -Excellent biomechanical properties<br>-Strong initial fixation | -Anterior knee pain<br>-Risk of patellar fracture | 28,29 |
| **Hamstring Autograft** | -Lower risk of anterior knee pain Reduced donor site morbidity | -Variable graft diameter and strength<br>-Potential for hamstring weakness | 28,30 |
| **Quadriceps Autograft** | -Minimal risk of anterior knee pain<br>-Potentially faster return to activities | -Harvest sit morbidity (less than BPTB)<br>-Variable graft size and strength | 28,31 |
| **Allografts (in general)** | -No donor site morbidity<br>-Can be advantageous in revision surgery<br>-Variety of graft choices | -Lower success rates compared to autografts<br>-Slower graft incorporation<br>-Potential disease transmission | 26,27 |
| **Synthetic Grafts** | -No donor site morbidity<br>-Can be an | -Limited long-term data on success and safety | 26,28 |

| | | | |
|---|---|---|---|
| | alternative for certain patients (old, low demand, quick recovery)<br>-No risk of disease transmission | -Variable outcomes base on material used<br>-May not mimic natural ligament properties | |

*Table 1. Summary of graft types, their pros and cons.*

**The role of ALL**

As mentioned in the introduction, other aspects of ALCR than graft choice may also make a difference. In recent years, the Anterolateral Ligament (ALL) has emerged as a critical component in the biomechanics of the knee, particularly in rotational stability. Research by Claes et al. and Helito et al. has provided valuable insights into the anatomy and function of the ALL, emphasizing its role in resisting internal rotation and controlling the pivot-shift phenomenon that often persists following traditional ACL reconstructions. [32,33] Recognition of the ALL's significance has led to a growing interest in surgical interventions that address both the ACL and the ALL concurrently. A study by Sonnery-Cottet et al. investigated combined ACL and ALL reconstructions, demonstrating improved rotational stability compared to isolated ACL reconstructions. [34] Furthermore, the work by Daggett et al. delved into the biomechanical consequences of not addressing the ALL during ACL surgery, highlighting its impact on restoring normal knee kinematics. [35] As orthopedic surgeons continue to refine their techniques, the role of the ALL in ACL reconstruction remains a focal point for enhancing surgical outcomes and preventing residual instability in the knee. Whether to reconstruct the ALL or not may occur as an even more important decision than graft choice.

**Orthobiology in ACLR**

Orthobiology plays a crucial role in advancing the field of ACL (Anterior Cruciate Ligament) reconstruction. It involves the use of various biological agents and techniques to enhance the healing and regenerative processes following anterior cruciate ligament injuries. One key component of orthobiology is platelet-rich plasma (PRP), which is derived from the patient's own blood and contains a concentrated source of platelets and growth factors. PRP has shown

promise in promoting tissue repair and reducing inflammation, making it a valuable adjunct in ACL reconstruction surgeries. [36]

One research investigated the temporal effects of PRP on pain and physical function in knee osteoarthritis, providing insights into the broader applications of PRP in musculoskeletal conditions. [37] Additionally, Xie et al. delved into the biology of PRP, elucidating its mechanisms in cartilage repair and underscoring its potential for improving outcomes in orthopedic procedures. [38]

Mesenchymal stem cells (MSCs) are another crucial aspect of orthobiology, exhibiting regenerative properties. Some studies explored the role of MSCs in ligament regeneration, shedding light on their potential to enhance graft maturation and overall healing in ACL reconstruction. [39-41]

While the use of orthobiological agents in ACL reconstruction holds promise, ongoing research, such as that by Sundman et al, continues to investigate the anti-inflammatory and matrix restorative mechanisms of PRP, providing a deeper understanding of its clinical applications in orthopedics. [42]

The integration of orthobiological interventions, including PRP and MSCs, represents a cutting-edge approach to optimizing ACL reconstruction outcomes. The cited studies contribute to the evolving body of knowledge in orthobiology, emphasizing the potential benefits of these biological agents in enhancing tissue healing and functional recovery after ACL injuries.

**Summary**

ACL rupture is one of the most common sport-related injuries of the knee. The amount of ACL reconstruction surgeries is expected to grow along with intensification and increased frequency of training sessions and competitions. Over the years many reconstruction methods and materials were developed, all of them having their own benefits and drawbacks. In this article we briefly recapped the history of ACLR surgeries and described the most often used types of ACL grafts.

There are multiple variables determining the optimal ACL graft choice for particular patient. Currently the gold standard is usage of autografts, each of which has their own advantages and disadvantages and should be picked accordingly to patient’s age, lifestyle and demands. The most novel type, the Quadriceps Tendon graft, is reported to have similar functional and

patient reported outcomes as other autografts but with lower rate of complications such as knee pain or short-term muscle strength deficit. The secondhand choice are allografts that may occur the best choice in certain patient groups, such as older, low-demand patients. Among the strong sides of allografts are short recovery period and lack of harvesting-related morbidities. The use of artificial grafts is currently limited. There is lack of strong evidence supporting their use and proving their clinical advantages over auto and allografts. Among the most important pros are quick recovery time, high availability, and no risk of disease transmission. In addition, they may come useful when an attempt to reconnect the torn ACL stumps is made.

Even though it has been almost 100 years since the first ACL reconstruction, scientist still investigate its anatomy and biomechanics with relation to other structures of the knee such as the ALL.

Modern orthopedic surgeons need to be aware of all ACL reconstruction graft types in order to suit patients' needs in the best possible manner. The graft choice should be made upon deep understanding of patients' lifestyle, health history and demands so to reduce the subjective significance of its shortcomings for the patient. Apart from that, keeping up with the latest reports from studies on biomechanics of the ACL and the role of orthobiology in ligament regeneration will let the surgeons even further improve the results of introduced treatment.

## Author's contribution

Conceptualization, KW, PH, MG-B and MagJ; methodology, MaxJ, KW; software, AT, AW; check, JP, EB and AD, AŻ-Ł; formal analysis, KW, EB; investigation, PH,; resources, KW; data curation, XX; writing - rough preparation, KW, PH, MG-B; writing - review and editing, MagJ, MaxJ; visualization, AT, JP; supervision, AD, AŻ-Ł; project administration, KW; receiving funding, (-).

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All data reported in our article can be found in PubMed database.

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References:

[1] Risberg MA, Lewek M, Snyder-Mackler L. A systematic review of evidence for anterior cruciate ligament rehabilitation: how much and what type? *Phys Ther Sport.* 2004;5(3):125–145.

[2] Chung KS, Kim JH, Kong DH, Park I, Kim JG, Ha JK. An Increasing Trend in the Number of Anterior Cruciate Ligament Reconstruction in Korea: A Nationwide Epidemiologic Study. Clin Orthop Surg. 2022 Jun;14(2):220-226. doi: 10.4055/cios20276. Epub 2021 Nov 24. PMID: 35685966; PMCID: PMC9152897.

[3] Csintalan RP, Inacio MC, Funahashi TT. Incidence rate of anterior cruciate ligament reconstructions. Perm J. 2008 Summer;12(3):17-21. doi: 10.7812/TPP/07-140. PMID: 21331205; PMCID: PMC3037119.

[4] D'Ambrosi R, Meena A, Arora ES, Attri M, Schäfer L, Migliorini F. Reconstruction of the anterior cruciate ligament: a historical view. Ann Transl Med. 2023 Aug 30;11(10):364. doi: 10.21037/atm-23-87. Epub 2023 Jun 19. PMID: 37675316; PMCID: PMC10477645.

[5] Sasaki N, Ishibashi Y, Tsuda E, Yamamoto Y, Maeda S, Mizukami H, Toh S, Yagihashi S, Tonosaki Y. The femoral insertion of the anterior cruciate ligament: discrepancy between macroscopic and histological observations. Arthroscopy. 2012;28:1135–1146.

[6] Śmigielski R, Zdanowicz U, Drwięga M, Ciszek B, Williams A. The anatomy of the anterior cruciate ligament and its relevance to the technique of reconstruction. *Bone Joint J.* 2016;98-B(8):1020-1026. doi:10.1302/0301-620X.98B8.37117

[7] Śmigielski R, Zdanowicz U, Drwięga M, Ciszek B, Ciszkowska-Łysoń B, Siebold R. Ribbon like appearance of the midsubstance fibres of the anterior cruciate ligament close to its femoral insertion site: a cadaveric study including 111 knees.

[8] Iliopoulos E, Galanis N, Zafeiridis A, Iosifidis M, Papadopoulos P, Potoupnis, M, Geladas N, Vrabas IS, Kirkos J (2017) Anatomic single-bundle anterior cruciate ligament reconstruction improves walking economy: hamstrings tendon versus patellar tendon grafts. Knee Surg Sports Traumatol Arthrosc 25(10):3155–3162

[9] Mohtadi N, Chan D, Barber R, Oddone Paolucci E (2015) A randomized clinical trial comparing patellar tendon, hamstring tendon, and doublebundle ACL reconstructions: patient-reported and clinical outcomes at a minimal 2-year follow-up. Clin J Sport Med 25(4):321–331

[10] Sajovic M, Stropnik D, Skaza K (2018) Long-term comparison of semitendinosus and gracilis tendon versus patellar tendon autografts for anterior cruciate ligament reconstruction: A 17-year follow-up of a randomized controlled trial. Am J Sports Med 46(8):1800–1808

[11] Akoto R, Albers M, Balke M, Bouillon B, Hoher J (2019) ACL reconstruction with quadriceps tendon graft and press-fit fixation versus quadruple hamstring graft and interference screw fixation - a matched pair analysis after one year follow up. BMC Musculoskelet Disord 20(1):109

[12] Belk JW, Kraeutler MJ, Marshall HA, Goodrich JA, McCarty EC (2018) Quadriceps tendon autograft for primary anterior cruciate ligament reconstruction: a systematic review of comparative studies with minimum 2-year follow-up. Arthroscopy 34(5):1699–1707

[13] Lind M, Nielsen TG, Soerensen OG, Mygind-Klavsen B, Faunř P (2020) Quadriceps tendon grafts does not cause patients to have inferior subjective outcome after anterior cruciate ligament (ACL) reconstruction than do hamstring grafts: a 2-year prospective randomised controlled trial. Br J Sports Med 54(3):183–187

[14] Martin-Alguacil JL, Arroyo-Morales M, Martín-Gomez JL, Monje-Cabrera IM, Abellán-Guillén JF, Esparza-Ros F, Lozano ML, Cantarero-Villanueva I (2018) Strength recovery after anterior cruciate ligament reconstruction with quadriceps tendon versus hamstring tendon autografts in soccer players: a randomized controlled trial. Knee 25(4):704–714

[15] Runer A, Wierer G, Herbst E, Hepperger C, Herbort M, Gfoller P, Hoser C, Fink C (2018) There is no difference between quadriceps- and hamstring tendon autografts in primary anterior cruciate ligament reconstruction: a 2-year patient-reported outcome

[16] Runer, A., Keeling, L., Wagala, N. *et al.* Current trends in graft choice for primary anterior cruciate ligament reconstruction – part II: In-vivo kinematics, patient reported outcomes, re-rupture rates, strength recovery, return to sports and complications. *J EXP ORTOP* **10**, 40 (2023). https://doi.org/10.1186/s40634-023-00601-3

[17] Andrez TN, Chagas JBM, D'Oliveira LB. GRAFTS FOR ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION: SYSTEMATIC REVIEW AND META-ANALYSIS. *Acta Ortop Bras. 2022;30(6):e256048. Published 2022 Dec 16. doi:10.1590/1413-785220223006e256048*

[18] Brophy RH, Schmitz L, Wright RW, Dunn WR, Parker RD, Andrish JT, McCarty EC, Spindler KP (2012) Return to play and future ACL injury risk after ACL reconstruction in soccer athletes from the Multicenter Orthopaedic Outcomes Network (MOON) group. The Am J Sports Med 40(11):2517–2522

[19] Bergeron JJ, Sercia QP, Drager J, Pelet S, Belzile EL. Return to baseline physical activity after bone-patellar tendon-bone versus hamstring tendon autografts for anterior cruciate ligament reconstruction: a systematic review and meta-analysis of randomized controlled trials. Am J Sports Med. 2021;50(8):2292-303.

[20] Krych AJ, Jackson JD, Hoskin TL, Dahm DL. A meta-analysis of patellar tendon autograft versus patellar tendon allograft in anterior cruciate ligament reconstruction. *Arthroscopy*.

[21] Wasserstein D, Sheth U, Cabrera A, Spindler KP: A systematic review of failed anterior cruciate ligament reconstruction with autograft compared with allograft in young patients. Sports Health 2015;7:207-216.

[22] Keizer MNJ, Hoogeslag RAG, van Raay JJAM, Otten E, Brouwer RW: Superior return to sports rate after patellar tendon autograft over patellar tendon allograft in revision anterior cruciate ligament reconstruction. Knee Surg Sports Traumatol Arthrosc 2018;26:574-581.

[23] Maletis GB, Chen J, Inacio MC, Funahashi TT: Age-related risk factors for revision anterior cruciate ligament reconstruction: A cohort study of 21,304 patients from the kaiser Permanente anterior cruciate ligament registry. Am J Sports Med 2016;44:331-336.

[24] Parchi PD, Ciapini G, Paglialunga C, Giuntoli M, Picece C, Chiellini F, Lisanti M, Scaglione M. Anterior cruciate ligament reconstruction with LARS artificial ligament-clinical results after a long-term follow-up. Joints. 2018;6(2):75–79. doi: 10.1055/s-0038-1653950.

[25] Tiefenboeck TM, et al. Clinical and functional outcome after anterior cruciate ligament reconstruction using the LARS system at a minimum follow-up of 10 years. Knee. 2015;22(6):565–568.

[26] Magnussen, R. A., Carey, J. L., Spindler, K. P. (2011). Rehabilitation following anterior cruciate ligament reconstruction: a systematic review. Journal of Orthopaedic & Sports Physical Therapy, 41(2), 98-112. doi: 10.2519/jospt.2011.3396.

[27] Mariscalco, M. W., Flanigan, D. C., Mitchell, J., & Pedroza, A. D. (2013). The influence of hamstring autograft size on patient-reported outcomes and risk of revision after anterior cruciate ligament reconstruction: a Multicenter Orthopaedic Outcomes Network (MOON) Cohort Study. Arthroscopy: The Journal of Arthroscopic & Related Surgery, 29(12), 1948-1953. doi: 10.1016/j.arthro.2013.08.027.

[28] Xergia, S. A., McClelland, J. A., Kvist, J., & Vasiliadis, H. S. (2011). Anterior cruciate ligament reconstruction grafts and their influence on knee kinematics and laxity: A systematic

review of in vivo comparisons. Arthroscopy: The Journal of Arthroscopic & Related Surgery, 27(9), 1259-1271. doi: 10.1016/j.arthro.2011.04.003.

[29] Fu, F. H., Bennett, C. H., Ma, C. B., Menetrey, J., Lattermann, C., & Current, Concepts. (2000). Current Concepts Review: Current Trends in Anterior Cruciate Ligament Reconstruction. Part II. Operative Procedures and Clinical Correlations. The American Journal of Sports Medicine, 28(1), 124-130. doi: 10.1177/03635465000280012001.

[30] Feller, J. A., Webster, K. E., & Gavin, B. (2001). Early post-operative morbidity following anterior cruciate ligament reconstruction: patellar tendon versus hamstring graft. Knee Surgery, Sports Traumatology, Arthroscopy, 9(4), 260-266. doi: 10.1007/s001670100198.

[31] Zaffagnini, S., Marcacci, M., Lo Presti, M., Giordano, G., Iacono, F., Neri, M. P., ... & Kon, E. (2003). Prospective and randomized evaluation of ACL reconstruction with three techniques: a clinical and radiographic evaluation at 5 years follow-up. Knee Surgery, Sports Traumatology, Arthroscopy, 11(3), 135-141. doi: 10.1007/s00167-003-0413-6.

[32] Claes S, Vereecke E, Maes M, Victor J, Verdonk P, Bellemans J. Anatomy of the anterolateral ligament of the knee. J Anat. 2013;223(4):321-328.

[33] Helito CP, Helito PVP, Costa HP, et al. Evaluation of the anterolateral ligament of the knee by means of magnetic resonance examination. Rev Bras Ortop. 2014;49(3):242-247.

[34] Sonnery-Cottet B, Thaunat M, Freychet B, Pupim BH, Murphy CG, Claes S. Outcome of a Combined Anterior Cruciate Ligament and Anterolateral Ligament Reconstruction Technique With a Minimum 2-Year Follow-up. Am J Sports Med. 2015;43(7):1598-1605.

[35] Daggett M, Helito CP, Cullen M, Andrade M, Bonadio MB, Pécora JR, Camanho GL, LaPrade RF. Effect of anterolateral complex reconstruction on the biomechanical outcomes of anterior cruciate ligament-reconstructed knees under pivot shift. Am J Sports Med. 2019;47(8):1791-1798.

[36] Zhu T, Zhou J, Hwang J, Xu X. Effects of Platelet-Rich Plasma on Clinical Outcomes After Anterior Cruciate Ligament Reconstruction: A Systematic Review and Meta-analysis. Orthop J Sports Med. 2022 Jan 31;10(1):23259671211061535. doi: 10.1177/23259671211061535. PMID: 35127959; PMCID: PMC8811441.

[37] Shen L, Yuan T, Chen S, et al. The temporal effect of platelet-rich plasma on pain and physical function in the treatment of knee osteoarthritis: systematic review and meta-analysis of randomized controlled trials. J Orthop Surg Res. 2017;12(1):16.

[38] Xie X, Zhang C, Tuan RS. Biology of platelet-rich plasma and its clinical application in cartilage repair. Arthritis Res Ther. 2014;16(1):204.

[39] Costa-Almeida R, Calejo I, Gomes ME. Mesenchymal Stem Cells Empowering Tendon Regenerative Therapies. Int J Mol Sci. 2019 Jun 19;20(12):3002. doi: 10.3390/ijms20123002. PMID: 31248196; PMCID: PMC6627139.

[40] Ayala-Cuellar AP, Kang JH, Jeung EB, Choi KC. Roles of Mesenchymal Stem Cells in Tissue Regeneration and Immunomodulation. Biomol Ther (Seoul). 2019 Jan 1;27(1):25-33. doi: 10.4062/biomolther.2017.260. PMID: 29902862; PMCID: PMC6319543.

[41] Bi F, Chen Y, Liu J, Hu W, Tian K. Bone Mesenchymal Stem Cells Contribute to Ligament Regeneration and Graft-Bone Healing after Anterior Cruciate Ligament Reconstruction with Silk-Collagen Scaffold. Stem Cells Int. 2021 Apr 23;2021:6697969. doi: 10.1155/2021/6697969. PMID: 33981343; PMCID: PMC8088362.

[42] Sundman EA, Cole BJ, Karas V, Della Valle C, Tetreault MW, Mohammed HO, Fortier LA. The anti-inflammatory and matrix restorative mechanisms of platelet-rich plasma in osteoarthritis. Am J Sports Med. 2014;42(1):35-41.