Invited Review

Ligament Advanced Reinforcement System (LARS) synthetic graft for PCL reconstruction: systematic review and meta-analysis

Filippo Migliorini¹, Andrea Pintore², Gianluca Vecchio², Francesco Oliva², Frank Hildebrand¹, and Nicola Maffulli²,⁴,⁵

¹Department of Orthopaedics, University Clinic Aachen, RWTH Aachen University Clinic, 52064 Aachen, Germany, ²Department of Orthopaedics, Surgery and Dentistry, University of Salerno, Via S. Allende, 84081 Baronissi, Italy, ³Department of Orthopedic and Trauma Surgery, Ospedale San Carlo, 076063 Potenza, Italy, ⁴Queen Mary University of London, Barts and the London School of Medicine and Dentistry, Centre for Sports and Exercise Medicine, Mile End Hospital, 275 Bancroft Road, London E1 4DG, UK, and ⁵School of Pharmacy and Bioengineering, Keele University Faculty of Medicine, Thornburrow Drive, 01782 Stoke on Trent, UK

*Correspondence address. Queen Mary University of London, Mile End Hospital, 275 Bancroft Road, London E1 4DG, England, UK. E-mail: n.maffulli@qmul.ac.uk

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Abstract

Introduction: Several strategies are available for posterior cruciate ligament (PCL) reconstruction.

Source of data: Recently published literature in PubMed, Google Scholar and Embase databases.

Areas of agreement: The Ligament Advanced Reinforcement System (LARS) is a scaffold type artificial ligament, which has been widely used for ligament reconstruction of the knee.

Areas of controversy: Current evidence on the reliability and feasibility of LARS for primary isolated PCL reconstruction is limited.

Growing points: The primary outcome of interest of the present work was to investigate the outcomes of PCL reconstruction using the LARS. The
secondary outcome of interest was to compare the LARS versus four-strand hamstring tendon (4SHT) autograft for PCL reconstruction.

**Areas timely for developing research:** LARS for primary isolated PCL reconstruction seems to be effective and safe, with results comparable to the 4SHT autograft.

**Key words:** knee, PCL reconstruction, LARS, graft

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**Introduction**

Posterior cruciate ligament (PCL) injuries may occur as a result of high-energy trauma car accidents and sports injuries. The reported incidence of PCL tears is 1%–44% of all acute knee ligament injuries. This variability probably results from differences in the patient populations studied, as PCL injury rates are likely to vary when comparing trauma patients to an athletic population. Patient history, physical examination and correct imaging techniques are useful to achieve a correct diagnosis. Operative management for acute or chronic isolated posterior tibial translation >10 mm should be reserved for patients with symptoms of pain or instability which have failed an adequate course of conservative treatment. Several techniques for PCL reconstruction (PCLR) have been described. Autograft, allograft and synthetic grafts can be used for PCLR. Graft versus host rejection and potential disease transmission are the main disadvantages of allografts, whereas autografts are burdened with donor site morbidity, limited size and availability and prolonged operative time. To overcome some of these limitations, synthetic grafts for PCL reconstruction have been introduced. Artificial ligaments have been introduced for knee ligament reconstruction over a century ago. Synthetic ligaments should allow faster surgical duration and post-operative recovery avoiding donor site morbidity and graft versus host reactions. The Ligament Advanced Reinforcement System (LARS) is a scaffold type artificial ligament composed of polyethylene terephthalate, which has been widely used for ligament reconstruction of the knee. The LARS was introduced in 1992, but the evidences of its use on PCL reconstruction are limited, and few long-term studies have been conducted. LARS demonstrated lower rates of failure, revision and synovitis when compared with older devices for anterior cruciate ligaments reconstruction. However, the evidence on the reliability and feasibility of LARS for primary isolated PCL reconstruction is limited.

The primary outcome of interest of the present study was to investigate the outcomes of PCL reconstruction using a LARS synthetic ligament. The secondary outcome of interest was to compare the outcome of the LARS versus four-strand hamstring tendon (4SHT) autograft for PCL reconstruction. The focus of the present study was on joint stability, patient reported outcome measures (PROMs) and complications.

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**Material and methods**

**Search strategy**

This systematic review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses: the 2020 PRISMA statement. The PICOT algorithm was preliminarily set out:

- **P (population):** PCL reconstruction;
- **I (intervention):** LARS;
- **C (comparison):** 4SHT;
- **O (outcomes):** laxity, PROMs, revision.
- **T (timing):** >12 months.
Data source

Two authors (F.M. & A.P.) independently performed the literature search accessing the following databases: Pubmed, Google scholar, Embase and Web of Science. The literature search was performed in May 2021. The following keywords were used in combination: knee, PCL, posterior cruciate ligament, injury, damage, rupture, tear, treatment, management, LARS, arthroscopy, surgery, reconstruction, hamstring tendon, PROMs, patient reported outcome measures, stability, laxity, instability, quality of life, function, revision, reoperation. The same authors independently screened the resulting titles and abstracts. The full-text of articles which matched the topic of interest were accessed. The references of the full-text articles were also screened to identify further articles. Disagreements between the authors were solved by a third author (N.M.).

Eligibility criteria

All the clinical trials investigating the role of LARS for PCL reconstruction were accessed. Given the authors capabilities, articles in English, German, Italian, French and Spanish were considered. Level I to III of evidence, according to Oxford Centre of Evidence-Based Medicine, were eligible. Only studies which performed primary PCL reconstruction were considered. Studies in which PCL repair had been performed were excluded, as were studies reporting outcomes in multiple ligament damage setting. Technical notes, opinions, reviews and meta-analysis, editorials, and comments were not eligible. Cadaveric, animals and biomechanics studies were not considered. Only studies with a minimum 12 months follow-up were eligible. Only articles reporting quantitative data under the outcomes of interest were considered for inclusion.

Data extraction

Two authors (F.M. & A.P.) separately performed data extraction. Patient demographics data at baseline were collected: mean age, gender, time elapsed from injury to surgery and the length of the follow-up were collected. The following data were collected at baseline and last follow-up: mean instrumental laxity, mean Lysholm score, mean Tegner activity scale, mean International Knee Document Committee (IKDC). The rate of complication at last follow-up was also retrieved. The instrumental laxity was evaluated using the arthrometers KT-1000 (MEDmetric Corp, San Diego, CA, USA), which applies a force on the tibia plateau over the femur condyles directed posteriorly of 134 N.

Outcomes of interest

The primary outcome of interest was to investigate the outcomes of PCL reconstruction using a LARS synthetic ligament. The secondary outcome of interest was to compare LARS versus 4SHT autograft for PCL reconstruction.

Methodology quality assessment

The Coleman Methodology Score (CMS) was calculated by a single author (A.P.) to evaluate the quality of the methodological assessment. The CMS is widely employed to evaluate systematic reviews and meta-analyses. This score rates several aspects of the included studies: study size, length of the follow-up, surgical approach, type of study, and the description of diagnosis, surgical technique, rehabilitation, outcome criteria assessment, procedures for assessing outcomes, and the subject selection process are also evaluated. The CMS evaluated each study in a value between 0 (poor) and 100 (excellent). An overall mean value >60 points is considered satisfactory.

Statistical analysis

The statistical analyses were performed by the main author (F.M.) using the IBM SPSS software version 25 for descriptive statistics and the Review Manager Software version 5.3 (The Nordic Cochrane Collaboration, Copenhagen) for the meta-analyses. For descriptive statistics, the Shapiro–Wilk test was
performed to investigate data distribution. For normal data, mean and standard deviation (SD) were calculated. For non-parametric data, median and interquartile range (IQR) were calculated. To investigate the improvement from baseline to the last follow-up, the mean difference (MD) effect measure was adopted and t-test to assess statistical significance. The meta-analyses were performed using the Review Manager Software version 5.3 (The Nordic Cochrane Collaboration, Copenhagen). The inverse variance was adopted for continuous variables, with MD effect measure. Dichotomic data were evaluated through a Mantel–Haenszel analysis, with odd ratio (OR) effect measure. The comparisons were performed with a fixed model effect as set up. Heterogeneity was assessed through the Higgins-I² test. If I² test >50%, a random model effect was adopted. The confidence intervals (CI) were set at 95% in all comparisons. The overall effect was considered statistically significant if \( P < 0.05 \). The funnel plot of the most commonly reported outcome was performed to assess the risk of publication bias.

### Results

**Search result**

The literature search resulted in 392 articles. Of them, 94 were excluded as they were duplicates. A further 288 articles were excluded as they did not fulfil the eligibility criteria: study design \( (N = 83) \), not matching the topic \( (N = 201) \), revision setting \( (N = 1) \), combined intervention \( (N = 3) \). A further three articles were excluded because did not report quantitative data under the outcomes of interest. This left seven clinical trials for the present study. The results of the literature search are shown in Fig. 1.

**Methodological quality assessment**

The retrospective design of the included studies represents the most important limitation. The study size and the length of the follow-up were limited in most of studies. Overall, surgical approach, diagnosis and rehabilitation protocols were clearly defined.

Outcome measures and timing of assessment were often well outlined, as were the procedures for assessing outcomes and subject selection. Concluding, the CMS scored 67, attesting the good quality of the studies included (Table 1).

**Patient demographics**

Data from 180 procedures on LARS were collected. The median length of the follow-up was 37 (IQR 24.6) months. The mean age of the patients was 31.3 ± 2.8 years. 32% (58 of 180 patients) were women. The median time span from injury to surgery was 8.5 ± 5.5 months. Study generalities and patient demographics are shown in Table 2.

**Outcomes of synthetic grafts**

All the endpoints of interest significantly improved from baseline to the last follow-up (Table 3): Lysholm score (+25.2; \( P < 0.0001 \)), Tegner activity scale (+3.5; \( P = 0.0009 \)), IKDC (+24.8; \( P = 0.04 \)), arthrometer laxity (−9.2; \( P = 0.01 \)).

**Meta-analyses**

Three studies (87 procedures) were included in the meta-analyses. There was good comparability in terms of Lysholm, Tegner, age and women at baseline \( (P > 0.1) \). At a mean of 37.5 ± 15.8 months, no difference was found between synthetic graft and 4SHT in terms of Lysholm score \( (P = 0.8) \), Tegner scale \( (P = 0.4) \) and reoperations \( (P = 0.8) \). These results are shown in greater detail in Fig. 2.

**Discussion**

According to the main findings of the present study, the LARS ligament for PCL reconstruction showed significantly improvement of the Lysholm, Tegner, IKDC scores and a reduced laxity at arthrometer at midterm follow-up. Moreover, Lysholm, Tegner and the rate of revisions of LARS were similar to those exhibited by patients undergoing 4SHT autografts at last follow-up.
Systematic reviews which analysed synthetic grafts for anterior cruciate ligament reconstruction showed good outcome scores for LARS, comparable to autograft techniques in the short to medium term.\textsuperscript{32,33} The clinical studies included in the meta-analyses which compared the LARS versus 4SHT reported controversial results. Li et al. compared the LARS versus 4SHG for PCL reconstruction in a clinical setting, concluding that LARS performed better compared to the 4SHG in terms of PROMs, laxity and patient satisfaction.\textsuperscript{46} Conversely, Xu et al.\textsuperscript{40} and Saragaglia et al.\textsuperscript{47} found similar clinical and functional results for the LARS and 4SHT, with both groups significantly improved at last follow-up.\textsuperscript{40,47} A possible explanation to these controversial results could be that the current literature is of poor methodological quality, and trials with long-term follow-up are required to determine the safety and efficacy of the LARS. A previous systematic review investigating the outcomes of the use of the LARS
Table 1  Coleman methodology score

| Endpoints                                                                 | Mean value |
|---------------------------------------------------------------------------|------------|
| Part A: Only one score to be given for each of the 7 sections             |            |
| 1. Study size: number of patients                                         4/10        |
| 2. Mean follow-up                                                         6/10        |
| 3. Surgical approach                                                      8/10        |
| 4. Type of study                                                          0/15        |
| 5. Description of diagnosis                                               5/5         |
| 6. Descriptions of surgical technique                                     10/10       |
| 7. Description of post-operative rehabilitation                           4/5         |
| Part B: Scores may be given for each option in each of the 3 sections if applicable |
| 1. Outcome criteria                                                       |            |
| Outcome measures clearly defined                                          2/2         |
| Timing of outcome assessment clearly stated                               2/2         |
| Use of outcome criteria that has reported reliability                     3/3         |
| General health measure included                                           2/3         |
| 2. Procedure of assessing outcomes                                         |            |
| Participants recruited                                                    5/5         |
| Investigator independent of surgeon                                       4/4         |
| Written assessment                                                        2/3         |
| Completion of assessment by patients themselves with minimal investigator assistance 3/3 |
| 3. Description of subject selection process                               |            |
| Selection criteria reported and unbiased                                  4/5         |
| Recruitment rate reported >80%                                             4/5         |
| Recruitment rate reported <80%                                             0/5         |

Table 2  Study generalities and patient demographic

| Author et al. (year) | Journal           | Design        | Treatment | Bundle | Follow-up (months) | Patients (n) | Mean age |
|----------------------|-------------------|---------------|-----------|--------|-------------------|--------------|----------|
| Chen et al. (2012)   | Orthopedics       | Retrospective | LARS      | Double | 37                | 38           | 32.6     |
| Chiang et al. (2019) | Knee              | Retrospective | LARS      | Double | 142.8             | 38           | 31.0     |
| Huang et al. (2010)  | Chin Med J        | Retrospective | LARS      | Single | 29.4              | 28           | 27.5     |
| Li et al. (2008)     | Int Orthop        | Retrospective | 4SHT      | Single | 28.8              | 21           | 20–43    |
| Saragaglia et al. (2020) | Int Orthop      | Retrospective | 4SHT      | Double | 26.4              | 21           | 18–47    |
| Shen et al. (2012)   | J Surg Res        | Retrospective | LARS      | Single | 44                | 41           | 34.0     |
| Xu et al. (2014)     | Arch Orthop Trauma Surg | Retrospective | LARS      | Single | 51                | 16           | 29.1     |

reported similar findings. Overall, they included five studies (129 procedures) and reported data at medium-term findings, from 10.5 to 44 months. They concluded that the LARS may be successfully employed for PCL reconstruction, although the authors suggested further studies to definitely
Table 3 Main results (FU: follow-up)

| Endpoints                  | Preoperative | Last FU     | MD  | P        |
|---------------------------|--------------|-------------|-----|----------|
| Lysholm score             | 63.3 ± 8.5   | 88.4 ± 4.3  | +25.2 | <0.0001  |
| Tegner activity scale     | 3.0 ± 0.6    | 6.5 ± 0.6   | +3.5 | 0.0009   |
| IKDC                      | 59.4 ± 1.1   | 84.1 ± 3.1  | +24.8 | 0.04     |
| KT-1000 arthrometer       | 12.5 ± 1.1   | 3.3 ± 0.9   | −9.2  | 0.005    |

Lysholm score

| Study or Subgroup         | 4SHT Mean  | SD  | Total | Synthetic Mean | SD  | Total | Weight |
|---------------------------|------------|-----|-------|----------------|-----|-------|--------|
| Saragalia et al. 2019     | 85.3       | 5.1 | 27    | 86.7           | 4.5 | 21    | 51.8%  |
| Xu et al. 2014            | 87.9       | 7.7 | 51    | 87             | 6.8 | 51    | 48.2%  |
| Total (95% CI)            | 78         |     | 72    |                |     | 100.0% |
| Heterogeneity: Chi² = 1.32, df = 1 (P = 0.25); I² = 24% |
| Test for overall effect: Z = 0.29 (P = 0.77) |

Tegner scale

| Study or Subgroup         | 4SHT Mean  | SD  | Total | Synthetic Mean | SD  | Total | Weight |
|---------------------------|------------|-----|-------|----------------|-----|-------|--------|
| Saragalia et al. 2019     | 7.1        | 0.8 | 27    | 7.2            | 0.7 | 21    | 35.7%  |
| Xu et al. 2014            | 6.31       | 0.79| 51    | 6.42           | 0.84| 51    | 64.3%  |
| Total (95% CI)            | 78         |     | 72    |                |     | 100.0% |
| Heterogeneity: Chi² = 0.00, df = 1 (P = 0.97); I² = 0% |
| Test for overall effect: Z = 0.82 (P = 0.41) |

Reoperations

| Study or Subgroup         | 4SHT Events | Total | Synthetic Events | Total | Weight |
|---------------------------|-------------|-------|-----------------|-------|--------|
| Li et. al. 2008           | 1           | 15    | 0               | 21    | 22.2%  |
| Xu et al. 2014            | 0           | 16    | 1               | 19    | 77.8%  |
| Total (95% CI)            | 31          |       | 40              |       | 100.0% |
| Total events              | 1           |       | 1               |       |        |
| Heterogeneity: Chi² = 1.10, df = 1 (P = 0.29); I² = 9% |
| Test for overall effect: Z = 0.24 (P = 0.81) |

Fig. 2 Forest plots.

ascertain the viability of the LARS as an alternative to autograft and allograft in PCL reconstruction.38

Synthetic grafts have been introduced to avoid complications such rejection and potential disease transmission of allografts, or donor site morbidity, limited size and availability, prolonged operative time of autografts.26–28,45 To avoid degeneration and weakness of auto- and allografts, the ligament
augmentation device (LAD) was introduced.\cite{48,49} The LAD aimed to have a load-sharing function between the device and the graft to protect the latter from degeneration and weakening over time.\cite{50} However, as other synthetic augmentation devices,\cite{51,52} the LAD was ineffective in augmenting the traditional biological grafts and its use is limited.\cite{53} During the last 15 years, the LARS has been the most commonly used artificial ligament in Europe, showing good clinical results and satisfactory torsional fatigue resistance.\cite{10,45} The rate of complications reported with LARS (e.g. rupture, reactive synovitis) is less than other synthetic ligaments.\cite{54,55} To simulate the native ligament, the intra-articular portion of the LARS ligament is made of parallel, longitudinal and totally independent fibres which do not cross or transverse the components. The scaffold structure is able to overcome fatigue and allows connective tissue ingrowth.\cite{39} Fibroblasts adhere to and surround the synthetic ligament fibres by building a capsule.\cite{56} The extra-articular woven fibres provide strength and resistance to elongation.\cite{39} The biocompatibility of the LARS has been demonstrated by the presence of fibroblast and osteoblast-like cells growth into its structure 6 months after surgery.\cite{10} In vitro ingrowth of blood vessels in the ligament has been also documented.\cite{56} Magnetic resonance imaging studies demonstrated similar fibrous tissue ingrowth in the midsubstance of LARS comparable to autograft and allograft.\cite{57} The intra-articular segment of the LARS seems to act as a scaffold for ingrowth of the ruptured ligament stump in the acute phase, reducing shear forces acting on it.\cite{56} Yu et al. described the histology and ultrastructure of LARS after implantation for anterior cruciate ligament reconstruction in rabbits.\cite{58} They demonstrated that progressive ‘ligamentization’ by means of autologous collagen tissue ingrowth is only achieved when the artificial ligament is implanted on a residual native ligament. A multicenter study including 159 patients showed that the LARS is more successful for anterior cruciate ligament reconstruction when patients preserved the residual stump.\cite{59}

Compared with autologous and allogeneic tendon, the LARS showed excellent biomechanical properties.\cite{45} It showed to help early function recovery, providing immediate stability for the knee after reconstruction, and correct dislocation motion.\cite{60} Therefore, the LARS can be considered when facing young athletes with high performance requirements, or patients who are not willing to undergo autograft or allograft reconstruction.\cite{29}

The present study has several limitations. Only three studies included a control group. All studies had limited small sample size, and only two studies reported follow-up data beyond 4 years. The LARS has been available for nearly 20 years, and it is surprising that there are only few long-term studies. It cannot be excluded that some problems related to the use of LARS for ligament reconstruction develop over time. Furthermore, there are not enough comparative studies of LARS versus autograft or allograft for PCL reconstruction. All studies were retrospective cohort studies, representing another potential limitation of the present study. We were not able to identify randomized clinical trials investigating PCL reconstruction using the LARS. Further high-quality comparative studies with larger sample size are needed to clarify the role of the LARS for PCL reconstruction. Given these limitations, data must be interpreted with caution, and these limitations should be addressed in future investigations.

**Conclusion**

The LARS for PCL reconstruction is effective, and its results were comparable to those achieved with 4SHT autografts.

**Conflict of interest statement**

The authors declare that they have no conflicts of interest.

**Ethical approval**

This article does not contain any studies with human participants or animals performed by any of the authors.
Informed consent

For this type of study informed consent is not required.

Data availability statement

The data underlying this article are available in the article and in its online supplementary material.

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References

1. Fanelli GC, Edson CJ (1995) Posterior cruciate ligament injuries in trauma patients: Part II. Art Ther 11 (5):526–9. https://doi.org/10.1016/0749-8063(95)90127-2.
2. Vaquero-Picado A, Rodriguez-Merchan EC (2017) Isolated posterior cruciate ligament tears: an update of management. EFORT Open Rev 2 (4):89–96. https://doi.org/10.1302/2058-5241.2.160009.
3. Wang SH, Chien WC, Chung CH, Wang YC, Lin LC, Pan RY (2018) Long-term results of posterior cruciate ligament tear with or without reconstruction: a nationwide, population-based cohort study. PLoS One 13 (10):e0205118. https://doi.org/10.1371/journal.pone.0205118.
4. Schulz MS, Russe K, Weiler A, Eichhorn HJ, Strobel MJ (2003) Epidemiology of posterior cruciate ligament injuries. Arch Orthop Trauma Surg 123 (4):186–91. https://doi.org/10.1007/s00402-002-0471-y.
5. Margheritini F, Mariani PP (2003) Diagnostic evaluation of posterior cruciate ligament injuries. Knee Surg Sports Traumatol Arthrosc 11 (5):282–8. https://doi.org/10.1007/s00167-003-0409-0.
6. LaPrade CM, Civitarese DM, Rasmussen MT, LaPrade RF (2015) Emerging updates on the posterior cruciate ligament: a review of the current literature. Am J Sports Med 43 (12):3077–92. https://doi.org/10.1177/0363546515572770.
7. Colvin AC, Meislin RJ (2009) Posterior cruciate ligament injuries in the athlete: diagnosis and treatment. Bull NYU Hosp Jt Dis 67 (1):45–51
8. Laoruengthana A, Jarusriwanna A (2012) Sensitivity and specificity of magnetic resonance imaging for knee injury and clinical application for the Naresuan University Hospital. J Med Assoc Thai 95 Suppl 10:S151–7.
9. Pache S, Aman ZS, Kennedy M, Nakama GY, Moatshe G, Ziegler C, LaPrade RF (2018) Posterior cruciate ligament: current concepts review. Arch Bone Jt Surg 6 (1):8–18.
10. Chen CP, Lin YM, Chiu YC, Wu HW, Lee CH, Tong KM, Huang KC (2012) Outcomes of arthroscopic double-bundle PCL reconstruction using the LARS artificial ligament. Orthopedics 35 (6):e800–6. https://doi.org/10.3928/01477447-20120525-16.
11. Petrillo S, Volpi P, Papalia R, Maffulli N, Denaro V (2017) Management of combined injuries of the posterior cruciate ligament and posterolateral corner of the knee: a systematic review. Br Med Bull 123 (1):47–57. https://doi.org/10.1093/bmb/ldx014.
12. Berg EE (1995) Posterior cruciate ligament tibial inlay reconstruction. Art Ther 11 (1):69–76. https://doi.org/10.1016/0749-8063(95)90091-8.
13. Hermans S, Corten K, Bellemans J (2009) Long-term results of isolated anterolateral bundle reconstructions of the posterior cruciate ligament: a 6- to 12-year follow-up study. Am J Sports Med 37 (8):1499–507. https://doi.org/10.1177/0363546509333479.
14. MacGillivray JD, Stein BE, Park M, Allen AA, Wickiewicz TL, Warren RF (2006) Comparison of tibial inlay versus transtibial techniques for isolated posterior cruciate ligament reconstruction: minimum 2-year follow-up. Art Ther 22 (3):320–8. https://doi.org/10.1016/j.arthro.2005.08.057.
15. Panchal HB, Sekiya JK (2011) Open tibial inlay versus arthroscopic transtibial posterior cruciate ligament reconstructions. Art Ther 27 (9):1289–95. https://doi.org/10.1016/j.arthro.2011.04.007.
16. Kang SH, Sohn KM, Lee DK, Lee BH, Yang SW, Wang JH (2020) Arthroscopic posterior cruciate ligament reconstruction: the Achilles Tendon Allograft versus the quadriceps Tendon Allograft. J Knee Surg 33 (6):553–9. https://doi.org/10.1055/s-0039-1681029.
17. Curry Rde P, Severino NR, Camargo OP, Aihara T, de Oliveira VM, Avakian R (2012) Posterior cruciate ligament reconstruction with autograft of the double semitendinosus muscles and middle third of the quadriceps Tendon with double femoral and single tibial tunnels: clinical results in two years follow up. Rev Bras Ortop 47 (1):57–65. https://doi.org/10.1016/S2255-4971(15)30346-3.
18. Ochiai S, Hagino T, Senga S, Yamashita T, Haro H (2019) Treatment outcome of reconstruction for isolated posterior cruciate injury: subjective and
objective evaluations. J Knee Surg 32 (6):506–12. https://doi.org/10.1055/s-0038-1653947.

19. Yoon KH, Bae DK, Song SJ, Cho HJ, Lee JH (2011) A prospective randomized study comparing arthroscopic single-bundle and double-bundle posterior cruciate ligament reconstructions preserving remnant fibers. Am J Sports Med 39 (3):474–80. https://doi.org/10.1177/0363546510382206.

20. Yoon KH, Kim EJ, Kwon YB, Kim SG (2019) Minimum 10-year results of single- versus double-bundle posterior cruciate ligament reconstruction: clinical, radiologic, and survivorship outcomes. Am J Sports Med 47 (4):822–7. https://doi.org/10.1177/0363546518825257.

21. Sun X, Zhang J, Qu X, Zheng Y (2015) Arthroscopic posterior cruciate ligament reconstruction with allograft versus autograft. Arch Med Sci 11 (2):395–401. https://doi.org/10.5114/aoms.2015.50971.

22. Wang R, Xu B, Wu L, Xu H (2018) Long-term outcomes after arthroscopic single-bundle reconstruction of the posterior cruciate ligament: a 7-year follow-up study. J Int Med Res 46 (2):865–72. https://doi.org/10.1177/03016050177722243.

23. Li B, Wang JS, He M, Wang GB, Shen P, Bai LH (2015) Comparison of hamstring tendon autograft and tibialis anterior allograft in arthroscopic transtibial single-bundle posterior cruciate ligament reconstruction. Knee Surg Sports Traumatol Arthrosc 23 (10):3077–84. https://doi.org/10.1007/s00167-014-3267-z.

24. Wang CJ, Chan YS, Weng LH, Yuan LJ, Chen HS (2004) Comparison of autogenous and allogeneous posterior cruciate ligament reconstructions of the knee. Injury 35 (12):1279–85. https://doi.org/10.1016/j.injury.2003.12.017.

25. Xu M, Zhang Q, Dai S, Teng X, Liu Y, Ma Z (2019) Double bundle versus single bundle reconstruction in the treatment of posterior cruciate ligament injury: a prospective comparative study. Indian J Orthop 53 (2):297–303. https://doi.org/10.4103/ortho.IJOrtho_430_17.

26. Min BH, Lee YS, Lee YS, Jin CZ, Son KH (2011) Evaluation of transtibial double-bundle posterior cruciate ligament reconstruction using a single-sling method with a tibialis anterior allograft. Am J Sports Med 39 (2):374–9. https://doi.org/10.1177/0363546510382207.

27. Sekiya JK, West RV, Ong BC, Irrgang JJ, Fu FH, Harner CD (2005) Clinical outcomes after isolated arthroscopic single-bundle posterior cruciate ligament reconstruction. Art Ther 21 (9):1042–50. https://doi.org/10.1016/j.arthro.2005.05.023.

28. Yoon KH, Bae DK, Song SJ, Lim CT (2005) Arthroscopic double-bundle augmentation of posterior cruciate ligament using split Achilles allograft. Art Ther 21 (12):1436–42. https://doi.org/10.1016/j.arthro.2005.09.002.

29. Shen G, Xu Y, Dong Q, Zhou H, Yu C (2012) Arthroscopic posterior cruciate ligament reconstruction using LARS artificial ligament: a retrospective study. J Surg Res 173 (1):75–82. https://doi.org/10.1016/j.jss.2010.08.015.

30. Corner EM. (1914) Notes of a case illustrative of an artificial anterior crucial ligament, demonstrating the action of that ligament. Proc R Soc Med 7 (Clin Sect) 7 (1):120–1.

31. Beauchamp P, Laurin CA, Bailon JP (1979) [A study of the tensile strength of cruciate ligaments with regard to the possibilities of prosthetic replacement (author’s transl]]. Rev Chir Orthop Reparatrice Appar Mot 65 (4):197–207.

32. Newman SD, Atkinson HD, Willis-Owen CA (2013) Anterior cruciate ligament reconstruction with the ligament augmentation and reconstruction system: a systematic review. Int Orthop 37 (2):321–6. https://doi.org/10.1007/s00264-012-1654-y.

33. Mulford JS, Chen D (2011) Anterior cruciate ligament reconstruction: a systematic review of polyethylene terephthalate grafts. ANZ J Surg 81 (11):785–9. https://doi.org/10.1111/j.1445-2197.2011.05884.x.

34. Brunet P, Charrois O, Degeorges R, Boisrenoult P, Beaufils P (2005) [Reconstruction of acute posterior cruciate ligament tears using a synthetic ligament]. Rev Chir Orthop Reparatrice Appar Mot 91 (1):34–43. https://doi.org/10.1016/s0035-1040(05)84273-4.

35. Harner CD, Vogrin TM, Hoher J, Ma CB, Woo SL (2000) Biomechanical analysis of a posterior cruciate ligament reconstruction. Deficiency of the posterolateral structures as a cause of graft failure. Am J Sports Med 28 (1):32–9. https://doi.org/10.1177/0363546500280011801.

36. Nau T, Lavoie P, Duval N (2002) A new generation of artificial ligaments in reconstruction of the anterior cruciate ligament. Two-year follow-up of a randomised trial. J Bone Joint Surg Br 84 (3):356–60. https://doi.org/10.1302/0301-620x.84b3.12400.

37. Machotka Z, Scarborough I, Duncan W et al. Anterior cruciate ligament repair with LARS (ligament advanced reinforcement system): a systematic review.
Sports Med Arthrosc Rehabil Ther Tech 2010;2:29. https://doi.org/10.1186/1758-2555-2-29.

38. Smith C, Ajuied A, Wong F, Norris M, Back D, Davies A (2014) The use of the ligament augmentation and reconstruction system (LARS) for posterior cruciate reconstruction. Art Ther 30 (1):111–20. https://doi.org/10.1016/j.artthro.2013.09.081.

39. Chiang LY, Lee CH, Tong KM, Wang SP, Lee KT, Tsai WC, Chen CP (2020) Posterior cruciate ligament reconstruction implemented by the Ligament Advanced Reinforcement System over a minimum follow-up of 10 years. Knee 27 (1):165–72. https://doi.org/10.1016/j.knee.2019.11.004.

40. Xu X, Huang T, Liu Z, Wen H, Ye L, Hu Y, Yu H, Pan X (2014) Hamstring tendon autograft versus LARS artificial ligament for arthroscopic posterior cruciate ligament reconstruction in a long-term follow-up. Arch Orthop Trauma Surg 134 (12):1753–9. https://doi.org/10.1007/s00402-014-2104-7.

41. Batty LM, Norsworthy CJ, Lash NJ, Wasiak J, Richmond AK, Feller JA (2015) Synthetic devices for reconstructive surgery of the cruciate ligaments: a systematic review. Art Ther 31 (5):957–68. https://doi.org/10.1016/j.artther.2014.11.032.

42. Page MJ, Moher D, Bossuyt PM et al. PRISMA 2020 explanation and elaboration: updated guidance and exemplars for reporting systematic reviews. BMJ 2021;372:n160. https://doi.org/10.1136/bmj.n160.

43. Guyatt GH et al. (2008) GRADE: an emerging consensus on rating quality of evidence and strength of recommendations. BMJ 336 (7650):924–6.

44. Coleman BD, Khan KM, Maffulli N, Cook JL, Wark JD (2000) Studies of surgical outcome after patellar tendinopathy: clinical significance of methodological deficiencies and guidelines for future studies. Victorian Institute of Sport Tendon Study Group. Scand J Med Sci Sports 10 (1):2–11. https://doi.org/10.1034/j.1600-0838.2000.010001002.x.

45. Huang JM, Wang Q, Shen F, Wang ZM, Kang YF (2010) Cruciate ligament reconstruction using LARS artificial ligament under arthroscopy: 81 cases report. Chin Med J (Engl) 123 (2):160–4.

46. Li B, Wen Y, Wu H, Qian Q, Wu Y, Lin X (2009) Arthroscopic single-bundle posterior cruciate ligament reconstruction: retrospective review of hamstring tendon graft versus LARS artificial ligament. Int Orthop 33 (4):991–6. https://doi.org/10.1007/s00264-008-0628-6.

47. Saragaglia D, Francony F, Gaillot J, Paillhe R, Rubens-Duval B, Lateur G (2020) Posterior cruciate ligament reconstruction for chronic lesions: clinical experience with hamstring versus ligament advanced reinforcement system as graft. Int Orthop 44 (1):179–85. https://doi.org/10.1007/s00264-019-04434-7.

48. Kumar K, Maffulli N (1999) The ligament augmentation device: an historical perspective. Art Ther 15 (4):422–32. https://doi.org/10.1016/s0749-8063(99)70061-7.

49. Kennedy JC, Roth JH, Mendenhall HV, Sanford JB (1980) Presidential address. Intraarticular replacement in the anterior cruciate ligament-deficient knee. Am J Sports Med 8 (1):1–8. https://doi.org/10.1177/036354658000800101.

50. Drogset JO, GrontvedT T (2002) Anterior cruciate ligament reconstruction with and without a ligament augmentation device: results at 8-Year follow-up. Am J Sports Med 30 (6):851–6. https://doi.org/10.1177/03635465020300061601.

51. Pinar H, Gillquist J (1989) Dacron augmentation of a free patellar tendon graft: a biomechanical study. Art Ther 5 (4):328–30. https://doi.org/10.1016/0749-8063(89)90151-5.

52. Puddu G, Cipolla M, Cerullo G, Franco V, Gianni E (1993) Anterior cruciate ligament reconstruction using LARS artificial ligament and augmentation with PDS graft. Clin Sports Med 12 (1):13–24.

53. Santi MD, Richardson AB (1994) The ligament augmentation device in hamstring grafts for reconstruction of the anterior cruciate ligament. Am J Sports Med 22 (4):524–30. https://doi.org/10.1177/036354659402200415.

54. Gillquist J, Odensten M (1993) Reconstruction of old anterior cruciate ligament tears with a Dacron prosthesis. A prospective study. Am J Sports Med 21 (3):358–66. https://doi.org/10.1177/036354659302100306.

55. Lukianov AV, Richmond JC, Barrett GR, Gillquist J (1989) A multicenter study on the results of anterior cruciate ligament reconstruction using a Dacron ligament prosthesis in "salvage" cases. Am J Sports Med 17 (3):380–5; discussion 385-386. https://doi.org/10.1177/03635465901700312.

56. Trieb K, Blahovec H, Brand G, Sabeti M, Dominkus M, Kortz R (2004) In vivo and in vitro cellular ingrowth into a new generation of artificial ligaments. Eur Surg Res 36 (3):148–51. https://doi.org/10.1159/000077256.

57. Alcala-Galiano A, Baeva M, Ismael M, Argueso MJ (2014) Imaging of posterior cruciate ligament (PCL) reconstruction: normal postsurgical appearance and complications. Skeletal Radiol 43 (12):1659–68. https://doi.org/10.1007/s00256-014-1975-6.
58. Yu SB, Yang RH, Zuo ZN, Dong QR (2014) Histological characteristics and ultrastructure of polyethylene terephthalate LARS ligament after the reconstruction of anterior cruciate ligament in rabbits. *Int J Clin Exp Med* 7 (9):2511–8.

59. Gao K, Chen S, Wang L, Zhang W, Kang Y, Dong Q, Zhou H, Li L (2010) Anterior cruciate ligament reconstruction with LARS artificial ligament: a multicenter study with 3-to 5-year follow-up. *Art Ther* 26 (4):515–23. https://doi.org/10.1016/j.arthro.2010.02.001.

60. Ibrahim SA, Ahmad FH, Salah M, Al Misfer AR, Ghaffer SA, Khirat S (2008) Surgical management of traumatic knee dislocation. *Art Ther* 24 (2):178–87. https://doi.org/10.1016/j.arthro.2007.08.007.