

Femoral Tunnel Widening Via Transcondylar Cross-Pin Fixation Versus Extracortical Suspensory Fixation After Single-Bundle ACLR

A Systematic Review and Meta-analysis

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Background: Compared with extracortical suspensory fixation, the close-to-joint transcondylar cross-pin fixation method in anterior cruciate ligament reconstruction (ACLR) is believed to entail less intratunnel graft motion and subsequently lead to less tunnel widening.

Purpose: To assess femoral tunnel widening via the transcondylar cross-pin method or the suspensory femoral fixation method in patients who had undergone ACLR.

Study Design: Systematic review; Level of evidence, 4.

Methods: This review focused on studies on femoral-tunnel widening after single-bundle ACLR with cross-pin (Rigidfix or Transfix) and/or Endobutton closed loop (CL). Two reviewers independently recorded data from each study, including the sample size and magnitude of tunnel widening after ACLR.

Results: Overall, 19 studies were included in this meta-analysis. There was no significant difference between cross-pin and Endobutton CL fixations in the pooled absolute change in tunnel widening from the immediate postoperative period to the final follow-up; this was true at both the tunnel aperture (2.48 mm [95% CI, 1.76-3.2 mm] vs 2.93 mm [95% CI, 1.73-4.13 mm], respectively; $P = .527$) and the midpoint of the femoral tunnel (2.43 mm [95% CI, 1.77-3.1 mm] vs 2.54 mm [95% CI, -0.33 to 5.42 mm], respectively; $P = .937$). No significant difference was found in the relative percentage of femoral-tunnel widening between the 2 fixation methods (cross-pin, 43.3% [95% CI, 25.8%-60.8%] vs Endobutton CL, 42.0% [95% CI, 34.1%-49.9%]; $P = .965$).

Conclusion: No significant difference in femoral tunnel widening was found to be associated with the use of either cross-pin or extracortical suspensory fixation in patients who underwent single-bundle ACLR.

Keywords: anterior cruciate ligament; anterior cruciate ligament reconstruction; transcondylar cross fixation; extracortical suspensory fixation; tunnel widening

Tunnel widening occurs frequently after anterior cruciate ligament (ACL) reconstruction (ACLR), especially with the use of a soft tissue graft such as hamstrings, and is a concern for orthopaedic surgeons when it comes to reconstruction failure.¹³ Tunnel widening can lead to clinical impairment due to delayed graft healing within the tunnel as well as problems with neighboring tunnel establishment as a result of insufficient bone stock during revision ACLR.²⁵ Although the cause of tunnel widening remains

unknown, one of the postulated mechanical causes is graft motion within the tunnel in either a longitudinal or transverse direction.¹⁰

Intratunnel graft motion is largely dependent on the stiffness of the fixation method and less on the graft itself.⁶ Considering this, a close-to-joint transcondylar cross-pin fixation method (eg, Rigidfix or Transfix) would be expected to result in less intratunnel graft motion and therefore less tunnel widening compared with an extracortical suspensory fixation via an Endobutton closed loop (CL). Several biomechanical studies found that greater micromotion was produced with extracortical suspensory fixation, theoretically resulting in tunnel widening.^{24,28} Studies comparing

The Orthopaedic Journal of Sports Medicine, 9(4), 2325967121993811

DOI: 10.1177/2325967121993811

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tunnel widening using cross-pin versus suspensory fixation have yielded conflicting results,^{15,18} although the locations and methods used to measure tunnel widening have differed.^{15,18,20,27} Although numerous confounding factors contribute to tunnel widening after ACLR, further exploration of tunnel widening between cross-pin and suspensory fixation might be helpful to surgeons, because suspensory fixation has become popular.

The present study was designed to compare femoral tunnel widening in patients who underwent ACLR via either transcondylar cross-pin or suspensory femoral fixation. We hypothesized that suspensory femoral fixation would lead to greater femoral tunnel widening than cross-pin fixation.

METHODS

Literature Search

The study design was based on the Cochrane Review Methods. In accordance with the guidelines of the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) statement, multiple comprehensive literature databases, including PubMed, Embase, and Cochrane Library, were searched for studies that evaluated tunnel widening in patients who had undergone arthroscopic ACLR. No restrictions on language or year of publication were imposed. The search terms used in the title, abstract, Medical Subject Headings, and keywords fields included (*ACL OR anterior cruciate ligament reconstruction*) AND (*ACL OR tunnel widening*) AND (*anterior cruciate ligament reconstruction OR tunnel enlargement*).

Study Selection

Two reviewers (H.C. and J-H.K.) evaluated the titles and abstracts of the retrieved papers and selected relevant studies for full review. If the abstract did not provide sufficient data, the complete article was reviewed. Studies were included in the analysis if they (1) included patients who had undergone primary arthroscopic single-bundle ACLR with cross-pin (Rigidfix [Mitek] or Transfix [Arthrex]) and/or Endobutton (Smith & Nephew) CL and a hamstring tendon autograft; (2) evaluated femoral-tunnel widening with validated imaging tools such as plain radiography, computed tomography, and magnetic resonance imaging; and (3) reported complete sets of data, including means, standard deviations, and sample numbers. Of suspensory femoral fixation devices, only fixed-loop suspensory fixation devices were included; adjustable-loop suspensory fixation devices such as TightRope (Arthrex) were excluded to avoid heterogeneity. Additional interference screw or

post-tied screws and washer suspensions on the femoral fixation were also excluded.

In assessing and organizing the pooled studies, we noted the country and city of the hospital or institution at which the arthroscopic surgeries were performed, the operating surgeon's name, and the evaluation period so as to exclude duplicate cohorts of patients. If the same patient cohort had been evaluated in more than 1 study, the most recent study with the longest follow-up period was included, and the others were excluded.

Data Extraction

Two investigators (H.C. and J-H.K.) independently extracted data from each study using a predefined data extraction form. Any disagreements unresolved by discussion were reviewed by a third investigator (D-H.L.) if needed. The main outcome of interest included the amount of femoral tunnel widening in the cross-pin and Endobutton CL fixation devices. Tunnel widening was calculated as a change in femoral tunnel diameter based on immediate postoperative imaging. If no data were available for immediate postoperative femoral tunnel diameter, drill-reamer size was substituted. The site of the tunnel-widening measurement was recorded as the aperture, midpoint, or widest portion of the femoral tunnel. Tunnel widening was described either as the absolute change in diameter (in millimeters) at the tunnel aperture or midpoint from immediately after surgery to final follow-up or as the relative change (in percentages) at the widest portion of the femoral tunnel from immediately after surgery to final follow-up. The surgical technique (transtibial, anteromedial portal, and outside-in) and basic demographic data, including patient age, sex, and time interval from surgery to measurement of tunnel widening, were also recorded for each included study.

Assessment of Methodological Quality

The original Coleman Methodology Score (CMS) uses 10 criteria to assess the method of a given study, resulting in total scores between 0 and 100, with a score of 100 indicating that the study largely avoided important systemic sources of bias and other confounding factors. The subsections that compose the CMS are based on the subsections of the CONSORT (Consolidated Standards of Reporting Trials) statement for randomized controlled trials but were modified to allow for other study designs. The original CMS, which was developed for surgical treatment of tendinopathy, was modified for arthroplasty of the knee. The quality of each included study was evaluated by 2

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Final revision submitted September 17, 2020; accepted November 13, 2020.

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independent investigators (H.C. and J.-H.K.) using the modified Coleman Methodology Score (MCMS).

Statistical Analysis

The main outcomes of this meta-analysis were the mean differences in tunnel widening after single-bundle ACLR between cross-pin and Endobutton CL fixation devices. Random-effect meta-analyses were performed to pool the outcomes of tunnel widening across the included studies by estimating the standardized mean differences in tunnel widening and their 95% CIs between the aperture and midpoint of the femoral tunnel. Heterogeneity was determined by estimating the proportion of between-study inconsistencies due to actual differences between studies, rather than differences due to random error or chance, using the I^2 statistic, with values of 25%, 50%, and 75% considered low, moderate, and high, respectively. Publication bias was assessed using funnel plots and the Egger test when the number of included studies was >10 for each variable. In addition, a meta-regression analysis was performed to assess the effect of the follow-up period on the measurement of any change in tunnel widening. Analyses were performed using the R statistical software Version 3.4.0 (metafor Package: a Meta-Analysis Package for R; R Foundation for Statistical Computing) and RevMan Version 5.2 (Nordic Cochrane Centre, The Cochrane Collaboration).

RESULTS

Identification of Studies, Study Characteristics, and Quality

An initial electronic search yielded 90 studies, and 2 additional publications^{2,8} were identified after manual searching. After inclusion and exclusion criteria were applied, 19 studies were included in this meta-analysis. Figure 1 shows the details of study identification, inclusion, and exclusion.

Details of the 19 included studies are shown in Appendix Table A1. A total of 1150 patients were evaluated, with 568 undergoing ACLR with the cross-pin (Rigidfix or Transfix) and 582 with suspensory fixation (Endobutton CL). Measurement of tunnel widening was reported as the absolute change at both the tunnel aperture and midpoint in 7 studies,^{1,3,7,16,20-22} absolute change only at the aperture in 3 studies,^{11,15,29} and absolute change at the midpoint in 1 study⁸; 7 studies^{2,5,14,17-19,33} reported the relative percentage of femoral tunnel widening, and 1 study²⁷ measured tunnel widening as both absolute change at the midpoint as well as relative percentage at the widest portion. Two studies^{1,17} reported intraclass correlation coefficients, showing satisfactory reliability in measurement. Lind et al¹⁷ reported 0.91 and 0.94 for femoral anteroposterior and lateral radiographic measurements, respectively, and Aga et al¹ reported 0.829 for interrater reliability and 0.963 for intrarater reliability.

The total mean \pm SD MCMS of the included studies was 67.5 ± 5.6 (range, 56-78) of 90, which corresponds to a CMS of 75 when transferred to a 0 to 100 score, and thus, they

were regarded as high-quality studies. Of the 19 studies, 13 studies^{1,3,5,8,11,16-21,29,33} had a mean CMS of >70, whereas no studies had a mean score of <55 (Appendix Table A1).

Measurement of Tunnel Widening as Absolute Change

In the 12 studies[¶] that reported femoral tunnel widening as absolute change from immediate postoperative status to the final follow-up, cross-pin fixation was used in 250 patients, and Endobutton CL fixation was used in 181 patients. The pooled mean change in tunnel widening at the aperture was 2.48 mm (95% CI, 1.76-3.2 mm) for cross-pin fixation and 2.93 mm (95% CI, 1.73-4.13 mm) for Endobutton CL fixation, a difference that was not statistically significant ($P = .527$) (Figure 2).

Similar findings were found in the pooled mean absolute change for tunnel widening at the midpoint: 2.43 mm (95% CI, 1.77 to 3.1 mm) for cross-pin fixation and 2.54 mm (95% CI, -0.33 to 5.42 mm) for Endobutton CL fixation ($P = .937$) (Figure 3).

Measurement of Tunnel Widening as Relative Percentages

A total of 7 studies^{2,5,14,17-19,33} evaluated femoral tunnel widening as a relative percentage of change at the widest portion from immediate postoperative status to the final follow-up. A total of 318 and 401 patients were included in the cross-pin and Endobutton CL femoral fixation groups, respectively. The pooled relative percentage of change in femoral-tunnel widening was 43.3% (95% CI, 25.8%-60.8%) for cross-pin fixation and 42.0% (95% CI, 34.1%-49.9%) for Endobutton fixation, the difference not being statistically significant ($P = .965$) (Figure 4).

Meta-Regression Analyses

The results of the meta-regression analyses are reported in Table 1. The follow-up period did not affect the mean absolute value in millimeters of tunnel widening from immediate postoperative status up to the final follow-up at both the aperture and midpoint. Furthermore, mean relative percentage of tunnel widening was not influenced by the follow-up period.

DISCUSSION

The most important finding in this study was that contrary to our hypothesis, femoral-tunnel widening after single-bundle ACLR was similar between cross-pin and suspensory fixations, regardless of whether tunnel widening was measured as an absolute change at the aperture or midpoint or as relative change at the widest portion.

There are several possible reasons for our findings. One of the most well-known mechanical causes for tunnel

[¶]References 1, 3, 7, 8, 11, 15, 16, 20-22, 27, 29.

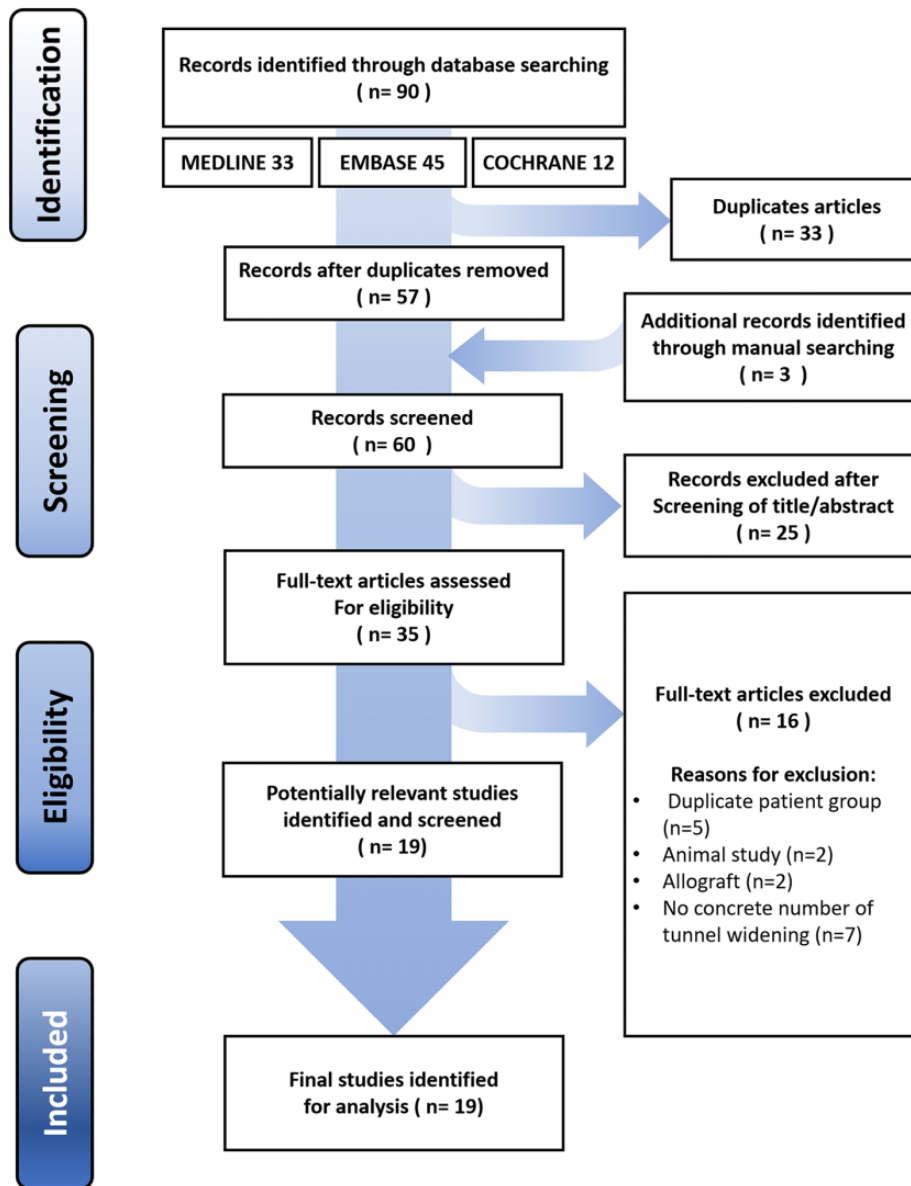


Figure 1. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flowchart of the identification and selection of studies included in this meta-analysis.

widening after ACLR is graft motion in the tunnel. The graft tunnel motion was mainly classified as longitudinal (bungee effect) and transverse (windshield wiper effect).²⁶ Several biomechanical studies have demonstrated that the longer the distance from the articular surface to the graft fixation, the greater will be the transverse graft micromotion at the tunnel aperture and longitudinal graft micromotion in the tunnel cylinder.^{24,28} In a cadaveric study performed by Hoher et al,⁹ the motion of a graft fixed by an Endobutton within the femoral tunnel could be 2 to 3 mm in the longitudinal direction even with physiological load and was positively correlated with the loop length of the Endobutton. In terms of transverse graft motion in suspensory fixation, Rodeo et al²³ showed that graft motion in

the femoral tunnel was significantly greater at the tunnel aperture than at midtunnel and the tunnel exit in a cadaveric rabbit model. However, those 2 biomechanical studies used the old version of suspensory fixation devices such as open Endobutton with hand-tied knot or suturing to the periosteum or surrounding soft tissues. With these 2 fixation devices, the mechanical strength of the device, which is the most important determinant of graft motion,⁶ was extremely weak; hence, graft motion in the tunnel occurred at least to some degree.

A recently enhanced version of the Endobutton CL with a polyester CL may decrease graft motion, not only in the longitudinal plane but also in the transverse plane, by increasing the mechanical strength of the fixation device

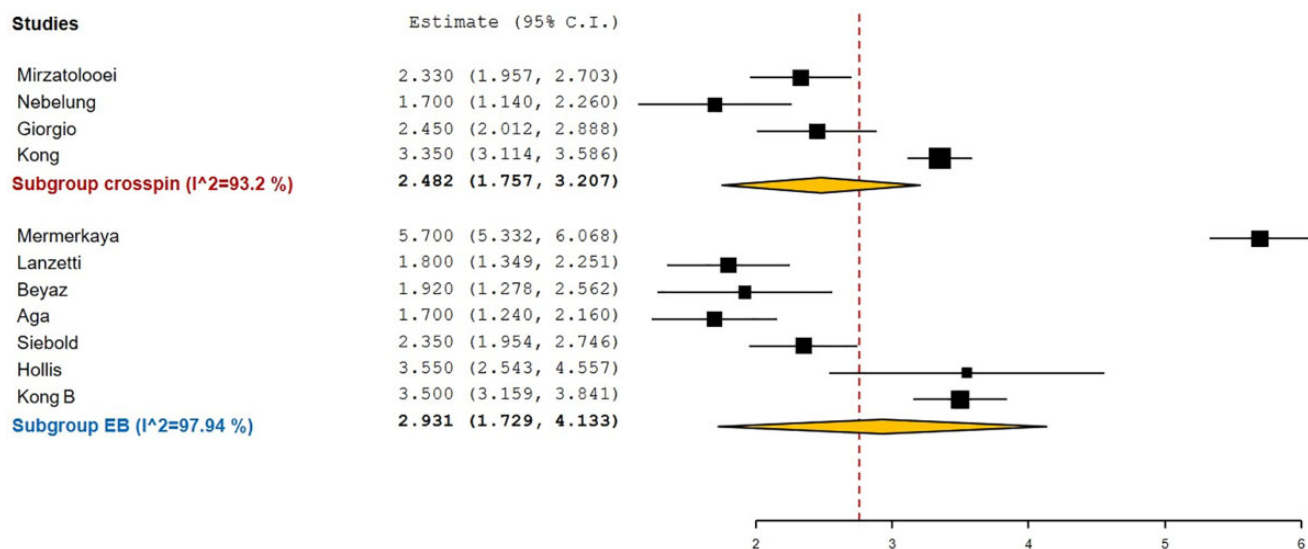


Figure 2. Forest plot showing absolute change in femoral-tunnel widening at the tunnel aperture for cross-pin versus extracortical suspensory fixation. EB, Endobutton closed loop.

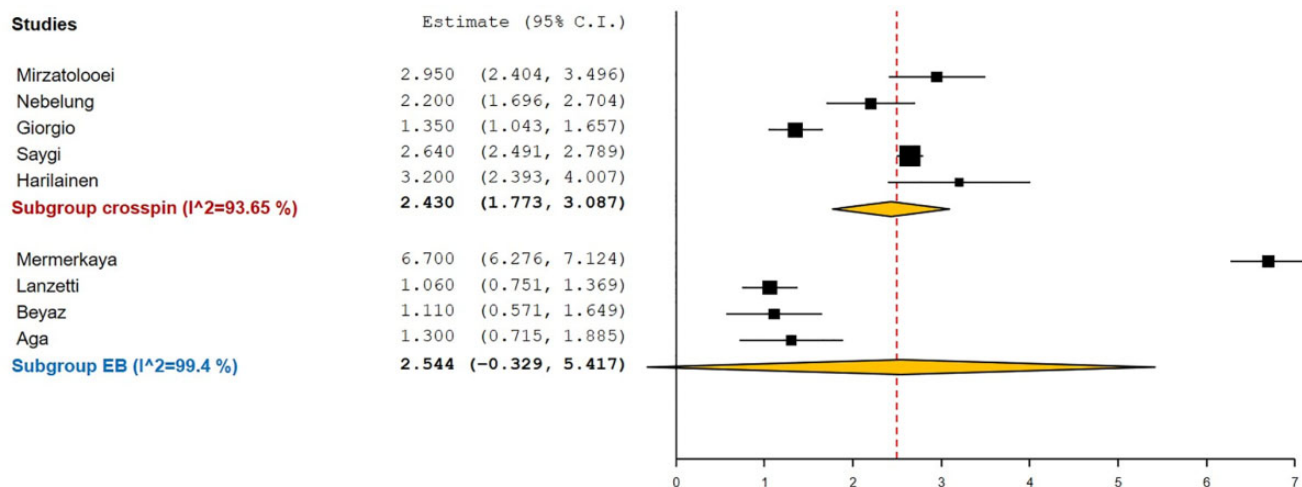


Figure 3. Forest plot showing absolute change in femoral tunnel widening at the midpoint for cross-pin versus extracortical suspensory fixation devices. EB, Endobutton closed loop.

compared with the previous hand-tied knot version.⁵ All included studies in the current study used the Endobutton CL with improved stiffness compared with open Endobutton with hand-tied knot. Another potential cause of tunnel widening could be biological factors, including local inflammation around the soft tissue graft and synovial bathing effect at the graft-tunnel interface.³⁰ As well, localized inflammation due to graft necrosis might trigger a resorptive effect of osteoclasts by releasing cytokines contained in the synovial fluid.²³ The fixation points of both Endobutton and cross-pin are far from the articular surface. Some graft micromotion in the tunnel due to a relatively longer graft fixation distance and a wider empty gap between the graft and the femoral tunnel aperture, rather than aperture fixation such as with a bioabsorbable

screw, facilitates easy invasion of synovial fluid at the graft-tunnel interface.

We believe that these biological mechanisms contribute to the development of tunnel widening to a greater extent than do biomechanical mechanisms. Similar femoral-tunnel widening in Endobutton and cross-pin at both the aperture and midpoint in our study is also suggestive of a greater role of a biological mechanism. A recent clinical study¹⁸ that compared femoral-tunnel widening after hamstring ACLR reported greater femoral tunnel widening when Rigidfix was used compared with extracortical fixation. A plausible cause of this result could be degradation of the absorbable material that makes up Rigidfix and creation of a chemical osmotic effect inside the bone tunnel, with a subsequent synovial bathing effect that could

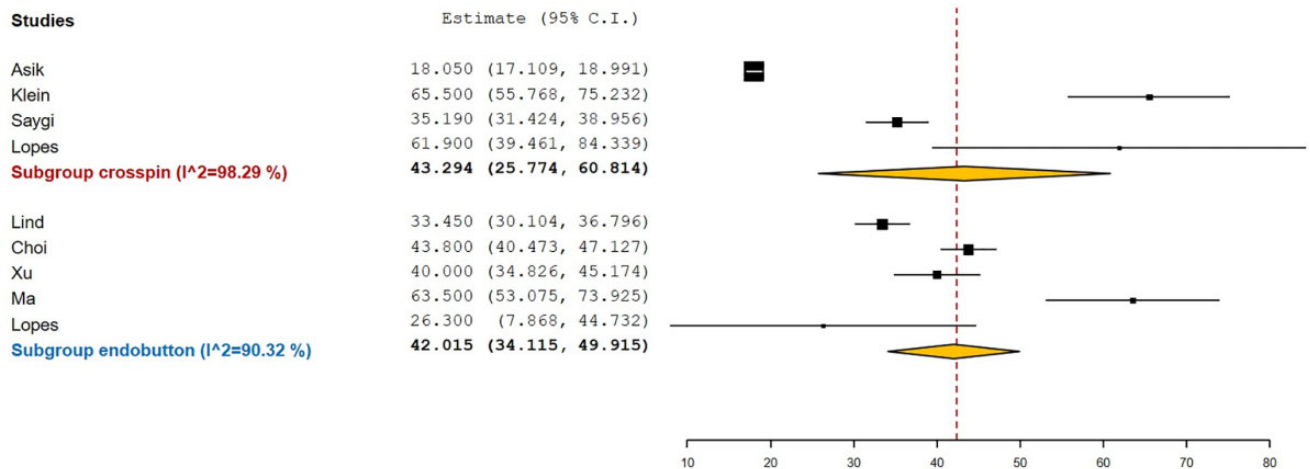


Figure 4. Forest plot showing relative percentage of femoral-tunnel widening at widest portion for cross-pin versus extracortical suspensory fixation devices.

TABLE 1

Results of Meta-Regression Analyses for Effect of Follow-up Period on Measurement of Change in Tunnel Widening^a

| Dependent Variable | Coefficient | SE | P Value | 95% CI |
|---|-------------|-------|---------|-----------------|
| Absolute change in TW at aperture | -0.002 | 0.201 | .991 | -0.040 to 0.039 |
| Absolute change in TW at midpoint | -0.003 | 0.032 | .916 | -0.066 to 0.059 |
| Relative change in TW at widest portion | -0.294 | 0.401 | .462 | -1.078 to 0.489 |

^aTW, tunnel widening.

promote femoral-tunnel widening. These findings also point to the role of a biological mechanism for the development of femoral-tunnel widening, apart from the mechanical factors related to fixation devices.

Limitations

This study had several limitations. One of the important shortcomings was that we could not entirely exclude other factors that may have affected tunnel widening, such as graft type, surgical technique, and time point of measurement of tunnel widening after surgery.^{4,22,31} However, we tried to reduce heterogeneity by including only single-bundle ACLR using a hamstring tendon autograft and cross-pin or extracortical suspensory methods of femoral fixation. Additionally, the results of the meta-regression analysis in our study showed that the follow-up time of the tunnel widening measurement had little influence on the mean change in widening, regardless of measurement site or method. Another limitation was that in case of absent information for immediate postoperative tunnel size, the size of the drill reamer was considered the baseline value

of femoral tunnel size. This substitution might result in an error in the immediate tunnel size. However, some recent studies have reported high reliability of size matching between femoral tunnel and femoral drill reamer, as per immediate postoperative computed tomography.^{12,32} Last, variations in measurement tools might be another limitation.

CONCLUSION

No significant difference in femoral-tunnel widening was found to be associated with the use of either cross-pin or extracortical suspensory fixation devices, both in terms of absolute millimeters and relative percentage, in patients who underwent single-bundle ACLR. This result might alleviate concerns regarding tunnel widening in patients undergoing ACLR with extracortical suspensory fixation devices, although studies with a high level of evidence are warranted in the future.

REFERENCES

1. Aga C, Wilson KJ, Johansen S, Dornan G, La Prade RF, Engebretsen L. Tunnel widening in single- versus double-bundle anterior cruciate ligament reconstructed knees. *Knee Surg Sports Traumatol Arthrosc.* 2017;25(4):1316-1327.
2. Asik M, Sen C, Tuncay I, Erdil M, Avci C, Taser OF. The mid- to long-term results of the anterior cruciate ligament reconstruction with hamstring tendons using Transfix technique. *Knee Surg Sports Traumatol Arthrosc.* 2007;15(8):965-972.
3. Beyaz S, Guler UO, Demir S, et al. Tunnel widening after single- versus double-bundle anterior cruciate ligament reconstruction: a randomized 8-year follow-up study. *Arch Orthop Trauma Surg.* 2017; 137(11):1547-1555.
4. Bin SI. Have evolving surgical methods improved clinical outcomes after anterior cruciate ligament reconstruction? *Knee Surg Relat Res.* 2017;29(1):1-2.

5. Choi NH, Oh JS, Jung SH, Victoroff BN. Correlation between Endobutton loop length and tunnel widening after hamstring anterior cruciate ligament reconstruction. *Am J Sports Med.* 2013;41(1):101-106.
 6. Fauno P, Kaalund S. Tunnel widening after hamstring anterior cruciate ligament reconstruction is influenced by the type of graft fixation used: a prospective randomized study. *Arthroscopy.* 2005;21(11):1337-1341.
 7. Giorgio N, Moretti L, Pignataro P, Carrozzo M, Vicenti G, Moretti B. Correlation between fixation systems elasticity and bone tunnel widening after ACL reconstruction. *Muscles Ligaments Tendons J.* 2016;6(4):467-472.
 8. Harilainen A, Sandelin J, Jansson KA. Cross-pin femoral fixation versus metal interference screw fixation in anterior cruciate ligament reconstruction with hamstring tendons: results of a controlled prospective randomized study with 2-year follow-up. *Arthroscopy.* 2005;21(1):25-33.
 9. Hoher J, Livesay GA, Ma CB, Withrow JD, Fu FH, Woo SL. Hamstring graft motion in the femoral bone tunnel when using titanium button/polyester tape fixation. *Knee Surg Sports Traumatol Arthrosc.* 1999;7(4):215-219.
 10. Hoher J, Moller HD, Fu FH. Bone tunnel enlargement after anterior cruciate ligament reconstruction: fact or fiction? *Knee Surg Sports Traumatol Arthrosc.* 1998;6(4):231-240.
 11. Hollis R, West H, Greis P, Brown N, Burks R. Autologous bone effects on femoral tunnel widening in hamstring anterior cruciate ligament reconstruction. *J Knee Surg.* 2009;22(2):114-119.
 12. Iorio R, Di Sanzo V, Vadala A, et al. ACL reconstruction with hamstrings: how different technique and fixation devices influence bone tunnel enlargement. *Eur Rev Med Pharmacol Sci.* 2013;17(21):2956-2961.
 13. Jeon YS, Choi SW, Park JH, Yoon JS, Shin JS, Kim MK. Mid-term outcomes of anterior cruciate ligament reconstruction with far antero-medial portal technique. *Knee Surg Relat Res.* 2017;29(1):19-25.
 14. Klein JP, Lintner DM, Downs D, Vavrenka K. The incidence and significance of femoral tunnel widening after quadrupled hamstring anterior cruciate ligament reconstruction using femoral cross pin fixation. *Arthroscopy.* 2003;19(5):470-476.
 15. Kong CG, In Y, Kim GH, Ahn CY. Cross pins versus Endobutton femoral fixation in hamstring anterior cruciate ligament reconstruction: minimum 4-year follow-up. *Knee Surg Relat Res.* 2012;24(1):34-39.
 16. Lanzetti RM, Monaco E, De Carli A, et al. Can an adjustable-loop length suspensory fixation device reduce femoral tunnel enlargement in anterior cruciate ligament reconstruction? A prospective computer tomography study. *Knee.* 2016;23(5):837-841.
 17. Lind M, Feller J, Webster KE. Bone tunnel widening after anterior cruciate ligament reconstruction using Endobutton or Endobutton continuous loop. *Arthroscopy.* 2009;25(11):1275-1280.
 18. Lopes OV Jr, de Freitas Spinelli L, Leite LHC, Buzzeto BQ, Saggin PRF, Kuhn A. Femoral tunnel enlargement after anterior cruciate ligament reconstruction using RigidFix compared with extracortical fixation. *Knee Surg Sports Traumatol Arthrosc.* 2017;25(5):1591-1597.
 19. Ma CB, Francis K, Towers J, Irrgang J, Fu FH, Harner CH. Hamstring anterior cruciate ligament reconstruction: a comparison of bioabsorbable interference screw and Endobutton-post fixation. *Arthroscopy.* 2004;20(2):122-128.
 20. Mermerkaya MU, Atay OA, Kaymaz B, Bekmez S, Karaaslan F, Doral MN. Anterior cruciate ligament reconstruction using a hamstring graft: a retrospective comparison of tunnel widening upon use of two different femoral fixation methods. *Knee Surg Sports Traumatol Arthrosc.* 2015;23(8):2283-2291.
 21. Mirzatalooei F, Alamdari MT, Khalkhali HR. The impact of platelet-rich plasma on the prevention of tunnel widening in anterior cruciate ligament reconstruction using quadrupled autologous hamstring tendon: a randomised clinical trial. *Bone Joint J.* 2013;95-B(1):65-69.
 22. Nebelung S, Deitmer G, Gebing R, Reichwein F, Nebelung W. High incidence of tunnel widening after anterior cruciate ligament reconstruction with transtibial femoral tunnel placement. *Arch Orthop Trauma Surg.* 2012;132(11):1653-1663.
 23. Rodeo SA, Kawamura S, Kim HJ, Dynybil C, Ying L. Tendon healing in a bone tunnel differs at the tunnel entrance versus the tunnel exit: an effect of graft-tunnel motion? *Am J Sports Med.* 2006;34(11):1790-1800.
 24. Rodriguez C, Garcia TE, Montes S, Rodriguez L, Maestro A. In vitro comparison between cortical and cortico-cancellous femoral suspension devices for anterior cruciate ligament reconstruction: implications for mobilization. *Knee Surg Sports Traumatol Arthrosc.* 2015;23(8):2324-2329.
 25. Sabzevari S, Rahnama-Azar AA, Shaikh HS, Arner JW, Irrgang JJ, Fu FH. Increased lateral tibial posterior slope is related to tibial tunnel widening after primary ACL reconstruction. *Knee Surg Sports Traumatol Arthrosc.* 2017;25(12):3906-3913.
 26. Saccomanno MF, Shin JJ, Mascarenhas R, et al. Clinical and functional outcomes after anterior cruciate ligament reconstruction using cortical button fixation versus transfemoral suspensory fixation: a systematic review of randomized controlled trials. *Arthroscopy.* 2014;30(11):1491-1498.
 27. Saygi B, Karaman O, Sirin E, Arslan I, Demir A, Oztermeli A. Comparison of different femoral fixation implants and fit techniques for tunnel widening and clinical outcome in ACL reconstruction using hamstring autograft. *Arch Orthop Trauma Surg.* 2016;136(2):241-247.
 28. Shen HC, Chang JH, Lee CH, et al. Biomechanical comparison of cross-pin and Endobutton-CL femoral fixation of a flexor tendon graft for anterior cruciate ligament reconstruction—a porcine femur-graft-tibia complex study. *J Surg Res.* 2010;161(2):282-287.
 29. Siebold R, Kiss ZS, Morris HG. Effect of compaction drilling during ACL reconstruction with hamstrings on postoperative tunnel widening. *Arch Orthop Trauma Surg.* 2008;128(5):461-468.
 30. Silva A, Sampaio R, Pinto E. Femoral tunnel enlargement after anatomic ACL reconstruction: a biological problem? *Knee Surg Sports Traumatol Arthrosc.* 2010;18(9):1189-1194.
 31. Taketomi S, Inui H, Tahara K, Shirakawa N, Tanaka S, Nakagawa T. Effects of initial graft tension on femoral tunnel widening after anatomic anterior cruciate ligament reconstruction using a bone-patellar tendon-bone graft. *Arch Orthop Trauma Surg.* 2017;137(9):1285-1291.
 32. Vadala A, Iorio R, De Carli A, et al. The effect of accelerated, brace free, rehabilitation on bone tunnel enlargement after ACL reconstruction using hamstring tendons: a CT study. *Knee Surg Sports Traumatol Arthrosc.* 2007;15(4):365-371.
 33. Xu Y, Ao Y, Wang J, Yu J, Cui G. Relation of tunnel enlargement and tunnel placement after single-bundle anterior cruciate ligament reconstruction. *Arthroscopy.* 2011;27(7):923-932.
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APPENDIX

TABLE A1
Characteristics of the Included Studies^a

| Lead Author (Year) | N | Imaging | Mean FU, mo | Surgery Type | Fixation Method | | Measurement Method (location) | Initial Tunnel Diameter Definition | MCMS |
|--------------------------------------|-----|---------|-------------------|-----------------|-----------------|-------------------------------------|--|---|------|
| | | | | | Femur | Tibia | | | |
| Cross-pin fixation | | | | | | | | | |
| Mirzatołooei ²¹ (2013) | 46 | CT | 3 | AMP | Transfix | Biointerference screw | Absolute change (aperture and midpoint) | Immediate postoperative CT | 71 |
| Nebelung ²² (2012) | 59 | MRI | 61 | TT | Transfix | Biointerference screw | Absolute change (aperture and midpoint) | Intraoperative drill bit size | 62 |
| Harilainen ⁸ (2005) | 26 | Radiogr | 24 | TT | Transfix | AO screw and washer post | Absolute change (midpoint) | Intraoperative drill bit size | 71 |
| Asik ² (2007) | 271 | Radiogr | 82 | TT | Transfix | Interference screw | Relative % (widest portion) | Intraoperative drill bit size | 62 |
| Lopes ¹⁸ (2017) | 20 | CT | 13 | AMP | Rigidfix | Biointerference screw | Relative % (widest portion) | Intraoperative drill bit size | 71 |
| Kong ¹⁵ (2012) | 56 | Radiogr | 56 | TT | Rigidfix | Interference screw/ Intrafix | Absolute change (aperture) | Intraoperative drill bit size | 62 |
| Saygi ²⁷ (2016) | 43 | Radiogr | 40 | TT | Rigidfix | Interference screw and staple | Absolute change (midpoint), relative % (widest portion) | Intraoperative drill bit size | 62 |
| Klein ¹⁴ (2003) | 27 | Radiogr | 18 | TT | Rigidfix | Interference screw | Relative % (widest portion) | Immediate postoperative radiogr | 62 |
| Giorgio ⁷ (2016) | 20 | MRI | 6 | TT | Rigidfix | Interference screw | Absolute change (aperture and midpoint) | Intraoperative drill bit size | 56 |
| Extracortical fixation | | | | | | | | | |
| Mermerkaya ²⁰ (2015) | 48 | Radiogr | 17 | AMP | Endo CL | Biointerference screw | Absolute change (aperture and midpoint) | Intraoperative drill bit size | 66 |
| Lanzetti ¹⁶ (2016) | 22 | CT | 12 | TT | Endo CL | Biointerference screw | Absolute change (aperture and midpoint) | Intraoperative drill bit size | 73 |
| Beyaz ³ (2017) | 16 | CT | 6 | TT | Endo CL | Biointerference screw | Absolute change (aperture and midpoint) | Comparison of 2-, 3-, and 6-month CT with 8-year CT | 71 |
| Aga ¹ (2017) | 22 | CT | 12 | AMP | Endo CL | Biointerference screw | Absolute change (aperture and midpoint) | Immediate postoperative CT | 78 |
| Kong ¹⁵ (2012) | 35 | Radiogr | 56 | TT | Endo CL | Interference screw/ Intrafix | Absolute change (aperture) | Intraoperative drill bit size | 62 |
| Siebold ²⁹ (2008) | 26 | CT | 4 | TT | Endo CL | Interference screw | Absolute change (aperture) | Intraoperative drill bit size | 66 |
| Hollis ¹¹ (2009) | 12 | Radiogr | 8 | TT | Endo CL | Interference screw | Absolute change (aperture) | Intraoperative drill bit size | 66 |
| Lind ¹⁷ (2009) | 120 | Radiogr | 12 | TT | Endo CL | Metallic interference screw | Relative % (widest portion) | Intraoperative drill bit size | 73 |
| Choi ⁵ (2013) | 171 | Radiogr | 24 | TT | Endo CL | Interference screw | Relative % (widest portion) | Intraoperative drill bit size | 71 |
| Xu ³³ (2011) | 72 | Radiogr | 12 | TT or AMP | Endo CL | Staple | Relative % (widest portion) | Immediate postoperative radiogr | 66 |
| Ma ¹⁹ (2004) | 15 | Radiogr | 35 | TT | Endo CL | Interference screw | Relative % (widest portion) | Immediate postoperative radiogr | 73 |
| Lopes ¹⁸ (2017) | 23 | CT | 13 | AMP | Endo CL | Biointerference screw | Relative % (widest portion) | Intraoperative drill bit size | 71 |

^aAMP, anteromedial portal; AO, Arbeitsgemeinschaft für Osteosynthesefragen; CT, computed tomography; Endo CL, Endobutton closed loop; FU, follow-up; MCMS, modified Coleman Methodology Score; MRI, magnetic resonance imaging; radiogr, radiograph; TT, transtibial.