Comparative Efficacy of Graft Options in Anterior Cruciate Ligament Reconstruction: A Systematic Review and Network Meta-Analysis

Zhuomao Mo, B.A., Dong Li, B.A., Binbin Yang, B.A., and Shujie Tang, M.D., Ph.D.

Purpose: To evaluate the effectiveness of various graft options for anterior cruciate ligament reconstruction using network meta-analysis. Methods: A medical literature search was conducted of PubMed, the Cochrane Library, Embase, SCOPUS, and Web of Science from their inception through March 1, 2019. The outcomes, including International Knee Documentation Committee (IKDC) form, Lachman test, Lysholm score, Pivot shift test, and Tegner score, were evaluated among graft options. Data extraction was carried out according to inclusion and exclusion criteria, and a network meta-analysis was performed using STATA 14.0. Results: A total of 45 trials with 3992 patients were included. The forest plots revealed no significant differences in IKDC, Lysholm, or Tegner score among the grafts. In Lachman score, a significant difference was found in the comparisons of hamstring tendon allograft (HT-AL) versus patellar tendon autograft (PT-AU) and HT-AL versus hamstring tendon autograft (HT-AU). In pivot shift test, PT-AU was superior to all the other grafts, and quadriceps tendon autograft (QT-AU) was superior to HT-AL and artificial ligament (Art-L) in the number of cases with negative results. According to the surface under the cumulative ranking area (SUCRA), PT-AU had the highest probability to be the best intervention in Lachman test and Tegner score; tibialis anterior tendon allograft (TA-AL) in IKDC and Lysholm score; and QT-AU in pivot shift test. Based on the cluster analysis of SUCRA, PT-AU was considered the most appropriate intervention in Lachman test. Conclusion: This study suggests that PT-AU may be the most appropriate graft for ACL reconstruction according to IKDC and Lachman test results. Level of Evidence: Level I, network meta-analysis of randomized controlled trials.

Introduction

As a critical component of anterior–posterior and rotational stabilizers, the anterior cruciate ligament (ACL) plays an important role in maintaining the stability of the knee joint. With the prevalence of sport and the improvement of competitive sport level, the incidence rate of ACL injury has been rising rapidly. Damage to the ACL is one of the most common knee injuries, and in the United States it occurs in >250,000 people per year. Furthermore, patients with ruptured ACL have unstable knee, cartilage injury, and meniscal damage that may lead to the occurrence of osteoarthritis (OA) and adversely affect the quality of life.

The standard procedure for ACL tear is surgical reconstruction, as conservative treatment is ineffective and direct repair is difficult. Approximately 100,000 cases of ACL reconstruction are performed in the United States annually, with the goal of returning individuals to stability and function. The efficacy of ACL reconstruction is mainly attributed to the type of graft. There are several conditions for ideal grafts, including easy accessibility, little donor site morbidity, immediate rigid fixation, and rapid wound healing, which may maximally reproduce those of native ACL. In clinical management, patellar tendon (PT) and hamstring tendon (HT) autografts are the most common and traditional choices. Nevertheless, they have some disadvantages, such as postoperative anterior knee pain, donor site morbidity, and quadriceps weakness in PT autograft and decreased hamstring tendon strength, delayed graft incorporation, and increased joint laxity in HT autograft.
more graft sources for ACL reconstruction, and now
many kinds of grafts such as quadriceps tendon (QT)
autograft, anterior or posterior tibialis tendon (TA/TP)
allograft, peroneus longus tendon (PLT), and artificial
ligament (ArtL) are also used in clinical practice.1,15,22-24

But which is the best graft for ACL reconstruction?
Some systematic reviews and direct meta-analyses have
been published to evaluate the effectiveness of graft
options. In 1 direct meta-analysis, Xie et al.11 found no
significant differences in IKDC score, Lachman test, or
pivot shift test between PT and HT autograft, but PT
autograft resulted in a higher incidence of anterior knee
pain, kneeling pain, and osteoarthritis. In another direct
meta-analysis, Riaz et al.25 found no significant differ-
cences in graft failure, stability, or percentage of patients
with a positive result of pivot shift test, but found sig-
nificant differences in graft site pain and kneeling pain
between QT and PT. Given the limitations of systematic
review and direct meta-analysis, it is difficult to deter-
mine which kind of graft is the most appropriate for
ACL reconstruction.

In recent years, network meta-analysis has been
developed rapidly. Network meta-analysis is a new
methodology to evaluate >3 interventions. Using fre-
cquency or Bayesian models, network meta-analysis can
provide estimates of relative efficacy between all in-
terventions, even though some have never been
compared head to head. Compared with direct meta-
analysis, it has many advantages, including compari-
sions of multiple interventions, calculation of indirect
evidence, and rank of included treatments.26,27 We
hypothesize that network meta-analysis will show no
difference in clinical outcomes among ACL graft
options, and we performed this network meta-analysis to
evaluate the effectiveness of various graft options for
ACL reconstruction.

Methods

Data Sources

A medical literature search was conducted in the
following databases from their inception through
March 1, 2019: PubMed, the Cochrane Library, Embase, SCOPUS and Web of Science. The search
strategy consisted of medical subject headings (MeSH)
and key words, including “anterior cruciate ligament
reconstruction,” “patellar tendon,” “hamstring tendon,”
“semitendinosus and gracilis tendons,” “semitendinosus
tendon,” “gracilis tendon,” “Leeds-Keio synthetic graft,”
“artificial ligament,” “Achilles tendon,” “posterior
tibialis tendon,” “anterior tibialis tendon,” “quadriceps
tendon,” “peroneal longus tendon,” “iliotibial band,”
and “randomized controlled trial.” The language of the
included studies was restricted to English. Two inves-

Investigators independently read the titles and abstracts of
the articles and selected the potential ones. The full
texts of the selected articles were reviewed based on
inclusion and exclusion criteria, in which a third
investigator checked the controversial articles.

Inclusion Criteria

Studies were included according to following criteria:
(1) randomized controlled trials (RCTs); (2) patients
who underwent ACL reconstruction; (3) studies
comparing the effectiveness of graft options in ACL
reconstruction; (4) follow-up ≥1 year; and (5) studies
with complete data.

Exclusion Criteria

The following studies were excluded: (1) literature
reviews; (2) duplicate studies; (3) formats other than
randomized controlled trials; (4) studies comparing
different fixations in which the same graft was used; (5)
studies in which patients had surgical history or mul-
tiligament injuries in the knee joint.

Data Extraction

Two investigators worked on the data extraction inde-
dependently and gathered the following information: (1)
basic characteristics, including study identification, inter-
vention, age and sex of patients, fixation, graft, and
follow-up duration; (2) outcome measurements,
including International Knee Documentation Committee
(IKDC) form, Lachman test, Lysholm score, Pivot shift
test, and Tegner score. For IKDC, the evaluation of overall
IKDC was used, and the number of the patients with grade
A or B was collected. For Lachman and Pivot shift tests, the
number of patients with negative results was collected.

Quality Assessment

Risk of bias was evaluated using the Cochrane Risk of
Bias Tool, which includes 6 domains: randomization
sequence generation, allocation concealment, blinding
of participants and outcome assessors, attrition bias,
reporting bias, and other bias. Each term was judged as
high risk, low risk, or unclear risk. The certainty of
evidence was evaluated based on the Grading of
Recommendations Assessment, Development, and
Evaluation (GRADE), which consists of 6 aspects:
within-study bias, across-studies bias, indirectness,
imprecision, heterogeneity, and incoherence, and the
procedure was performed using the CINeMA website
(http://cinema.ispm.ch). Quality assessment was inde-
dependently performed by 2 investigators, and disagree-
ments were checked by a third investigator.

Statistical Analysis

A network meta-analysis was performed using
STATA version 14.0. Continuous variables (Lysholm

z mo et al. e646
score and Tegner score) were analyzed using mean difference (MD) and its 95% credible interval (CrI), whereas the dichotomous variables (IKDC, Lachman test, and pivot shift test) used odds ratios (ORs). At the beginning of the network meta-analysis, pairwise meta-analyses were carried out for studies within DerSimonian-Laird random effects, then direct and indirect comparisons were performed, and interventions were ranked in order. A network plot was used to demonstrate different arms and integrations in each outcome, and a forest plot was used to show the results of network meta-analysis, the bold part indicating a significant difference. Rank was demonstrated according to the surface under the cumulative ranking area (SUCRA). Global inconsistency, loop specific inconsistency analysis, and node-splitting method were performed to estimate the inconsistency, and the result indicated no statistical inconsistency when \( p > .05 \). Furthermore, a subgroup analysis of IKDC and Lachman test was carried out based on the variables including follow-up, allocation concealment, and sample size, in which the result of B represented a significant difference. In addition, a meta-analysis of direct comparisons was performed for adverse events using Review Manager 5.3.

**Results**

**Identification of Relevant Studies**

1149 studies were identified according to our search strategy; 117 were excluded for duplication. The remaining 1032 studies were checked by reading titles and abstracts, of which 356 were excluded for systematic reviews and 460 for irrelevant topics. The full texts of 216 studies were assessed for eligibility, of which 32 were excluded for <1 year follow-up, 32 for comparing different fixations using the same graft, 34 for quasi-randomized controlled trials, and 73 for no related data provided. Finally, 45 studies were included
Characteristics of the Included Studies

The characteristics of included studies are summarized in the Appendix. All 45 studies were published in English, 3992 patients were involved, and the sample size ranged from 38 to 282 cases. In the included trials, Aune 200130 and Holm 201043; Barenius 201031 and size ranged from 38 to 282 cases. In the included trials, English, 3992 patients were involved, and the sample studies29,30,32,33,36,39,43,47,51,54,55,58,66,69-72 compared In terms of the grafts used, 17 female patients ranged from 13% to 100%.

In the included studies, the mean age of patients ranged from 20.1 to 42 years, and the percentage of follow-up durations.

In the included studies, the mean age of patients ranged from 20.1 to 42 years, and the percentage of follow-up durations.

Quality Assessment and GRADE

Based on the Cochrane Risk of Bias tool, the risk of bias varied in the studies (Appendix). All the studies had low risk of bias in randomized sequence generation, attrition bias, and reporting bias; 15 studies7,31,34,36-38,40,44,47,48,50,52,53,65,66 had low risk of bias in allocation concealment, 4 studies40,41,46,55 had low risk of bias in blinding participants, and 26 trials had low risk of bias in blinding outcome assessors (Appendix). In terms of GRADE evaluation, 110 comparisons were judged as moderate evidence, 21 as low evidence, and 5 as very low evidence (Appendix).

Results of Pairwise Meta-Analysis

A total of 24 direct comparisons from 5 outcomes were analyzed. The results (Appendix) indicated that 16 comparisons were low heterogeneity ($I^2 < 25\%$), 2 comparisons were moderate heterogeneity (25% $\leq I^2 \leq 50\%$), and 6 comparisons were high heterogeneity ($I^2 < 50\%$).

Results of Network Meta-Analysis

As illustrated in Fig 2, IKDC outcome was reported in 21 studies30,32,34,37-41,49-52,57,58,61-66,69 involving 8 interventions. The forest plot showed no significant difference in this outcome among the comparisons. The results of SUCRA indicated that TA-AL had the highest probability to be the best intervention, followed by PT-AU, HT-AU, ST-AU, PT-AL, HT-AL, Art-L, and Ac-AL (Appendix).

The outcome of Lachman test was reported in 20 studies31,33,35,37,38,40,42,44,45,48,52,57-59,61-64,67,68,72 involving 9 interventions (Fig 3). Two comparisons, HT-AL versus PT-AU and HT-AL versus HT-AU, demonstrated a significant difference in this outcome. SUCRA indicated that PT-AU had the highest probability to be the best intervention, followed by ST-AU, TA-AL, PT-AL, Art-L, HT-AU, PLT-AU, Ac-AL, and HT-AL (Appendix).

In terms of Lysholm score, 16 studies32,35,36,43,45-47,56,60,65,67,68 were analyzed (Appendix). Similar to the results of IKDC, no significant difference was found in this outcome among the comparisons. The cumulative probability of PT-AU, HT-AU, ST-AU, PT-AL, HT-AL, TA-AL, and ITB-AU to be the best intervention was 27.7%, 51%, 74.3%, 61%, 26.4%, 84%, and 25.7%, respectively (Appendix).

Concerning pivot shift test, the results showed that PT-AU was superior to other interventions in improving knee function (Appendix). Compared with QT-AU, HT-AL and Art-L showed fewer cases with negative results. The results of SUCRA showed that QT-AU had the highest probability to be the best intervention, followed by PT-AU, TA-AL, ST-AU, HT-AU, Ac-AL, PT-AL, HT-AL, and Art-L (Appendix).

The outcome of Tegner score was reported in 11 studies32,34,35,37,38,40,42,44,45,52 involving 5 kinds of grafts (Appendix). The forest plot indicated no significant difference in this score among the comparisons. The cumulative probability of PT-AU, HT-AU, PT-AL, and TP-AL to be the best intervention was 69.2%, 65.1%, 34.9%, 23.6%, and 57.1%, respectively (Appendix).

Cluster Analysis

According to the different probability of intervention in different outcomes, we perform a cluster analysis based on IKDC and Lachman test outcomes. As illustrated in Fig 4, PT-AU both got the higher probability in 2 outcomes among the included grafts.

Consistency Analysis, Contribution Plot, and Funnel Plot

As shown in the Appendix, no significant inconsistency was found in global inconsistency, loop-specific inconsistency, and node-splitting analysis. In
addition, the subgroup analysis showed no significant differences in IKDC and Lachman test based on follow-up, allocation concealment, and sample size (Appendix). The results of contribution plots and funnel plots are presented in the Appendix.

Complications

Thirty-seven studies mentioned complications, of which 4 studies reported no complications and 33 studies mentioned various complications. All the complications are listed in the Appendix. The complications with relatively higher incidence in ACL reconstruction, including graft rupture, graft failure, superficial infection, deep infection, and nerve injury, were analyzed. Based on the results of Fig 5, no significant difference was found in graft rupture, superficial infection, or deep infection among studies, whereas HT-AU showed a lower incidence than TP-AL (MD 0.25, 95% CrI 0.08 to 0.84), and PT-AL showed a lower incidence than HT-AL (MD 0.19, 95% CrI 0.04 to 0.95) in graft failure, and HT-AU showed a higher incidence than HT-AL in nerve injury (MD 28.50, 95% CrI 1.68 to 482.30).

Discussion

Main Findings

In this study, according to cluster analysis, PT-AU demonstrated superiority to other grafts in IKDC and Lachman test, which may be because the patellar tendon is 3 to 4 times stiffer than anterior cruciate ligaments. In previously published direct meta-analysis, PT-AU was reported to have better stability; in this network meta-analysis, the same conclusion was confirmed. Regarding the outcome of pivot shift test, QT-AU had the highest probability to be the best intervention. Meanwhile, the QT-AU showed the highest effect and widest CrI in the forest plot. However, only 1 study involving QT-AU was included and the superiority of QT-AU in the results should be taken cautiously.

Although no significant consistency was found in our research, the data that only compared the type of graft may have some problems. In the clinic, the graft options in ACL reconstruction involve different surgical technique, fixation systems, and number of grafts. The surgical method involving the type of graft, fixation, and other characteristics should be treated as a unique...
intervention in the comparison of network meta-analysis. Nevertheless, up to now, few trials have concentrated on comparing different surgical methods in ACL reconstruction. Meanwhile, the type of graft has an important effect on ACL reconstruction. Our research tried to find out the appropriate graft based on the existing trials, and we look forward to performing a comprehensive network meta-analysis that involves the detailed interventions.

Moreover, in the outcomes of SUCRA for IKDC and Lysholm score, TA-AL was the best intervention, which may be attributed to the higher effect of the studies involving TA-AL according to contribution plot and the small sample size of these studies in network plot. Meanwhile, the reoperation rate of allograft was higher than that of autograft, and consequently, the second choice, PT-AU, may be more appropriate than TA-AL in IKDC. In addition, a previous study suggested that a validated minimal clinically important difference has not been established for Lysholm score, and an 8-point difference likely trends toward a clinically important difference. However, our results of TA-AL in Lysholm score did not reach the suggested value.
Based on the cluster analysis in Fig 4, PT-AU may be the best graft for ACL reconstruction. However, the forest plots indicated no significant differences in IKDC, Lysholm, and Tegner score among the grafts, except that PT-AU and HT-AU were superior to HT-AL in postoperative negative rates of Lachman test, and PT-AU and QT-AU showed a favorable effect compared with HT-AL and Art-L in postoperative negative rate of pivot-shift test. The results of forest plots were not consistent with those of SUCRA, which may be attributed to the small quantities of the included trials. There are some methodological strengths in our review: (1) most of the included studies were high-quality RCTs based on the Cochrane Risk of Bias Tool; (2) no significant inconsistency existed in the included studies according to inconsistency analysis; and (3) no conspicuous publication bias was observed in our results.

Limitations
Our network meta-analysis has some limitations. First, in the included trials, different fixation systems were used for ACL reconstruction, which may affect the final outcomes, but we did not take it into consideration because of the diversity of the fixation systems used in the trials. Second, the complications were various, and each complication involved ≤3 grafts, so we did not make a network meta-analysis for it. Third, the small sample size of some interventions was an intrinsic weakness. On the one hand, most of the highly inconsistent results in pairwise meta-analysis involved fewer comparisons. On the other hand, some interventions that involved small sample sizes but reached a large difference make our results unsteady. Furthermore, most of the comparisons in GRADE in our research were moderate evidence.

Conclusions
This study suggests that PT-AU may be the most appropriate graft for ACL reconstruction according to IKDC and Lachman test results.

Acknowledgments
Z. Mo and D. Li contributed equally to this article.
References

1. Zlotnicki JP, Naendrup JH, Ferrer GA, Debski RE. Basic biomechanic principles of knee instability. *Curr Rev Musculoskelet Med* 2016;9:114-122.

2. Shuzhen L, Wei S, Jimin Z, et al. A meta-analysis of hamstring autografts versus bone-patellar tendon-bone autografts for reconstruction of the anterior cruciate ligament. *Knee* 2011;18:287-293.

3. Lohmander LS, Englund PM, Dahl L, Roos E. The long-term consequence of anterior cruciate ligament and meniscus injuries: Osteoarthritis. *Am J Sports Med* 2007;35:1756-1769.

4. Moses B, Orchard J, Orchard J. Systematic review: Annual incidence of ACL injury and surgery in various populations. *Res Sports Med* 2012;20:157-179.

5. van Meer BL, Oei EH, Meuffels DE, et al. Degenerative changes in the knee 2 years after anterior cruciate ligament rupture and related risk factors: A prospective observational follow-up study. *Am J Sports Med* 2016;44:1524-1533.

6. Paschos NK. Anterior cruciate ligament reconstruction and knee osteoarthritis. *World J Orthop* 2017;8:212.

7. Engebretsen L, Benum P, Fasting O, Molster A, Strand T. Anterior cruciate ligament reconstruction: An 11-year follow-up of a randomized controlled trial. *Am J Sports Med* 2011;39:2161-2169.

8. Chee MY, Chen Y, Pearce CJ, et al. Outcome of patellar tendon versus 4-strand hamstring tendon autografts for anterior cruciate ligament reconstruction: A systematic review and meta-analysis of prospective randomized trials. *Arthroscopy* 2017;33:450-463.

9. Zaffagnini S, Grassi A, Serra M, Marcacci M. Return to sport after ACL reconstruction: How, when and why? A narrative review of current evidence. *Joints* 2015;3:25-30.

10. McAllister DR, Joyce MJ, Mann BJ, Vangsness CT. Allograft update: The current status of tissue regulation, procurement, processing, and sterilization. *Am J Sports Med* 2007;35:2148-2158.

11. Middleton K, Hamilton T, Irrgang J, Karlsson J, Harner C, Fu F. Anatomic anterior cruciate ligament (ACL) reconstruction: A global perspective. Part 1. *Knee Surg Sports Traumatol Arthrosc* 2014;22:1467-1482.

12. Mo Z, Li D, Zhang R, Chang M, Yang B, Tang S. Comparative effectiveness and safety of posterior lumbar interbody fusion, CoFlex, Wallis, and X-stop for lumbar degenerative diseases: A systematic review and network meta-analysis. *Clin Neurol Neurosurg* 2018;74-81.

13. Mo Z, Li D, Zhang R, Chang M, Yang B, Tang S. Comparative effectiveness and safety of posterior lumbar interbody fusion, CoFlex, Wallis, and X-stop for lumbar degenerative diseases: A systematic review and network meta-analysis. *Clin Neurol Neurosurg* 2020;43:813-823.

14. Hamner DL, Brown CH, Steiner ME, Hecker AT, Hayes W. Hamstring tendon grafts for reconstruction of the anterior cruciate ligament: Biomechanical evaluation of the use of multiple strands and tensioning techniques. *J Bone Joint Surg* Am 1999;81:549-557.

15. Steiner ME, Hecker AT, Brown CH Jr, Hayes WC. Anterior cruciate ligament graft fixation: comparison of hamstring and patellar tendon grafts. *Am J Sports Med* 1994;22:240-247.
tendon-bone autograft for anterior cruciate ligament reconstruction: A randomized study with two-year follow-up. *Am J Sports Med* 2001;29:722-728.
31. Barenius B, Nordlander M, Ponzer S, Tidermark J, Eriksson K. Quality of life and clinical outcome after anterior cruciate ligament reconstruction using patellar tendon graft or quadrupled semitendinosus graft: An 8-year follow-up of a randomized controlled trial. *Am J Sports Med* 2010;38:1533-1541.
32. Beard D, Anderson J, Davies S, Price A, Dodd C. Hamstrings vs. patella tendon for anterior cruciate ligament reconstruction: A randomised controlled trial. *Knee* 2001;8:45-50.
33. Beynnon BD, Johnson RJ, Fleming BC, et al. Anterior cruciate ligament replacement: Comparison of bone-patellar tendon-bone grafts with two-strand hamstring grafts: a prospective, randomized study. *J Bone Joint Surg Am* 2002;84:1503-1513.
34. Bottini CR, Smith EL, Shaha J, et al. Autograft versus allograft anterior cruciate ligament reconstruction: a prospective, randomized clinical study with a minimum 10-year follow-up. *Am J Sports Med* 2015;43:2501-2509.
35. Dai C, Wang F, Wang X, Wang R, Wang S, Tang S. Arthroscopic single-bundle anterior cruciate ligament reconstruction with six-strand hamstring tendon allograft versus bone-patellar tendon-bone allograft. *Knee Surg Sports Traumatol Arthrosc* 2016;24:2915-2922.
36. Drogset JO, Strand T, Uppheim G, Ødegård B, Bøe A, Grøntvedt T. Autologous patellar tendon and quadrupled hamstring grafts in anterior cruciate ligament reconstruction: A prospective randomized multicenter review of different fixation methods. *Knee Surg Sports Traumatol Arthrosc* 2010;18:1085-1093.
37. Ejerhed L, Kartus J, Sernert N, Kohler K, Karlsson J. Patellar tendon or semitendinosus tendon autografts for anterior cruciate ligament reconstruction? A prospective randomized study with a two-year follow-up. *Am J Sports Med* 2003;31:19-25.
38. Eriksson K, Anderberg P, Hamberg P, et al. A comparison of quadruple semitendinosus and patellar tendon grafts in reconstruction of the anterior cruciate ligament. *J Bone Joint Surg Br* 2001;83:348-354.
39. Feller JA, Webster KE. A randomized comparison of patellar tendon and hamstring tendon anterior cruciate ligament reconstruction. *Am J Sports Med* 2003;31:564-573.
40. Ghalayini SR, Helm AT, Bonshahi AY, Lavender A, Johnson DS, Smith RB. Arthroscopic anterior cruciate ligament surgery: Results of autogenous patellar tendon graft versus the Leeds-Keio synthetic graft five year follow-up of a prospective randomised controlled trial. *Knee* 2010;17:334-339.
41. Gobbi A, Domzalski M, Pascual J, Zanazzo M. Hamstring anterior cruciate ligament reconstruction: Is it necessary to sacrifice the gracilis? *Arthroscopy* 2005;21:275-280.
42. Grøntvedt T, Engebretsen L. Comparison between two techniques for surgical repair of the acutely torn anterior cruciate ligament. A prospective, randomized follow-up study of 48 patients. *Scand J Med Sci Sports* 1995;5:358-363.
43. Holm I, Oiestad BE, Risberg MA, Aune AK. No difference in knee function or prevalence of osteoarthritis after reconstruction of the anterior cruciate ligament with 4-strand hamstring autograft versus patellar tendon-bone autograft: A randomized study with 10-year follow-up. *Am J Sports Med* 2010;38:448-454.
44. Jia YH, Sun PF. Comparison of clinical outcome of autograft and allograft reconstruction for anterior cruciate ligament tears. *Chin Med J (Engl)* 2015;128:3163-3166.
45. Kang HJ, Wang XJ, Wu CJ, Cao JH, Yu DH, Zheng ZM. Single-bundle modified patellar tendon versus double-bundle tibialis anterior allograft ACL reconstruction: A prospective randomized study. *Knee Surg Sports Traumatol Arthrosc* 2015;23:2244-2249.
46. Karimi-Mobarakeh M, Mardani-Kivi M, Mortazavi A, Saheb-Ekhtiar K, Hashemi-Motlagh K. Role of gracilis harvesting in four-strand hamstring tendon anterior cruciate ligament reconstruction: A double-blinded prospective randomized clinical trial. *Knee Surg Sports Traumatol Arthrosc* 2015;23:1086-1091.
47. Kautzner J, Kos P, Hanus M, Trc T, Havlas V. A comparison of ACL reconstruction using patellar tendon versus hamstring autograft in female patients: a prospective randomised study. *Int Orthop* 2015;39:125-130.
48. Konrads C, Reppenhagen S, Plumhoff P, Hoberg M, Rudert M, Barthel T. No significant difference in clinical outcome and knee stability between patellar tendon and semitendinosus tendon in anterior cruciate ligament reconstruction. *Arch Orthop Trauma Surg* 2016;136:521-525.
49. Lawhorn KW, Howell SM, Traina SM, Gottlieb JE, Meade TD, Freedberg HI. The effect of graft tissue on anterior cruciate ligament outcomes: A multicenter, prospective, randomized controlled trial comparing autograft hamstrings with fresh-frozen anterior tibialis allograft. *Arthroscopy* 2012;28:1079-1086.
50. Laxdal G, Kartus J, Hansson L, Heidwall M, Ejerhed L, Karlsson J. A prospective randomized comparison of bone-patellar tendon-bone and hamstring grafts for anterior cruciate ligament reconstruction. *Arthroscopy* 2005;21:34-42.
51. Leitgeb J, Kottstorfer J, Schuster R, Kovar FM, Platzer P, Aldrian S. Primary anterior cruciate ligament reconstruction in athletes: A 5-year follow-up comparing patellar tendon versus hamstring tendon autograft. *Wien Klin Wochenschr* 2014;126:397-402.
52. Liden M, Ejerhed L, Sernert N, Laxdal G, Kartus J. Patellar tendon or semitendinosus tendon autografts for anterior cruciate ligament reconstruction: A comparison of ACL reconstruction using patellar tendon versus hamstring autograft in female patients: a prospective randomised study. *Int Orthop* 2015;39:125-130.
53. Lund B, Nielsen T, Fauno P, Christiansen SE, Lind M. Is quadriceps tendon a better graft choice than patellar tendon? A prospective randomized study. *Arthroscopy* 2014;30:593-598.
54. Maletis GB, Cameron SL, Tengan JJ, Burchette RJ. A prospective randomized study of anterior cruciate ligament reconstruction: A comparison of patellar tendon and quadruple-strand semitendinosus/gracilis tendons fixed with bioabsorbable interference screws. *Am J Sports Med* 2007;35:384-394.
55. Mohtadi N, Chan D, Barber R, Oddone Paolucci E. A randomized clinical trial comparing patellar tendon, hamstring tendon, and double-bundle ACL reconstructions: Patient-reported and clinical outcomes at a minimal 2-year follow-up. *Clin J Sport Med* 2015;25:321-331.

56. Niu Y, Niu C, Wang X, et al. Improved ACL reconstruction outcome using double-layer BPTB allograft compared to that using four-strand hamstring tendon allograft. *Knee* 2016;23:1093-1097.

57. Noh JH, Yi SR, Song SJ, Kim SW, Kim W. Comparison between hamstring autograft and free tendon Achilles allograft: Minimum 2-year follow-up after anterior cruciate ligament reconstruction using EndoButton and Intrafix. *Knee Surg Sports Traumatol Arthrosc* 2011;19:816-822.

58. Razi M, Sarzaeem MM, Kazemian GH, Najafi F, Najafi MA. Reconstruction of the anterior cruciate ligament: A comparison between bone-patellar tendon-bone grafts and four-strand hamstring grafts. *Med J Islam Repub Iran* 2014;28:134.

59. Shi FD, Hess DE, Zuo JZ, et al. Peroneus longus tendon autograft is a safe and effective alternative for anterior cruciate ligament reconstruction. *J Knee Surg* 2018;32:804-811.

60. Stensbirk F, Thorborg K, Konradsen L, Jorgensen U, Holmich P. Iliotibial band autograft versus bone-patellar-tendon-bone autograft, a possible alternative for ACL reconstruction: A 15-year prospective randomized controlled trial. *Knee Surg Sports Traumatol Arthrosc* 2014;22:2094-2101.

61. Sun K, Tian S, Zhang J, Xia C, Zhang C, Yu T. Anterior cruciate ligament reconstruction with BPTB autograft, irradiated versus non-irradiated allograft: A prospective randomized clinical study. *Knee Surg Sports Traumatol Arthrosc* 2009;17:464-474.

62. Sun K, Tian SQ, Zhang JH, Xia CS, Zhang CL, Yu TB. Anterior cruciate ligament reconstruction with bone-patellar tendon-bone autograft versus allograft. *Arthroscopy* 2009;25:750-759.

63. Sun K, Zhang J, Wang Y, et al. Arthroscopic reconstruction of the anterior cruciate ligament with hamstring tendon autograft and fresh-frozen allograft: A prospective, randomized controlled study. *Am J Sports Med* 2011;39:1430-1438.

64. Sun K, Zhang J, Wang Y, et al. Arthroscopic anterior cruciate ligament reconstruction with at least 2.5 years’ follow-up comparing hamstring tendon autograft and irradiated allograft. *Arthroscopy* 2011;27:1195-1202.

65. Sun R, Chen BC, Wang F, Wang XF, Chen JQ. Prospective randomized comparison of knee stability and joint degeneration for double- and single-bundle ACL reconstruction. *Knee Surg Sports Traumatol Arthrosc* 2015;23:1171-1178.

66. Taylor DC, DeBerardino TM, Nelson BJ, et al. Patellar tendon versus hamstring tendon autografts for anterior cruciate ligament reconstruction: A randomized controlled trial using similar femoral and tibial fixation methods. *Am J Sports Med* 2009;37:1946-1957.

67. Tian S, Wang B, Liu L, et al. Irradiated hamstring tendon allograft versus autograft for anatomic double-bundle anterior cruciate ligament reconstruction: Midterm clinical outcomes. *Am J Sports Med* 2016;44:2579-2588.

68. Tian S, Wang Y, Wang B, et al. Anatomic double-bundle anterior cruciate ligament reconstruction with a hamstring tendon autograft and fresh-frozen allograft: A prospective, randomized, and controlled study. *Arthroscopy* 2016;32:2521-2531.

69. Webster KE, Feller JA, Hameister KA. Bone tunnel enlargement following anterior cruciate ligament reconstruction: A randomised comparison of hamstring and patellar tendon grafts with 2-year follow-up. *Knee Surg Sports Traumatol Arthrosc* 2001;9:86-91.

70. Webster KE, Feller JA, Hartnett N, Leigh WB, Richmond AK. Comparison of patellar tendon and hamstring tendon anterior cruciate ligament reconstruction: A 15-year follow-up of a randomized controlled trial. *Am J Sports Med* 2016;44:83-90.

71. Zaffagnini S, Bruni D, Marcheggiani Muccioli GM, et al. Single-bundle patellar tendon versus non-anatomical double-bundle hamstrings ACL reconstruction: A prospective randomized study at 8-year minimum follow-up. *Knee Surg Sports Traumatol Arthrosc* 2011;19:390-397.

72. Zaffagnini S, Maracci M, Lo Presti M, Giordano G, Iacono F, Neri MP. Prospective and randomized evaluation of ACL reconstruction with three techniques: A clinical and radiographic evaluation at 5 years follow-up. *Knee Surg Sports Traumatol Arthrosc* 2006;14:1060-1069.

73. Noyes F, Butler D, Grood E, Zernicke R, Hefzy M. Biomechanical analysis of human ligament grafts used in knee-ligament. *J Bone Joint Surg Am* 1984;66:344-352.

74. 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* 2007;15:851-856.

75. Blau 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.

76. Mehta VM, Cassie M, Danielle F, Petsche TS. Comparison of revision rates in bone-patella tendon-bone autograft and allograft anterior cruciate ligament reconstruction. *Orthopedics* 2010;33:12.

77. Wright RW, Gill CS, Chen L, et al. Outcome of revision anterior cruciate ligament reconstruction: a systematic review. *J Bone Joint Surg Am* 2012;94:531-536.