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Review article

Preserving the hamstring tendon insertion during ACL reconstruction with an autograft: Systematic literature review

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ABSTRACT

Introduction: The hamstring tendons (gracilis and semitendinosus) are often used as an autograft for anterior cruciate ligament (ACL) reconstruction. Healing of this graft involves a slow biological process called ligamentization. To encourage this process, some authors have proposed preserving the insertion of the hamstring tendons.
Hypothesis: Leaving the tibial insertion of the hamstring tendons intact will provide better early biological incorporation and superior tibial mechanical fixation resulting in various clinical advantages.
Materials and methods: In January 2022, a systematic literature review was carried out independently by two authors of the Medline, PubMed and Embase databases. The keywords used were "pedicular" or "pedicled" or "preservation of tibial attachment" or "hamstring tibial insertion" AND "ACL reconstruction". Each author's data was analyzed separately.
Results: Sixteen articles were analyzed. Preserving the hamstring tibial insertion during ACL reconstruction improves the graft's biological incorporation during the initial postoperative phase according to clinical studies with MRI analysis and provides a mechanical advantage at the graft's tibial attachment according to biomechanical studies (construct up to 65% stiffer). There was no difference in the clinical and functional scores when compared to the conventional technique in which the hamstring tendons are detached from their tibial insertion.
Discussion: The main conclusion of this systematic literature review was that preserving the hamstring tibial insertion during ACL reconstruction appears to improve the graft's ligamentization with biological and mechanical advantages relative to detaching the hamstring tendons. The clinical and functional results were comparable to other techniques. Prospective studies with large cohorts are still needed to confirm these findings.
Level of evidence: IV; Systematic review of literature.

1. Introduction

Reconstruction of the anterior cruciate ligament (ACL) is a common procedure [1] whose functional outcomes can still be improved [2,3]. This procedure can be done with an autograft to encourage the initial ligamentization or biological incorporation [4,5]. The most commonly used grafts are the hamstring tendons (gracilis – G and semitendinosus – ST) harvested over their distal tibial insertions [6,7]. In the literature, the functional outcomes appear comparable, no matter which type of graft is used [3,8–10]. Harvesting the hamstring tendons is easier to do and causes less morbidity than harvesting the patellar tendon [11,12] and their use allows some flexibility in which surgical technique will be utilized (STG, short ST4 graft [13], combined ACL + ALL [anterolateral ligament] graft using the STG [14,15]). However, the failure rate after ACL reconstruction with a hamstring tendon appears to be higher than when the patellar tendon is used [16,17], but similar to the quadriceps tendon [9,10].

Some authors advocate for leaving the tibial insertion of the hamstring tendons intact [18–21]. Similar to preserving the ligament ACL remnant [22,23], the aim is to maintain the vascular supply of the graft that remains pedicled [24]. Besides, the graft's tibial fixation is a weak point of the construct during ligament

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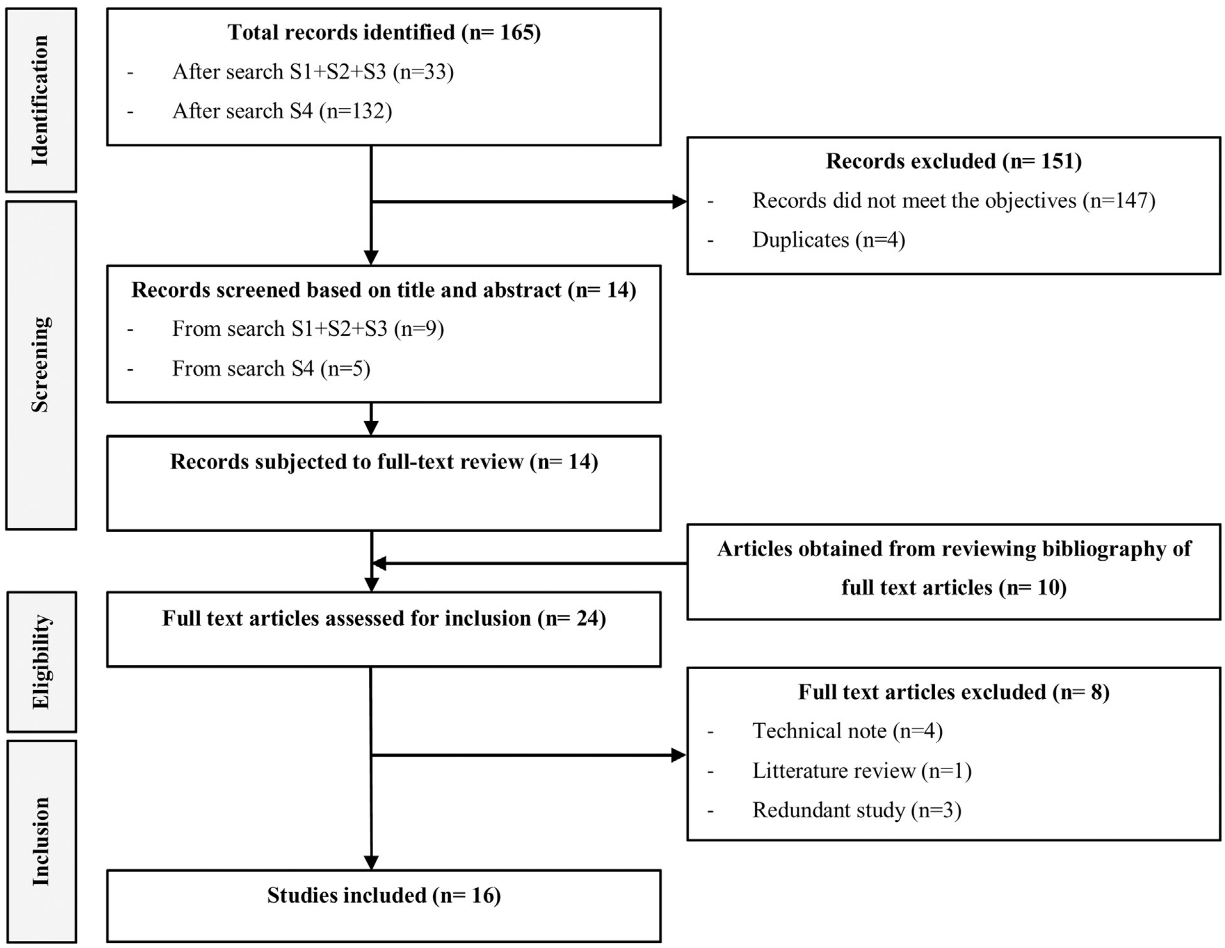

Fig. 1. Flow chart summarizing the selection of articles according to PRISMA guidelines.

reconstruction [25]. Preserving the tibial insertion of the hamstring tendons make double tibial fixation possible: original tendon fixation [26] and interference screw fixation [27]. And from a practical viewpoint, preserving the tibial insertion helps to avoid accidentally dropping the graft and limits the number of manipulations needed for a multiple bundle preparation [28].

While the advantages of this technique have been described, particularly in a 2015 literature review by Ruffilli [19], the impact on clinical results, functional scores and knee laxity have not been fully described. The objective of this systematic literature review was to answer the following question: Is preserving the tibial insertion of the hamstring tendons during ACL reconstruction a biologically, clinically, radiologically and biomechanically relevant technique? The hypothesis was that this technique has biological, clinical, radiological and biomechanical relevance.

2. Materials and methods

2.1. Search strategy

The structure of this review followed the recommendations on systematic reviews of literature and meta-analyses [29,30]. The objectives, analytic methods and inclusion criteria were determined before collecting data by following the PRISMA recommendations. In January 2022, a bibliographic search of the PubMed, Medline, CINAHL, Cochrane, and Embase databases was done. The MeSH terms used were "pedicled" or "pedicular" or "preservation of tibial attachment" or "hamstring tibial insertion" AND "ACL reconstruction" for search 1 (S1), search 2 (S2), search 3 (S3) and search 4 (S4), respectively.

The initial selection of articles based on the title and abstract was carried out by two of the authors (TN, AH) independently. If there was disagreement about the status of an article, the two authors discussed it to come to a consensus. A second filtering step was applied by reading the entire article and reviewing the reference list of each selected article to make sure that no article on this topic had been overlooked. The selected studies (1) had no time limit on the publication date, (2) were written in either English or French, (3) had an abstract available online.

2.2. Inclusion criteria

Included were all the articles that reported histological, biological, mechanical, technical, radiological and functional data of ACL reconstruction performed with a hamstring graft with preserved tibial insertion, including anatomical, biomechanical and clinical studies (case series and comparative studies).

2.3. Exclusion criteria

Technical notes and systematic literature reviews were excluded from the analysis.

2.4. Article selection

Search strategies S1, S2 and S3 (Fig. 1) identified 33 articles, which were screened based on their title and abstract to yield 9

Table 1
Articles selected for the final analysis.

Authors Year of publication	Type of study	Number of patients	Average follow-up (months)	Outcomes	Main findings
Papachristou et al. [35] 2007	Animal study Prospective Comparative	39 (rabbits): – 30 attached – 9 detached	3	At 3, 6, 12 weeks: – Histological progression of graft	– No avascular necrosis at 3 weeks – Architecture and cellularity preserved at 12 weeks
Liu et al. 2018	Animal study Prospective Comparative Randomized	64 (rabbits): – 32 attached – 32 detached	6	At 3, 6, 12, 24 weeks: – Histological progression of graft – Osseointegration – Mechanical strength – Laxity	– No avascular necrosis at 3 and 6 weeks – Earlier appearance of Sharpey fibers (3 vs. 12 weeks) – Better integration in tibial tunnel at 6, 12 and 24 weeks – Less tibial tunnel widening at 6 weeks* – Better mechanical strength at 12 and 24 weeks* – Better control over laxity at 24 weeks *
Bahlau [27] 2019	Cadaver study Comparative	10 (cadavers): – 5 attached w/o screw – 5 attached w/screw – 5 detached w/screw‡	0	– Load to failure	– Load to failure 33% higher (attached w/o screw vs. detached) *(ns)* – Load to failure 25% higher (attached w screw vs. attached w/o screw) *(ns)* – Load to failure 65% higher (attached vs. detached w/screw)*
Santos et al. [36] 2020	Cadaver study Comparative	23 (cadavers): – 11 attached w/o screw – 12 detached w/screw	0	– Mechanical strength	– Native fixation was better (force, elongation, tension, rigidity)*
Ali et al. [37] 2006	Observational Retrospective	74 patients	64	– Lysholm score – Tegner score – KT-1000	– Lysholm = 79.2 ± *x* – Tegner = 5.9 ± *x* – Δ laxity = 1.43 mm ± 3.86
Buda et al. [38] 2008	Observational Prospective	28 patients	25.8	– IKDC – MRI	– MRI between 15 and 40 months: 80% Howell stage 1 – Positive correlation between graft appearance and functional outcomes*
Sinha et al. [26] 2018	Observational Prospective	79 patients	24	– Lysholm score – Tegner score – KT-1000	– Lysholm = 96.8 ± 2.4 – Tegner = 5.87 ± 0.67 – Δ laxity = 0.13 mm ± *x*
Bahlau et al. [21] 2019	Observational Prospective	21 patients	30	– Lysholm score – IKDC – KT-1000 – Isokinetic testing	– Lysholm = 95 ± 8 – IKDC = 91 ± *x* – Δ laxity = 2 mm ± 1.2 – Isokinetic testing at 12 months: quadriceps deficit 16%, hamstring deficit 12%
Gupta et al. [39] 2021	Observational Prospective	25 patients	14	– Lysholm score – Tegner score – MRI	– MRI at 8 and 14 months: Faster graft integration at tibia than femur (evaluated by signal intensity at bone/tendon interface)* – Positive correlation between graft integration and functional outcomes*
Favreau et al. [40] 2020	Observational Retrospective	14 patients (repeat rupture)	45	– Lysholm score – IKDC – Tegner score – KT-1000	– Lysholm = 91.8 ± *x* – IKDC = 85.5 ± *x* – Tegner = 5.5 ± *x* – Δ laxity = 2.5 mm ± *x*

Table 1 (*Continued*)

Authors Year of publication	Type of study	Number of patients	Average follow-up (months)	Outcomes	Main findings
Ruffilli et al. [41] 2016	Observational Prospective Comparative randomized	40 patients: – 20 attached† – 20 detached	24	– IKDC – Tegner score – MRI	– IKDC † = 91.6 ± *x* (*ns*) – Tegner † = 6.4 ± *x* (*ns*) – MRI at 6 months: Better ligamentization (evaluated by intensity of intra-articular graft signal)* Comparable integration (evaluated by absence of synovial fluid at bone/tendon interface)
Liu et al. [42] 2018	Observational Prospective Comparative randomized	37 patients: – 18 attached † – 19 detached	24	– Lysholm score – IKDC – Tegner score – KT-1000 – MRI	– Lysholm † = 88.9 ± 4.6 (*ns*) – IKDC † = 88.4 ± 4.6 ((*ns*) – Tegner †= 5.9 ± 0.9 (*ns*) – Δ laxity † = 1.4 mm ± 0.8 (*ns*) – MRI at 6 and 12 months: Better ligamentization (evaluated by intra-articular SNQ)* – MRI at 2 years: SNQ comparable intra-articular portion *(ns)*
Zhang et al. [43] 2020	Observational Prospective Comparative randomized	37 patients: – 18 attached† – 19 detached	60	– Lysholm score – IKDC – Tegner score – KT-1000 – MRI	– Lysholm † = 87.3 ± 6.6 (*ns*) – IKDC † = 86.4 ± 6.2 (*ns*) – Tegner † = 5.8 ± 0.7 (*ns*) – Δ laxity † = 1.4 mm ± 1 (*ns*) – MRI at 6 and 12 months: Better ligamentization (evaluated by intra-articular and tibial/femoral tunnel SNQ)* – MRI at 5 years: SNQ comparable intra-articular portion and tibial/femoral tunnels *(ns)*
Gupta et al. [44] 2020	Observational Prospective Comparative randomized	160 patients: – 80 attached† – 80 bone-tendon-bone	24	– Lysholm score – WOMAC score – KT-1000	– Lysholm † = 96.1 ± 5.81 (*ns*) – WOMAC † = 3.3 ± 2.76 (*ns*) – Δ laxity † = 2.23 mm ± 1.6 (*ns*)
Grassi et al. [45] 2021	Observational Prospective Comparative randomized	20 patients: – 10 attached† – 10 detached	18	– KOOS Score – KT-1000 – MRI	– MRI at 18 months †: 80% Howell stage 1 – MRI at 4 and 18 months: SNQ comparable for intra-articular portion *(ns)* Less edema in graft (evaluated as presence of fluid in graft)* Better SNQ in tibial tunnel* Less tibial tunnel widening* – Functional outcomes and knee laxity comparable between groups *(ns)* – No correlation between graft appearance and functional outcomes *(ns)*
Lang et al. [46] 2022	Observational Prospective Comparative consecutive	120 patients: – 60 attached† – 60 detached	0	– Operative time – Complications	– Operative time† = 30.8 min ± 2.8 (*ns*) – Complications† = 3.3% conversion to conventional technique (detached hamstring)

Numerical values of the main results are given as mean ± standard deviation. Abbreviations: ns: no significant difference; IKDC: International Knee Documentation Committee; WOMAC: Western Ontario and McMaster Universities Osteoarthritis Index; KOOS: Knee Injury and Osteoarthritis Outcome Score; SNQ: signal to noise quotient. Δ = difference between healthy and operated knee; ‡ = from the first group; † = attached hamstring graft; * = significant difference with $p < 0.05$.

articles. The S4 strategy identified 132 records from which 5 articles were selected. Four articles appeared in one or more of the searches. Ten articles were added after reviewing the reference list of the selected articles. Thus, 24 articles (9 + 5 + 10) had their full text reviewed for eligibility. Four technical notes [18,20,31,32] and one review of literature [19] were excluded. Three other articles were excluded because they did not provide new data related to the hypothesis of this systematic review [24,33,34]. In the end, 16 articles were included in the final analysis (Table 1).

The clinical results reported in the articles selected for the analysis consisted of validated knee-specific scores and knee laxity measurements. The scores used were all subjective functional outcomes: Lysholm, Tegner, IKDC (International Knee Documentation Committee), KOOS (Knee Injury and Osteoarthritis Outcome Score) and WOMAC (Western Ontario and McMaster Universities Osteoarthritis Index). The residual postoperative laxity was measured with the KT-1000® to produce an objective measurement of side-to-side differences between the healthy and operated knee in millimeters (mm) [47].

3. Results

3.1. Technical aspects and feasibility

Lang [46] reported a 97% success rate when using an attached hamstring graft. The failures were due to the tendon graft being too short, which required it to be detached from its tibial insertion. The operating time for these two techniques appeared similar.

3.2. Biological aspects and ligamentization

In a rabbit model, Papachristou [35] reported that the avascular necrosis phase had disappeared when the tibial insertion was preserved. This finding was confirmed by Lui , who also reported that Sharpey fibers developed more quickly at the tendon–bone interface.

3.3. Clinical analysis

The clinical and knee laxity results were comparable to standard techniques with no increase in the complication rate [21,37,41–44]. These findings were confirmed during revision surgery cases in a retrospective study by Favreau [40].

3.4. Imaging (MRI) findings

The graft's appearance on MRI was correlated to the clinical scores postoperatively [38,39]. Maturation and bone integration in the tunnels was faster with an attached hamstring graft during the first 2 years postoperative [41,42,44,45].

3.5. Biomechanical aspects

In 10 cadaver knees, Bahlau [27] found that the failure strength of hamstring grafts was 33% higher when the tibial insertion was preserved without an interference screw versus detached hamstring graft fixed with an interference screw. Adding an interference screw helped to increase the failure strength of attached grafts by another 25%. Santos had similar findings [36] in terms of load, elongation, tension and stiffness, and this was confirmed in a rabbit model .

Sinha [26] provided clinical support based on 79 ACL reconstructions with the hamstring graft in which the original tendon insertion was the only tibial fixation. At 2 years' follow-up, the functional outcomes were satisfactory. No re-rupture or pathological laxity (side-to-side difference on KT-1000®: 0.13 mm) was reported.

4. Discussion

ACL reconstruction with a hamstring graft in which the tibial insertion is preserved is mechanically and biologically appropriate without specific complications. This was an original study consisting of a systematic literature review with new data that was not included in the 2015 literature review by Ruffilli [19]. However, it has several limitations: broad selection criteria, varied study types with numerous biases and few randomized prospective studies [41–45].

In France, an autograft is the most common choice when doing ACL reconstruction. As an alternative, an allograft can be used to reduce the morbidity related to harvesting and postoperative pain [48,49]; however the re-rupture rates are higher [5,7,50].

For better ligamentization in the immediate postoperative phase, some authors recommend preserving the ligament remnant [51,52] and leaving the tendons attached at their tibial insertion [24]. In 1997, Kim [31] was the first to reconstruct the ACL using hamstring tendons in which the tibial insertion was preserved. Since then, this technique has regularly been used for primary reconstruction [19] and for revision ACL surgery [40]. The ligamentization phase can last up to 3 years [53] and is characterized – on the histological front – by avascular necrosis of the graft in the first 3 months, hypocellularity and chaotic reorganization of collagen fibers [54,55]. Rich vascularization from the inferior medial genicular artery is found at the distal tibial insertion of the hamstring tendons. This vascularization becomes sparser along the tendon. Over this insertion, mechanoreceptors are present (Ruffini and Pacini corpuscles) like the ones found in the original ACL [56,57]. Preserving the tibial insertion of the hamstring tendons helps to avoid the initial avascular necrosis phase and yields better histological scores at the tendon/bone interface, which improves the graft's ligamentization and its mechanical properties [35]. No signs of necrosis or hypocellularity were found during the various stages of graft maturation, contrary to detached hamstring tendons in these studies.

This is confirmed in MRI studies, where the maturation of grafts with an intact tibial insertion is better at the level of the tunnels [39,43,45] and the intra-articular portion [41–43,45]. Maturation occurs over the first 2 years postoperative, then slows down [41,43], with the graft's appearance being comparable between intact and detached tendons at 2 years [42] and 5 years [43] postoperative. When the clinical results were poor, the graft was not visible or continuous, with heterogenous intensity signals and intra-ligamentous cystic formations in the tunnels [38]. But not all studies have found a correlation between the clinical outcomes and graft maturation on MRI [45].

The clinical outcomes and knee laxity more than 2 years after ACL reconstruction with attached hamstring tendons [21,26,37] are comparable to reconstruction with detached hamstring tendons [42,43], and reconstructions with bone-tendon-bone autografts [44]. From a surgical point of view, preserving the tibial insertion is validated in the literature for primary [19] and revision procedures [40], with a need to detach the tendons in only 3% of cases [46]. This technique allows for double tibial fixation, which provides higher primary pull-out strength [27,36] and prevents one from accidentally dropping the graft.

5. Conclusion

Leaving the hamstring tendons attached at the tibial insertion during ACL reconstruction helps to avoid the initial avascular necrosis phase for better ligamentization, it increases the pull-out strength due to the second tibial fixation and ensures faster and longer lasting graft maturation based in MRI analysis over time. The clinical and functional outcomes are like other ACL reconstruction techniques described in the literature with excellent feasibility (97%).

Disclosure of interest

TN: Consultant with Arthrex and Parcus Veodis.

RL: Consultant with Arthrex, Development Consulting with Serf, Implant Services Orthopédie, and Orthonov.

AH: Webmaster for OTSR.

CT and LG: None.

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References

[1] Anderson MJ, Browning WM, Urband CE, Kluczynski MA, Bisson LJ. A systematic summary of systematic reviews on the topic of the anterior cruciate ligament. Orthop J Sports Med 2016;4 [2325967116634074].
[2] Rousseau R, Labruyere C, Kajetanek C, Deschamps O, Makridis KG, Djian P. Complications after anterior cruciate ligament reconstruction and their relation to the type of graft: a prospective study of 958 cases. Am J Sports Med 2019;47:2543–9.
[3] Randsborg P-H, Cepeda N, Adamec D, Rodeo SA, Ranawat A, Pearle AD. Patient-reported outcome, return to sport, and revision rates 7-9 years after anterior cruciate ligament reconstruction: results from a cohort of 2042 patients. Am J Sports Med 2022;50:423–32.
[4] Prodromos C, Joyce B, Shi K. A meta-analysis of stability of autografts compared to allografts after anterior cruciate ligament reconstruction. Knee Surg Sports Traumatol Arthrosc Off J ESSKA 2007;15:851–6.
[5] Zeng C, Gao S, Li H, Yang T, Luo W, Li Y, et al. Autograft versus allograft in anterior cruciate ligament reconstruction: a meta-analysis of randomized controlled trials and systematic review of overlapping systematic reviews. Arthrosc J Arthrosc Relat Surg Off Publ Arthrosc Assoc N Am Int Arthrosc Assoc 2016;32:153–63.
[6] Arnold MP, Calcei JG, Vogel N, Magnussen RA, Clatworthy M, Spalding T, et al. ACL Study Group survey reveals the evolution of anterior cruciate ligament reconstruction graft choice over the past three decades. Knee Surg Sports Traumatol Arthrosc Off J ESSKA 2021;29:3871–6.
[7] Musahl V, Engler ID, Nazzal EM, Dalton JF, Lucidi GA, Hughes JD, et al. Current trends in the anterior cruciate ligament part II: evaluation, surgical technique, prevention, and rehabilitation. Knee Surg Sports Traumatol Arthrosc Off J ESSKA 2022;30:34–51.
[8] Spindler KP, Kuhn JE, Freedman KB, Matthews CE, Dittus RS, Harrell FE. Anterior cruciate ligament reconstruction autograft choice: bone-tendon-bone versus hamstring: does it really matter? A systematic review. Am J Sports Med 2004;32:1986–95.
[9] Mouarbes D, Menetrey J, Marot V, Courtot L, Berard E, Cavaignac E. Anterior cruciate ligament reconstruction: a systematic review and meta-analysis of outcomes for quadriceps tendon autograft versus bone-patellar tendon-bone and hamstring-tendon autografts. Am J Sports Med 2019;47:3531–40.
[10] Dai W, Leng X, Wang J, Cheng J, Hu X, Ao Y. Quadriceps tendon autograft versus bone-patellar tendon-bone and hamstring tendon autografts for anterior cruciate ligament reconstruction: a systematic review and meta-analysis. Am J Sports Med 2021 [3635465211030259].
[11] Biau DJ, Tournoux C, Katsahian S, Schranz PJ, Nizard RS. Bone-patellar tendon-bone autografts versus hamstring autografts for reconstruction of anterior cruciate ligament: meta-analysis. BMJ 2006;332:995–1001.
[12] Hardy A, Casabianca L, Andrieu K, Baverel L, Noailles T, Junior French Arthroscopy Society. Complications following harvesting of patellar tendon or hamstring tendon grafts for anterior cruciate ligament reconstruction: systematic review of literature. Orthop Traumatol Surg Res OTSR 2017;103:S245–8.
[13] Colombet P, Graveleau N. An anterior cruciate ligament reconstruction technique with 4-strand semitendinosus grafts, using outside-in tibial tunnel drilling and suspensory fixation devices. Arthrosc Tech 2015;4:e507–11.
[14] Saithna A, Thaunat M, Delaloye JR, Ouanezar H, Fayard JM, Sonnery-Cottet B. Combined ACL and anterolateral ligament reconstruction. JBJS Essent Surg Tech 2018;8:e2.
[15] Sonnery-Cottet B, Daggett M, Helito CP, Fayard J-M, Thaunat M. Combined anterior cruciate ligament and anterolateral ligament reconstruction. Arthrosc Tech 2016;5 [e1253-9].
[16] Gifstad T, Foss OA, Engebretsen L, Lind M, Forssblad M, Albrektsen G, et al. Lower risk of revision with patellar tendon autografts compared with hamstring autografts: a registry study based on 45,998 primary ACL reconstructions in Scandinavia. Am J Sports Med 2014;42:2319–28.
[17] Samuelsen BT, Webster KE, Johnson NR, Hewett TE, Krych AJ. Hamstring autograft versus patellar tendon autograft for acl reconstruction: is there a difference in graft failure rate? A meta-analysis of 47,613 Patients. Clin Orthop 2017;475:2459–68.
[18] Zaffagnini S, Marcheggiani Muccioli GM, Bonanzinga T, Nitri M, Grassi A, Marcacci M. Anatomic double-bundle anterior cruciate ligament reconstruction leaving hamstrings tibial insertion intact: technical note. Musculoskelet Surg 2013;97:39–43.
[19] Ruffilli A, Traina F, Evangelisti G, Borghi R, Perna F, Faldini C. Preservation of hamstring tibial insertion in anterior cruciate ligament reconstruction: a review of the current literature. Musculoskelet Surg 2015;99:87–92.
[20] Gupta R, Bahadur R, Malhotra A, Masih GD, Gupta P. Anterior cruciate ligament reconstruction using hamstring tendon autograft with preserved insertions. Arthrosc Tech 2016;5 [e269-274].
[21] Bahlau D, Favreau H, Eichler D, Lustig S, Bonnomet F, Ehlinger M. Clinical, functional, and isokinetic study of a prospective series of anterior cruciate ligament ligamentoplasty with pedicular hamstrings. Int Orthop 2019;43: 2557–62.
[22] Takahashi T, Kimura M, Hagiwara K, Ohsawa T, Takeshita K. The effect of remnant tissue preservation in anatomic double-bundle ACL reconstruction on knee stability and graft maturation. J Knee Surg 2019;32:565–76.
[23] Takazawa Y, Ikeda H, Kawasaki T, Ishijima M, Kubota M, Saita Y, et al. ACL reconstruction preserving the ACL remnant achieves good clinical outcomes and can reduce subsequent graft rupture. Orthop J Sports Med 2013;1 [2325967113505076].
[24] Löcherbach C, Zayni R, Chambat P, Sonnery-Cottet B. Biologically enhanced ACL reconstruction. Orthop Traumatol Surg Res OTSR 2010;96:810–5.
[25] Hill PF, Russell VJ, Salmon LJ, Pinczewski LA. The influence of supplementary tibial fixation on laxity measurements after anterior cruciate ligament reconstruction with hamstring tendons in female patients. Am J Sports Med 2005;33:94–101.
[26] Sinha S, Naik AK, Maheshwari M, Sandanshiv S, Meena D, Arya RK. Anterior cruciate ligament reconstruction with tibial attachment preserving hamstring graft without implant on tibial side. Indian J Orthop 2018;52:170–6.
[27] Bahlau D, Clavert P, Favreau H, Ollivier M, Lustig S, Bonnomet F, et al. Mechanical advantage of preserving the hamstring tibial insertion for anterior cruciate ligament reconstruction - A cadaver study. Orthop Traumatol Surg Res OTSR 2019;105:89–93.
[28] Shen X, Qin Y, Zuo J, Liu T, Xiao J. Comparison of the sterilization efficiency of 3 disinfectants for dropped anterior cruciate ligament grafts: a systematic review and meta-analysis. Orthop J Sports Med 2021;9 [23259671211002870].
[29] Wright RW, Brand RA, Dunn W, Spindler KP. How to write a systematic review. Clin Orthop 2007;455:23–9.
[30] Moher D, Liberati A, Tetzlaff J, Altman DG, Group PRISMA. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. PLoS Med 2009;6:e1000097.
[31] Kim SJ, Kim HK, Lee YT. Arthroscopic anterior cruciate ligament reconstruction using autogenous hamstring tendon graft without detachment of the tibial insertion. Arthrosc J Arthrosc Relat Surg Off Publ Arthrosc Assoc N Am Int Arthrosc Assoc 1997;13:656–60.
[32] Buda R, Ruffilli A, Vannini F, Parma A, Giannini S. Anatomic anterior cruciate ligament reconstruction using distally inserted doubled hamstrings tendons. Orthopedics 2013;36:449–53.
[33] Zhang Q, Yang Y, Li J, Zhang H, Fu Y, Wang Y. Functional double-bundle anterior cruciate ligament reconstruction using hamstring tendon autografts with preserved insertions is an effective treatment for tibiofemoral instability. Knee Surg Sports Traumatol Arthrosc Off J ESSKA 2019;27:3471–80.
[34] Natali S, Buda R, Giuriati L, Pagliazzi G, Baldassarri M, Calderoni E. Anatomic ACL reconstruction using distally inserted double hamstring tendons: surgical techniques and result. J Orthop 2013;5:147–51.
[35] Papachristou G, Nikolaou V, Efstathopoulos N, Sourlas J, Lazarettos J, Frangia K, et al. ACL reconstruction with semitendinosus tendon autograft without detachment of its tibial insertion: a histologic study in a rabbit model. Knee Surg Sports Traumatol Arthrosc Off J ESSKA 2007;15:1175–80.
[36] Santos A, de A, Carneiro-Filho M, Albuquerque RF, da ME, Moura JPFM, de Franciozi CE, Luzo MVM. Mechanical evaluation of tibial fixation of the hamstring tendon in anterior cruciate ligament double-bundle reconstruction with and without interference screws. Clin Sao Paulo Braz 2020;75:e1123.
[37] Ali MS, Kumar A, Adnaan Ali S, Hislop T. Anterior cruciate ligament reconstruction using hamstring tendon graft without detachment of the tibial insertion. Arch Orthop Trauma Surg 2006;126:644–8.
[38] Buda R, Di Caprio F, Giuriati L, Luciani D, Busacca M, Giannini S. Partial ACL tears augmented with distally inserted hamstring tendons and over-the-top fixation: an MRI evaluation. The Knee 2008;15:111–6.
[39] Gupta R, Singh S, Kapoor A, Soni A, Kaur R, Kaur N. Graft tunnel integration occurs early in the tibial tunnel compared with the femoral tunnel after anterior

cruciate ligament reconstruction with preserved insertion hamstring tendon graft. Knee Surg Relat Res 2021;33:37.
[40] Favreau H, Eichler D, Bonnomet F, Lustig S, Adam P, Ehlinger M. Revision of anterior cruciate ligament reconstruction with a pedicled quadruple hamstring autograft. Eur J Orthop Surg Traumatol Orthop Traumatol 2020;30:1033–8.
[41] Ruffilli A, Pagliazzi G, Ferranti E, Busacca M, Capannelli D, Buda R. Hamstring graft tibial insertion preservation versus detachment in anterior cruciate ligament reconstruction: a prospective randomized comparative study. Eur J Orthop Surg Traumatol Orthop Traumatol 2016;26:657–64.
[42] Liu S, Li H, Tao H, Sun Y, Chen S, Chen J. A randomized clinical trial to evaluate attached hamstring anterior cruciate ligament graft maturity with magnetic resonance imaging. Am J Sports Med 2018;46:1143–9.
[43] Zhang Y, Liu S, Chen Q, Hu Y, Sun Y, Chen J. Maturity progression of the entire anterior cruciate ligament graft of insertion-preserved hamstring tendons by 5 years: a prospective randomized controlled study based on magnetic resonance imaging evaluation. Am J Sports Med 2020;48:2970–7.
[44] Gupta R, Kapoor A, Soni A, Khatri S, Masih GD, Raghav M. No difference in outcome of anterior cruciate ligament reconstruction with “bone-patellar tendon-bone versus semitendinosus-gracilis graft with preserved insertion”: a randomized clinical trial. Indian J Orthop 2020;54:665–71.
[45] Grassi A, Casali M, Macchiarola L, Lucidi GA, Cucurnia I, Filardo G, et al. Hamstring grafts for anterior cruciate ligament reconstruction show better magnetic resonance features when tibial insertion is preserved. Knee Surg Sports Traumatol Arthrosc Off J ESSKA 2021;29:507–18.
[46] Lang E, Hardy A, Tufis O, Grimaud O, Gerometta A, Bohu Y, et al. Surgical technique of anterior cruciate ligament ligamentoplasty with pedicular hamstrings via an inside-out approach: BIOFAST hamstring tendons graft. Orthop Traumatol Surg Res OTSR 2022;108:103192.
[47] Pugh L, Mascarenhas R, Arneja S, Chin PYK, Leith JM. Current concepts in instrumented knee-laxity testing. Am J Sports Med 2009;37:199–210.
[48] Cole DW, Ginn TA, Chen GJ, Smith BP, Curl WW, Martin DF, et al. Cost comparison of anterior cruciate ligament reconstruction: autograft versus allograft. Arthrosc J Arthrosc Relat Surg Off Publ Arthrosc Assoc N Am Int Arthrosc Assoc 2005;21:786–90.
[49] Poehling GG, Curl WW, Lee CA, Ginn TA, Rushing JT, Naughton MJ, et al. Analysis of outcomes of anterior cruciate ligament repair with 5-year follow-up: allograft versus autograft. Arthrosc J Arthrosc Relat Surg Off Publ Arthrosc Assoc N Am Int Arthrosc Assoc 2005;21:774–85.
[50] Kaeding CC, Pedroza AD, Reinke EK, Huston LJ, Consortium MOON, Spindler KP. Risk Factors and Predictors of Subsequent ACL Injury in Either Knee After ACL Reconstruction: Prospective Analysis of 2488 Primary ACL Reconstructions From the MOON Cohort. Am J Sports Med 2015;43:1583–90.
[51] Buscayret F, Temponi EF, Saithna A, Thaunat M, Sonnery-Cottet B, Three-Dimensional CT. Evaluation of Tunnel Positioning in ACL Reconstruction Using the Single Anteromedial Bundle Biological Augmentation (SAMBBA) Technique. Orthop J Sports Med 2017;5 [2325967117706511].
[52] Sonnery-Cottet B, Freychet B, Murphy CG, Pupim BHB, Thaunat M. Anterior Cruciate Ligament Reconstruction and Preservation: The Single-Anteromedial Bundle Biological Augmentation (SAMBBA) Technique. Arthrosc Tech 2014;3:e689–93.
[53] Rougraff B, Shelbourne KD, Gerth PK, Warner J. Arthroscopic and histologic analysis of human patellar tendon autografts used for anterior cruciate ligament reconstruction. Am J Sports Med 1993;21:277–84.
[54] Claes S, Verdonk P, Forsyth R, Bellemans J. The “ligamentization” process in anterior cruciate ligament reconstruction: what happens to the human graft? A systematic review of the literature. Am J Sports Med 2011; 39:2476–83.
[55] Muller B, Bowman KF, Bedi A. ACL graft healing and biologics. Clin Sports Med 2013;32:93–109.
[56] Olewnik Ł, Gonera B, Podgórski M, Polguj M, Jezierski H, Topol M. A proposal for a new classification of pes anserinus morphology. Knee Surg Sports Traumatol Arthrosc Off J ESSKA 2019;27:2984–93.
[57] Zaffagnini S, Golanò P, Farinas O, Depasquale V, Strocchi R, Cortecchia S, et al. Vascularity and neuroreceptors of the pes anserinus: anatomic study. Clin Anat N Y N 2003;16:19–24.