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Efficacy of Repair for ACL Injury: A Meta-analysis of Randomized Controlled Trials

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Author
Zhuoyang Li

Affiliation
Zhejiang University School of Medicine First Affiliated Hospital, Orthopedics, Hangzhou, China

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Correspondence
Dr. Zhuoyang Li
Zhejiang University School of Medicine First Affiliated Hospital
Orthopedics
Qingchun road 79, hangzhou, China
310003 Hangzhou
China
Tel.: +139/681/51 204, Fax: +872/368/48
1317027@zju.edu.cn

ABSTRACT

We aim to compare the curative effect of primary repair for anterior cruciate ligament (ACL) injury with reconstruction and provide the reliable evidence for its clinical application. The literatures were searched in PubMed, EMBASE, Springer, and other medical literature databases published between January 1970 and June 2021. Basic characteristics, surgery technique, clinical outcome scores and physical examination results were recorded and evaluated. Seven randomized controlled trials (RCT) were eligible for inclusion. The results showed that there were no statistically significant differences between arthroscopic ACL repair and ACL reconstruction for Tegner, Lysholm, Lachman, KT-1000, range of motion (ROM), functional outcomes and reoperation rate ($P>0.05$), even the result of IKDC scores showed that arthroscopic repair was better than reconstruction ($P=0.04$). However, through the subgroup analysis, it was found that the short-term follow-up results of arthroscopic ACL repair were indeed better than those of open ACL repair. Therefore, we can assume that the arthroscopic ACL repair technique is an optional and promising surgical method to treat ACL injury.

Introduction

Anterior cruciate ligament (ACL) injury is one of the most common types of knee joint injury. According to statistics, 85 out of every 100,000 people aged 16–39 suffer from ACL injury [1]. Mayo et al. successfully performed one-stage open ACL repair surgery for the first time since 1895 and reported the good results of the surgery [2]. By the 1970s, after a long-term follow-up study of ACL repair Feagin and other scholars found that although the early follow-up results were satisfactory, the long-term curative effect was not good enough, and the rate of patients receiving reoperation within 5 years was also relatively high [3–6]. Therefore, primary ACL repair surgery was no longer popular.

After that, ACLR gradually replaced ACL repair as the mainstream surgical method for the treatment of ACL injury. However, many studies have pointed out that ACLR surgery has some deficiencies such as postoperative ligament proprioception loss, tendon donor site complications, autologous or allogeneic graft infection, etc., and the postoperative functional recovery still needs to be improved [7, 8]. This may be related to the fact that the reconstructed ligament cannot effectively restore the normal anatomical structure and physiological function of ACL [9, 10]. Therefore, more and more scholars are focusing on preserving the biology of ACL to improve the surgical results. With the wide application of arthroscopy, the use of new surgical instruments and implants, and the deepening understanding of the biological knowledge of ACL, people have generated new interest in ACL repair [11–14]. At the same time, compared with ACLR, ACL repair has less damage, no donor site complications and can restore active function earlier [15, 16].

In recent years, we have reason to think that ACL repair should be re-evaluated with the rapid development of some arthroscopic techniques and the adjustment of postoperative rehabilitation strategies. Considering that some results in historical literature were not satisfactory [17–20], we will re-evaluate the safety and effectiveness of one-stage ACL repair technology by meta-analysis. Although some review studies have been reported in recent years [21–23], there has been no high-quality systematic review related to randomized controlled trial (RCT). The objective of this study is to evaluate all clinical RCT research of primary ACL repair (open and arthroscopic) in recent decades, and compare the results between ACL repair and reconstruction, so as to provide more reliable evidence for clinical treatment.

Materials and Methods

Retrieval strategies

We searched PubMed, EMBASE, Springer, Ovid, the Cochrane Library, and other medical literature databases for the literature related to the comparison of clinical outcomes between one-stage ACL repair and ACLR in all adults published between January 1970 and June 2021. Keywords: anterior cruciate ligament, injury, repair, reconstruction. The type of studies included was RCT only. Also, review articles on this topic were reviewed to retrieve relevant studies that might have been missed.

Inclusion criteria

Inclusion criteria included (1) diagnosis of ACL injury; (2) RCT; (3) intervention: experimental group with ACL repair techniques; control group with conventional ACLR. (4) The observation indexes included: prognostic indexes (Tegner, Lysholm, IKDC scores), physical examination results (Lachman test, range of motion, tibial anterior displacement), reoperation rate, and functional outcomes.

Exclusion criteria

Exclusion criteria included the following: (1) non-RCT studies; (2) no relevant interventions were included in the above types of literature; (2) follow-up less than 12 months; (3) cadaveric studies, biomechanical studies, and in vitro or animal studies; and (4) duplicate published studies were excluded, and abstracts, lectures, and reviews were also excluded.

Data extraction and quality evaluation

We extracted relevant data by retrieving information and summarized them into tables and forest plots. The quality of the included studies was evaluated using Revman software. The parameters included sequence generation (selection bias), allocation hiding (selection bias), blindness (performance bias), incomplete result data (detection bias), selective result reporting (reporting bias), and other issues. Each parameter could be classified as low risk, high risk, or unclear.

Statistical analysis

Statistical analyses were performed using Revman manager 5.3 software (Cochrane Collaboration, NordicCochrane Centre, Copenhagen, Denmark). Continuous variables were analyzed using weighted mean differences, and categorical variables were assessed using relative risk or absolute risk differences. $p < 0.05$ was considered statistically significant. Heterogeneity analysis was tested by Q-statistic ($P < 0.1$), and I2-statistic ($I^2 > 50\,\%$). When there was no statistically significant heterogeneity, a fixed-effects model was used; conversely, a random-effects model was used. In addition, we performed subgroup analyses depending on the intervention.

Results

Study selection

The literature search identified 86 papers that met the study objectives, and we selected 7 RCTs that met the inclusion criteria [17–20, 24–26], with a total of 745 patients, of which a total of 61 patients were lost to follow-up, with the rate of 8.2 %. The literature search process is shown in ▶ **Fig. 1**, and the basic characteristics of these studies are shown in ▶ **Table 1**.

Surgical techniques

ACL repair technique

There were 3 papers on open ACL repair [24–26], including 109 patients. The surgical techniques consisted of 2 main categories: primary repair without augmentation or with ligament augmentation device (LAD). The surgical procedures were described in detail in previous literature [24, 25, 27]. primary repair technique of the 3 studies was performed according to the method reported by Palmer [28].

The arthroscopic ACL repair technique had been reported in 4 papers [17–20], including 160 patients. These patients were treated with the DIS technique and BEAR technique, respectively. The DIS procedure was performed according to the technique described by Kösters [29] and Eggli [30]. A total of 96 patients were included. The BEAR procedure was performed according to the technique described by Murray [31] and included a total of 64 patients.

ACLR technique

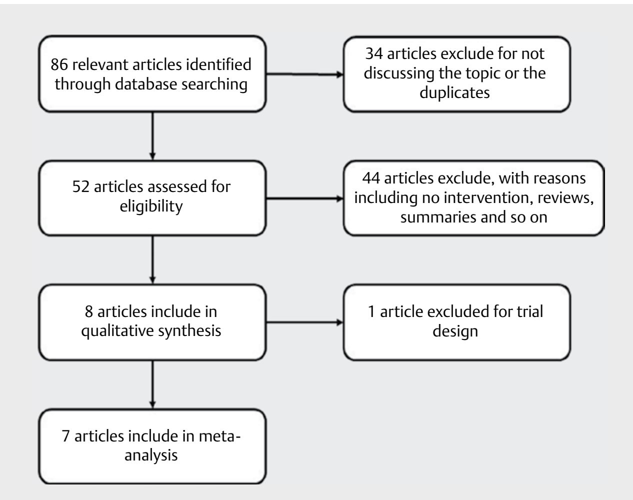
ACLR interventions were used in all seven publications, including a total of 415 patients. The ACLR grafts used included: 1. Bone-patellar tendon-bone graft; 2. autologous semitendinosus-gracilis tendon graft.

Quality assessment

We performed a quality assessment of the seven included RCTs using the Cochrane Risk of Bias Assessment Tool. The entire assessment was performed by two reviewers separately, and any disagreements were resolved by a third reviewer. As shown in ▶ **Fig. 2**, the quality of the included studies was high. The funnel plot shows no visual evidence of publication bias.

Meta-analysis results

The seven included studies used different knee function scoring systems. We divided the results of the studies into two groups, the experimental ACL repair group and the control ACLR group, for comparison. It needs to be mentioned that we combined the data from the ACL repair with or without LAD group at the same time for the meta-analysis, and did the independent subgroup analysis respectively, in order to evaluate the results of the meta-analysis in a comprehensive manner.



▶ **Fig. 1** Search strategy flow diagram.

Knee clinical scores

Tegner score and subgroup analysis

We included five studies comparing the results of postoperative Tegner scores in the two groups. The Tegner scores in the two groups were 3–6.8 and 4–7.1, respectively. The difference between the two groups was statistically significant, and overall, the postoperative Tegner score was higher in the ACLR group than in the ACL repair group (SMD = −0.55, 95 %CI −0.88 to −0.21, p = 0.001, I^2 = 0 %) (▶ **Fig. 3a**).

We also performed subgroup analysis by intervention and showed that there was no statistically significant difference in Tegner scores between arthroscopic ACL repair and ACLR (SMD = −0.22,95 % CI −0.82 to 0.39, P = 0.49, I^2 = 0 %). In contrast, the difference between open ACL repair and ACLR was statistically significant (SMD = −0.69,95 % CI −1.09 to −0.29, P = 0.0007, I^2 = 0 %). Overall, the postoperative Tegner score was higher in the ACLR group than in the open ACL repair group (▶ **Fig. 3a**).

Lysholm score and subgroup analysis

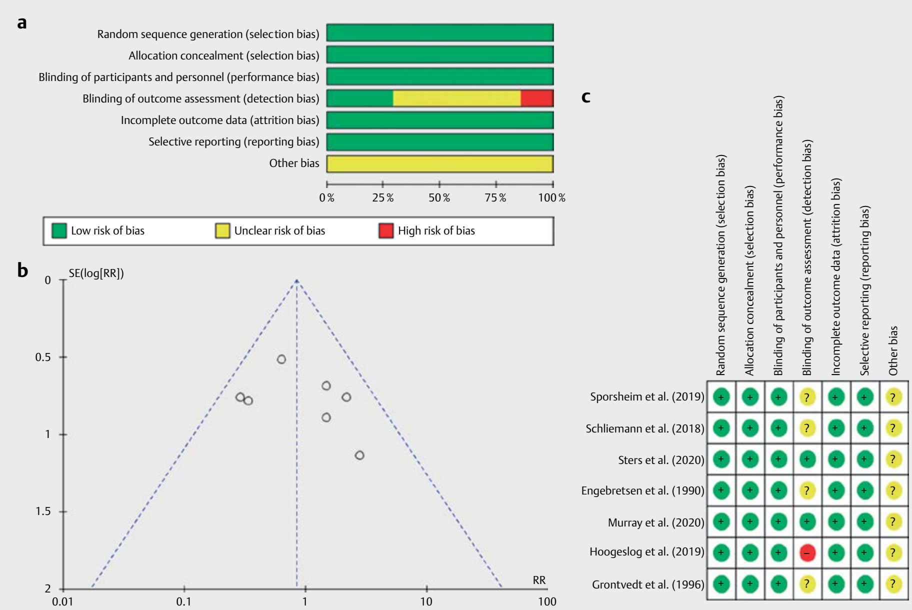
There were five included studies comparing the results of postoperative Lysholm scores between the two groups. The differences between the two groups were statistically significant, with higher postoperative Lysholm score in the ACLR group than in the ACL repair group overall (SMD = −3.26,95 %CI −5.98 to −0.54, p = 0.02, I2 = 67 %) (▶ **Fig. 3b**).

We also performed subgroup analysis by intervention and showed that there was no statistically significant difference in Lysholm scores between arthroscopic ACL repair and ACLR (SMD = 2.35,95 %CI −1.97 to 6.66, P = 0.29, I2 = 0 %). In contrast, the difference between open ACL repair and ACLR was statistically significant, with higher postop-

▶ **Table 1** Basic characteristics of included studies

Included Studies	N	Age (y)	Repair technique	Reconstruction technique	Injury to operation	F/U	
	(M %/F %)	Mean ± SD (Min–Max)			Interval (d)	Duration (y)	n (% Lost F/U)
Engebretsen et al. (1990) [24]	150 (54 %/46 %)	28.7 (16–50)	Primary repair with or without LAD	BPTB	10	2	3 (2 %)
Grontvedt et al. (1996) [25]	150	29 (16–50)	Primary repair with or without LAD	BPTB	10	5	9 (6 %)
Sporsheim et al. (2019) [26]	150	29 (16–54)	Primary repair with or without LAD	BPTB	NA	30	37 (24.7 %)
Schliemann et al. (2018) [17]	62 (62 %/38 %)	28.7 ± 11.4	DIS	ACLR (semitendinosus autograft)	21	1	2 (3.2 %)
Hoogeslag et al. (2019) [20]	48 (77 %/23 %)	21.5 ± 2.7	DIS	ACLR (semitendinosus autograft)	21	2	4 (8.3 %)
Murray et al. (2020) [18]	100 (44 %/56 %)	17 ± 1.5	BEAR	ACLR (semitendinosus autograft)	45	2	4 (4 %)
Sters et al. (2020) [19]	85 (66 %/34 %)	28.2 ± 11 (18–46)	DIS	ACLR (semitendinosus autograft)	NA	1	2 (2.3 %)

LAD, ligament- augmentation device; BPTB, bone-patella tendon-bone; FU, follow-up; DIS, dynamic intraligamentary stabilization; BEAR, bridge-enhanced anterior cruciate ligament repair; ACLR, anterior cruciate ligament reconstruction; NA, not applicable.



▶ **Fig. 2** **a** Risk of bias graph exhibiting the review of the authors' judgments about each risk of bias item presented as percentages across all included studies. **b** Risk of bias summary revealing the review of the authors' judgments about each risk of bias item for included RCTs. Minus sign represents the risk of bias present, plus sign indicates the risk of bias absent, and question mark equals the risk of bias uncertain. **c** The funnel plots of the included studies. RR, relative risks; SE, standard error.

erative Lysholm score in the ACLR group than in the open ACL repair group overall (SMD = −4.80,95 % CI −6.24 to −3.36, P < 0.05, I2 = 0 %). (▶ **Fig. 3b**).

IKDC scores

There were four included studies of arthroscopic ACL repair comparing the results of postoperative IKDC scores between the two groups. The IKDC scores in the two groups were 85.7–95.4 and 84.8–94.3, respectively. The difference between the two groups was statistically significant, and the postoperative IKDC scores were higher in the arthroscopic ACL repair group than in the ACLR group overall (SMD = 2.12,95 %CI 0.14 to 4.10, p = 0.04. I2 = 0 %) (▶ **Fig. 4a**).

Physical examination results

Lachman test

There were five included studies comparing the postoperative Lachman test results (2 + /3 +) between the two groups. There was no statistically significant difference in the postoperative Lachman test results between the two groups, with Lachman 2 + /3 + rates of 22.3 and 7.8 %, respectively (SMD = 0.09, 95 % CI −0.06 to 0.24, P = 0.24, I2 = 90 %) (▶ **Fig. 5**).

We also performed subgroup analysis by intervention and showed that there was no statistically significant difference in Lachman test results between arthroscopic ACL repair and ACLR (SMD = −0.02, 95 % CI −0.08 to 0.04, P = 0.48, I2 = 0 %). In contrast, the difference between open ACL repair and ACLR was statistically significant (SMD = 0.18, 95 % CI 0.01 to 0.34, P = 0.04, I2 = 77 %). (▶ **Fig. 3a**). Overall, the rate of postoperative Lachman test 2 + /3 + was lower in the ACLR group than in the open ACL repair group, which were 9.7 and 30.7 %, respectively.

Anterior-posterior knee stability test (KT-1000)

All three included open ACL repair studies compared the results of the postoperative KT-1000 test (> = 3 mm) between the two groups. The results showed no statistically significant difference between the two groups (SMD = 1.58, 95 % CI 0.54 to 4.62, P = 0.40, I2 = 90 %) (▶ **Fig. 4b**).

Knee flexion mobility

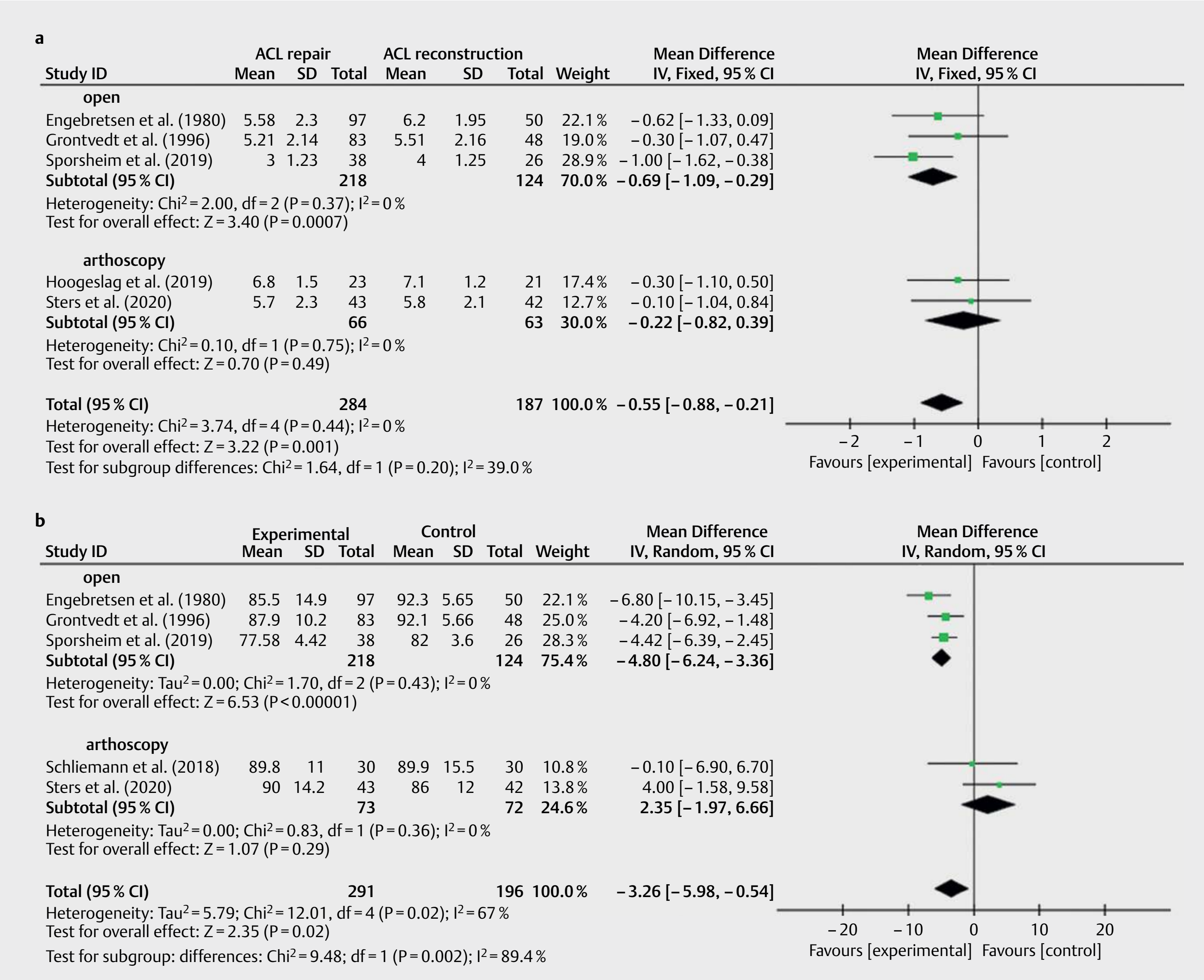
There were four included studies comparing the results of postoperative knee flexion mobility changes between the two groups. The results showed no statistically significant difference between the two groups, with 8.2 and 6.9 % of knee flexion limitations greater than 10 °, respectively. (SMD = 1.22, 95 % CI 0.62 to 2.42, P = 0.56, I2 = 0 %) (▶ **Fig. 6a**).

Knee extension mobility

There were four included studies comparing the results of postoperative knee extension mobility changes between the two groups. The results showed no statistically significant difference between the two groups, with 9.6 and 13.2 % of knee extension limitations greater than 5 °, respectively. (SMD = 0.76, 95 % CI 0.45 to 1.30, P = 0.32, I2 = 3 %) (▶ **Fig. 6b**).

knee functional outcomes

There were 2 studies assessing the strength changes of muscles surrounding the knee joint in patients after surgery, such as the



▶ **Fig. 3** **a** Difference in the Tegner score and the subgroup analysis; **b** Difference in the Lysholm score and the subgroup analysis. CI, confidence interval; IV, inverse variance; SD, standard deviation. The solid squares indicate the mean difference and are proportional to the weights used in the meta-analysis. The solid vertical line indicates no effect. The horizontal lines represent the 95 % CI. The diamond indicates the weighted mean difference, and the lateral tips of the diamond indicate the associated 95 % CI.

hamstrings, quadriceps and hip abductor muscle groups. The results were as follows: There was no statistically significant difference in the comparison of knee muscle functional outcomes between the two groups. (SMD = 0.27, 95 % CI −2.69 to 3.23, P = 0.86, I2 = 92 %) (▶ **Fig. 7**).

Reoperation rate

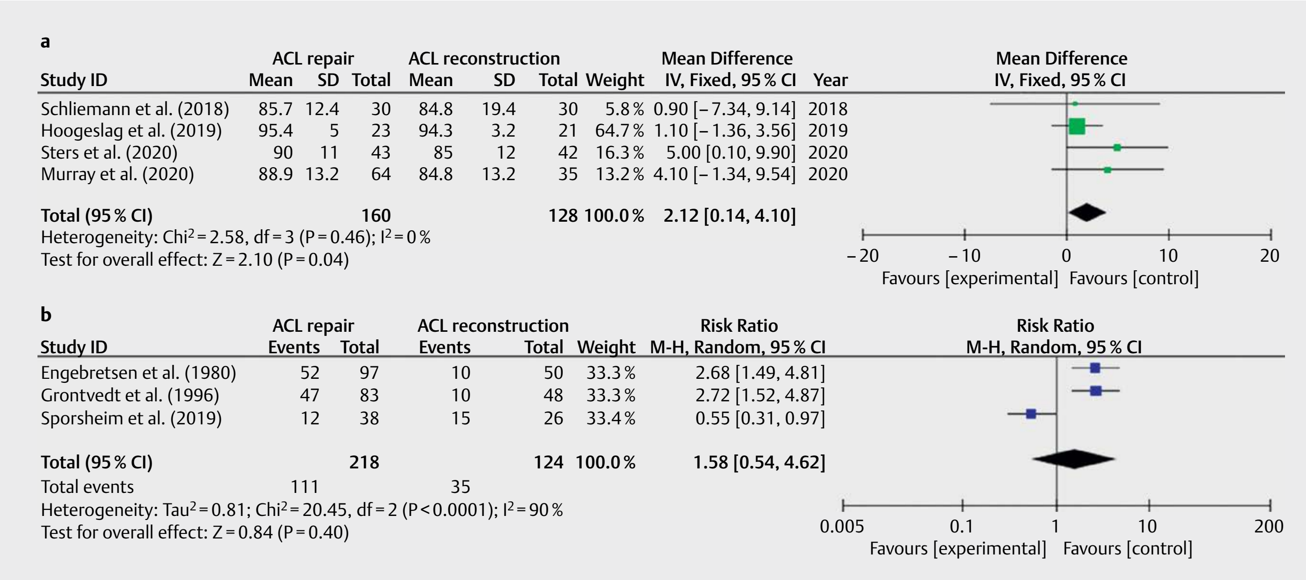
There were five included studies comparing the reoperation rates during postoperative follow-up between the two groups. The results showed that the difference between the two groups in postoperative reoperation rates was not statistically significant, with rates of 15.5 and 9.8 %, respectively (SMD = 1.61, 95 % CI 0.99 to 2.61, P = 0.06, I2 = 31 %) (▶ **Fig. 8**).

Our subgroup analysis by intervention showed that there was no statistically significant difference in the reoperation rates between arthroscopic ACL repair and ACLR (SMD = 1.02, 95 % CI 0.48 to 2.18, P = 0.95, I2 = 0 %). In contrast, the difference between open ACL repair and ACLR was statistically significant, and the rate of postoperative reoperation was lower in the ACLR group than in the open ACL repair group overall, which were 7.4 and 15.4 %, respectively (SMD = 2.05, 95 %CI 1.08 to 3.88, P = 0.03, I2 = 48 %) (▶ **Fig. 8**).

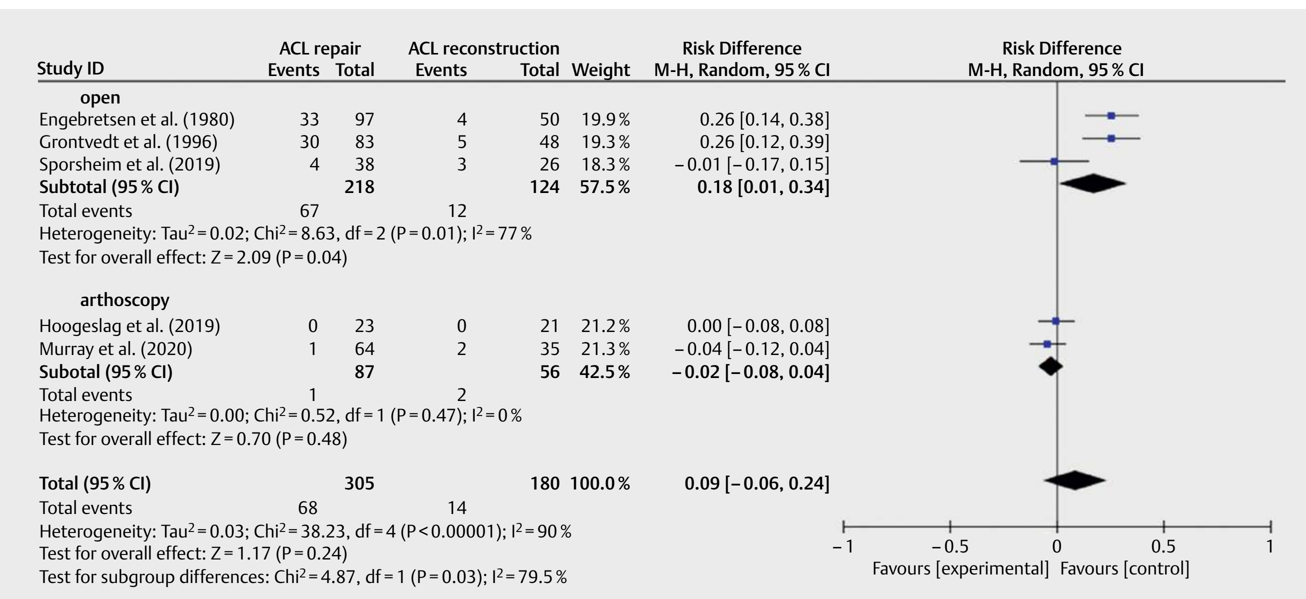
Subgroup analysis of LAD

Finally, we performed subgroup analysis on whether to use LAD for ACL repair or not. And the statistical analysis was performed separately according to the type of data, and the results were summarized in (▶ **Fig. 9, 10**).

The results showed that for ACL repair with or without LAD assistance, there was no statistically significant difference between the two groups for comparison of either subjective knee scores or



▶ **Fig. 4** **a** Difference in the IKDC score; **b** Difference in the incidence of KT-1000 (≥ 3 mm). CI, confidence interval; IV, inverse variance; M-H, Mantel-Haenszel. The solid squares indicate the mean difference and are proportional to the weights used in the meta-analysis. The solid vertical line indicates no effect. The horizontal lines represent the 95 % CI. The diamond indicates the weighted mean difference, and the lateral tips of the diamond indicate the associated 95 % CI.



▶ **Fig. 5** Difference in the incidence of Lachman test (2 + /3 +) and the subgroup analysis; CI, confidence interval; IV, inverse variance; M-H, Mantel-Haenszel. The solid squares indicate the mean difference and are proportional to the weights used in the meta-analysis. The solid vertical line indicates no effect. The horizontal lines represent the 95 % CI. The diamond indicates the weighted mean difference, and the lateral tips of the diamond indicate the associated 95 % CI.

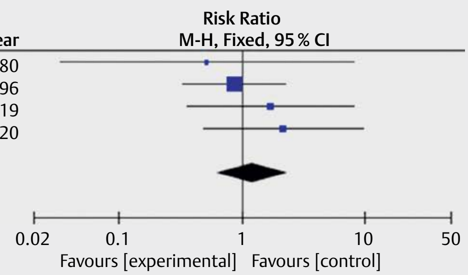
objective examination findings. (SMD = −0.18, 95 %CI −0.67 to 0.31, P = 0.48, I2 = 30 %; SMD = 0.06, 95 %CI −0.00 to 0.12, P = 0.06, I2 = 63 %).

Moreover, we performed subgroup analyses of each scoring system and found that there were no statistically significant differences in the results of each test except for the Lysholm score and KT-1000 test (P = 0.89, 0.32, 0.50, 0.95, 0.68), which showed better results in the ACL + LAD group than in the ACL repair alone (P = 0.01 and 0.003).

a

Study ID	ACL repair Events	ACL repair Total	ACL reconstruction Events	ACL reconstruction Total	Weight	Risk Ratio M-H, Fixed, 95 % CI	Year
Engebretsen et al. (1980)	1	97	1	50	9.5 %	0.52 [0.03, 8.07]	1980
Grontvedt et al. (1996)	9	83	6	48	54.8 %	0.87 [0.33, 2.29]	1996
Sporsheim et al. (2019)	5	38	2	26	17.1 %	1.71 [0.36, 8.16]	2019
Murray et al. (2020)	8	64	2	35	18.6 %	2.19 [0.49, 9.74]	2020
Total (95 % CI)		**282**		**159**	**100.0 %**	**1.22 [0.62, 2.42]**	
Total events	23		11				

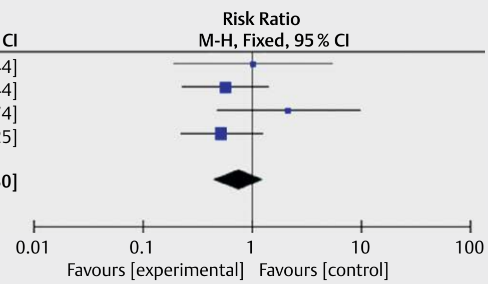
Heterogeneity: $Chi^2 = 1.62$, df = 3 (P = 0.65); $I^2 = 0\,\%$
Test for overall effect: Z = 0.58 (P = 0.56)



b

Study ID	ACL repair Events	ACL repair Total	ACL reconstruction Events	ACL reconstruction Total	Weight	Risk Ratio M-H, Fixed, 95 % CI
Engebretsen et al. (1980)	4	97	2	50	10.1 %	1.03 [0.20, 5.44]
Grontvedt et al. (1996)	8	83	8	48	38.9 %	0.58 [0.23, 1.44]
Murray et al. (2020)	8	64	2	35	9.9 %	2.19 [0.49, 9.74]
Sporsheim et al. (2019)	7	38	9	26	41.0 %	0.53 [0.23, 1.25]
Total (95 % CI)		**282**		**159**	**100.0 %**	**0.76 [0.45, 1.30]**
Total events	27		21			

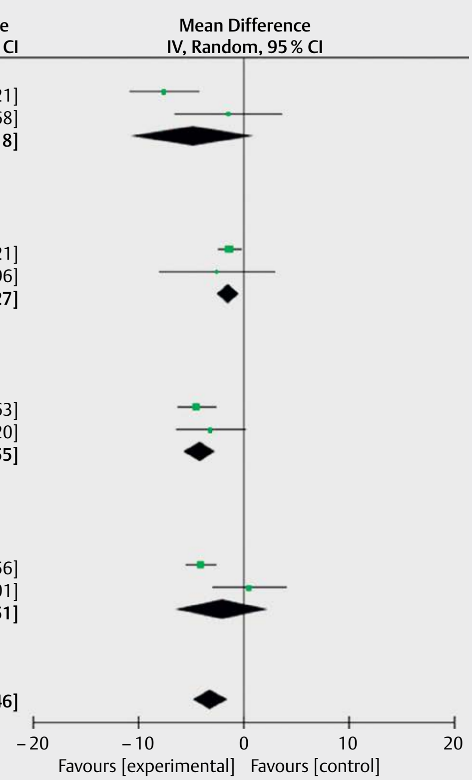
Heterogeneity: $Chi^2 = 3.08$, df = 3 (P = 0.38); $I^2 = 3\,\%$
Test for overall effect: Z = 0.99 (P = 0.32)



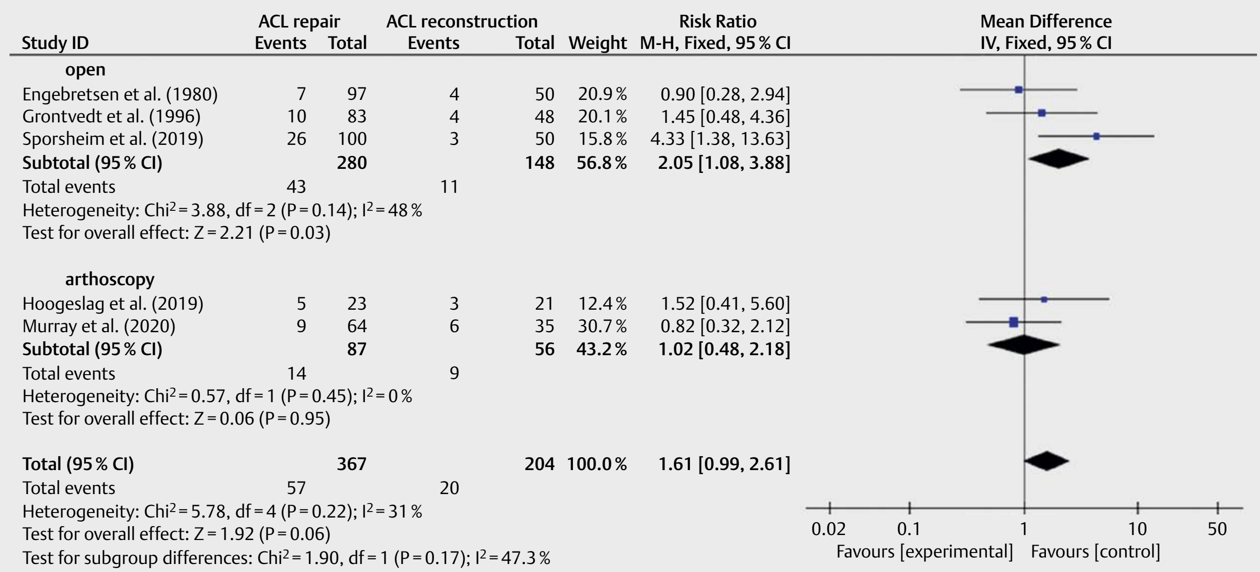
▶ **Fig. 6** **a** Difference in the incidence of flexion limitation (≥ 10 °); **b** Difference in the incidence of extension limitation (≥ 5 °). CI, confidence interval; IV, inverse variance; M-H, Mantel-Haenszel. The solid squares indicate the mean difference and are proportional to the weights used in the meta-analysis. The solid vertical line indicates no effect. The horizontal lines represent the 95 % CI. The diamond indicates the weighted mean difference, and the lateral tips of the diamond indicate the associated 95 % CI.

Study ID	ACL repair Mean	ACL repair SD	ACL repair Total	ACL reconstruction Mean	ACL reconstruction SD	ACL reconstruction Total	Weight	Mean Difference IV, Random, 95 % CI
Quad								
Hoogeslag et al. (2019)	91	4.3	23	98.5	6.5	21	11.2 %	−7.50 [−10.79, −4.21]
Murray et al. (2020)	100.1	12.2	64	101.5	12.4	35	6.8 %	−1.40 [−6.48, 3.68]
Subtotal (95 % CI)			**87**			**56**	**18.0 %**	**−4.77 [−10.71, 1.18]**
Heterogeneity: $Tau^2 = 13.84$; $Chi^2 = 3.90$, df = 1 (P = 0.05); $I^2 = 74\,\%$								
Test for overall effect: Z = 1.57 (P = 0.12)								
Hop single								
Hoogeslag et al. (2019)	99.6	1.9	23	100.9	1.8	21	19.1 %	−1.30 [−2.39, −0.21]
Murray et al. (2020)	94.4	13	64	96.9	13.4	35	6.2 %	−2.50 [−7.96, 2.96]
Subtotal (95 % CI)			**87**			**56**	**25.3 %**	**−1.35 [−2.42, −0.27]**
Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 0.18$, df = 1 (P = 0.67); $I^2 = 0\,\%$								
Test for overall effect: Z = 2.46 (P = 0.01)								
triple								
Hoogeslag et al. (2019)	96	2.6	23	100.4	3.3	21	16.7 %	−4.40 [−6.17, −2.63]
Murray et al. (2020)	94.9	9.7	64	98	6.9	35	11.2 %	−3.10 [−6.40, 0.20]
Subtotal (95 % CI)			**87**			**56**	**27.9 %**	**−4.11 [−5.67, −2.55]**
Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 0.46$, df = 1 (P = 0.50); $I^2 = 0\,\%$								
Test for overall effect: Z = 5.17 (P < 0.00001)								
side								
Hoogeslag et al. (2019)	96	2.1	23	100	2.7	21	17.9 %	−4.00 [−5.44, −2.56]
Murray et al. (2020)	96.6	9.8	64	96	7.3	35	10.8 %	0.60 [−2.81, 4.01]
Subtotal (95 % CI)			**87**			**56**	**28.8 %**	**−1.97 [−6.45, 2.51]**
Heterogeneity: $Tau^2 = 8.80$; $Chi^2 = 5.94$, df = 1 (P = 0.01); $I^2 = 83\,\%$								
Test for overall effect: Z = 0.86 (P = 0.39)								
Total (95 % CI)			**348**			**224**	**100.0 %**	**−3.07 [−4.69, −1.46]**

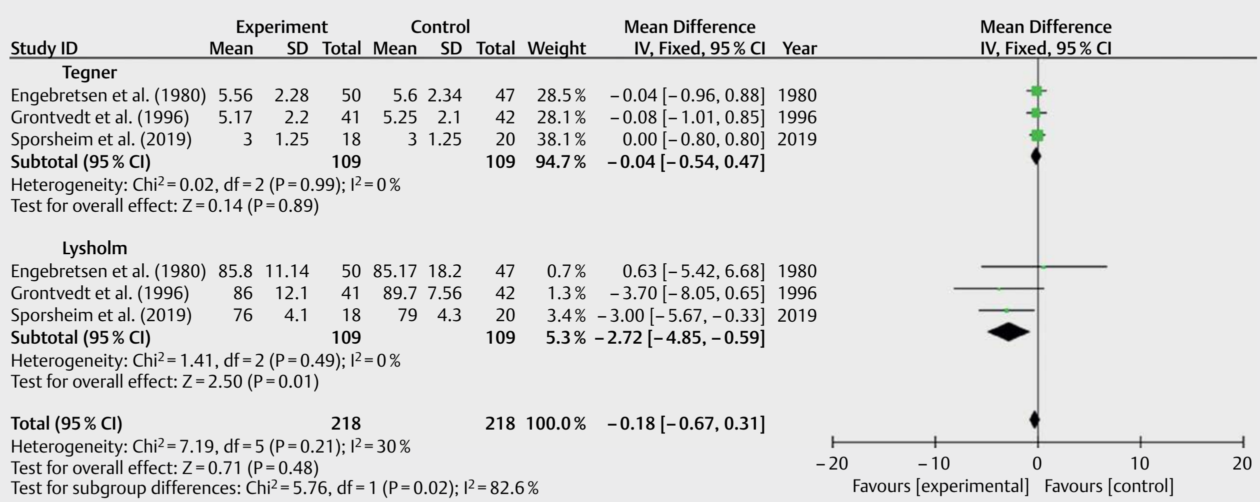
Heterogeneity: $Tau^2 = 3.25$; $Chi^2 = 25.05$, df = 7 (P = 0.0007); $I^2 = 72\,\%$
Test for overall effect: Z = 3.73 (P = 0.0002)
Test for subgroup differences: $Chi^2 = 8.91$, df = 3 (P = 0.03); $I^2 = 66.3\,\%$



▶ **Fig. 7** Difference in the functional outcomes of muscle strength and the subgroup analysis. CI, confidence interval; IV, inverse variance; SD, standard deviation. The solid squares indicate the mean difference and are proportional to the weights used in the meta-analysis. The solid vertical line indicates no effect. The horizontal lines represent the 95 % CI. The diamond indicates the weighted mean difference, and the lateral tips of the diamond indicate the associated 95 % CI.



▶ **Fig. 8** Difference in the incidence of reoperation and the subgroup analysis. CI, confidence interval; M-H, Mantel-Haenszel. The solid squares indicate the mean difference and are proportional to the weights used in the meta-analysis. The solid vertical line indicates no effect. The horizontal lines represent the 95 % CI. The diamond indicates the weighted mean difference, and the lateral tips of the diamond indicate the associated 95 % CI.

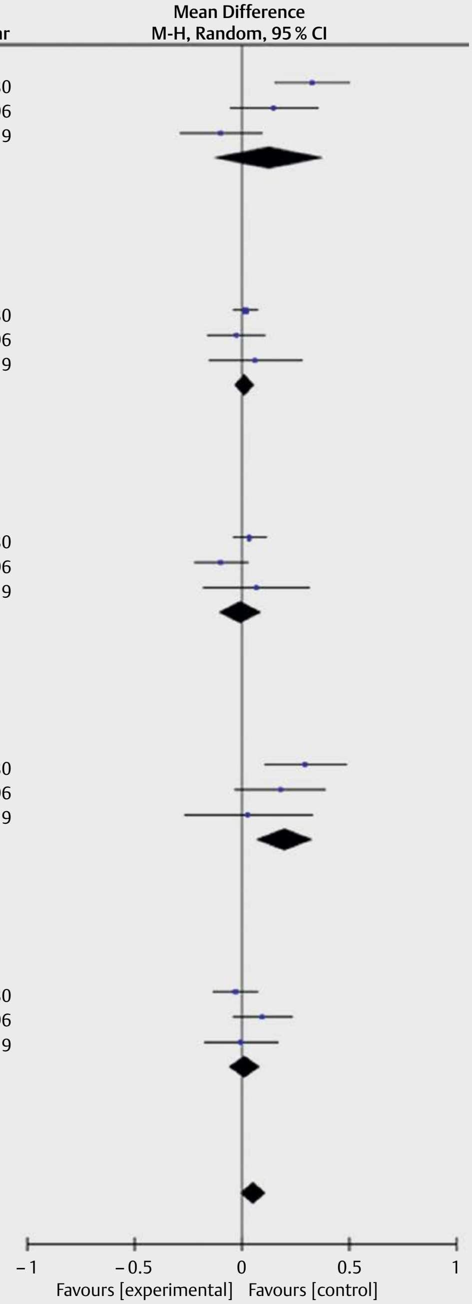


▶ **Fig. 9** Difference in the continuous variable results for ACL repair and the subgroup analysis. CI, confidence interval; IV, inverse variance; SD, standard deviation; The solid squares indicate the mean difference and are proportional to the weights used in the meta-analysis. The solid vertical line indicates no effect. The horizontal lines represent the 95 % CI. The diamond indicates the weighted mean difference, and the lateral tips of the diamond indicate the associated 95 % CI.

Postoperative rehabilitation protocols

We summarized the protocols reported in the 7 included RCT studies regarding postoperative rehabilitation, as summarized in the table below. the 3 open ACL repair studies basically used the same rehabilitation protocol: long leg cast immobilization for 2 weeks, brace immobilization for 6 weeks, weight bearing after 8 weeks, muscle rehabilitation exercises after 12 weeks, and return to sports after 12 months. Compared to open ACL repair, the rehabilitation protocols of the 4 arthroscopic ACL repair studies would be relatively more aggressive. There was no cast fixation, with adjustable brace use ranging from 4 days to 12 weeks, full weight bearing after 4 weeks, and a lower requirement for knee ROM limitation, with return to sports after 5–6 months (▶ **Table 2**).

Study ID	Experiment Events	Experiment Total	Control Events	Control Total	Weight	Risk Difference M-H, Random, 95 % CI	Year
Lachman							
Engebretsen et al. (1980)	25	50	8	47	6.1 %	0.33 [0.15, 0.51]	1980
Grontvedt et al. (1996)	18	41	12	42	5.2 %	0.15 [− 0.05, 0.36]	1996
Sporsheim et al. (2019)	1	18	3	20	5.6 %	− 0.09 [− 0.28, 0.09]	2019
Subtotal (95 % CI)		**109**		**109**	**16.9 %**	**0.13 [− 0.13, 0.39]**	
Total events	44		23				
Heterogeneity: $Tau^2 = 0.04$; $Chi^2 = 11.23$, df = 2 (P = 0.004); $I^2 = 82\%$							
Test for overall effect: Z = 0.99 (P = 0.32)							
ROM-F							
Engebretsen et al. (1980)	1	50	0	47	11.3 %	0.02 [− 0.03, 0.07]	1980
Grontvedt et al. (1996)	4	41	5	42	7.8 %	− 0.02 [− 0.16, 0.11]	1996
Sporsheim et al. (2019)	3	18	2	20	4.8 %	0.07 [− 0.15, 0.28]	2019
Subtotal (95 % CI)		**109**		**109**	**23.9 %**	**0.02 [− 0.03, 0.07]**	
Total events	8		7				
Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 0.56$, df = 2 (P = 0.75); $I^2 = 0\%$							
Test for overall effect: Z = 0.67 (P = 0.50)							
ROM-E							
Engebretsen et al. (1980)	3	50	1	47	10.3 %	0.04 [− 0.04, 0.12]	1980
Grontvedt et al. (1996)	2	41	6	42	8.2 %	− 0.09 [− 0.22, 0.03]	1996
Sporsheim et al. (2019)	4	18	3	20	4.1 %	0.07 [− 0.18, 0.32]	2019
Subtotal (95 % CI)		**109**		**109**	**22.5 %**	**− 0.00 [− 0.10, 0.10]**	
Total events	9		10				
Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 3.57$, df = 2 (P = 0.17); $I^2 = 44\%$							
Test for overall effect: Z = 0.06 (P = 0.95)							
KT-1000							
Engebretsen et al. (1980)	34	50	18	47	5.6 %	0.30 [0.11, 0.49]	1980
Grontvedt et al. (1996)	27	41	20	42	5.0 %	0.18 [− 0.03, 0.39]	1996
Sporsheim et al. (2019)	6	18	6	20	3.1 %	0.03 [− 0.26, 0.33]	2019
Subtotal (95 % CI)		**109**		**109**	**13.8 %**	**0.20 [0.07, 0.34]**	
Total events	67		44				
Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 2.24$, df = 2 (P = 0.33); $I^2 = 11\%$							
Test for overall effect: Z = 2.94 (P = 0.003)							
Reoperation							
Engebretsen et al. (1980)	3	50	4	47	9.1 %	− 0.03 [− 0.13, 0.08]	1980
Grontvedt et al. (1996)	7	41	3	42	7.5 %	0.10 [− 0.04, 0.24]	1996
Sporsheim et al. (2019)	13	50	13	50	6.2 %	0.00 [− 0.17, 0.17]	2019
Subtotal (95 % CI)		**141**		**139**	**22.9 %**	**0.02 [− 0.06, 0.09]**	
Total events	23		20				
Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 2.04$, df = 2 (P = 0.36); $I^2 = 2\%$							
Test for overall effect: Z = 0.41 (P = 0.68)							
Total (95 % CI)		**577**		**575**	**100.0 %**	**0.06 [− 0.00, 0.12]**	
Total events	151		104				
Heterogeneity: $Tau^2 = 0.01$; $Chi^2 = 38.33$, df = 14 (P = 0.0005); $I^2 = 63\%$							
Test for overall effect: Z = 1.87 (P = 0.06)							
Test for subgroup differences: $Chi^2 = 7.68$, df = 4 (P = 0.010); $I^2 = 47.9\%$							



▶ **Fig. 10** Difference in the categorical variable results for ACL repair and the subgroup analysis. CI, confidence interval; M-H, Mantel-Haenszel. The solid squares indicate the mean difference and are proportional to the weights used in the meta-analysis. The solid vertical line indicates no effect. The horizontal lines represent the 95 % CI. The diamond indicates the weighted mean difference, and the lateral tips of the diamond indicate the associated 95 % CI.

Discussion

This meta-analysis evaluates the difference in surgical efficacy between ACL repair and ACLR. The main finding is that there was no significant difference in clinical results between ACL repair and ACLR group, including IKDC, range of motion (ROM), Lachman test, laxity difference, reoperation rate and muscle strength. No matter whether LAD was used or not, there was no obvious difference in the postoperative curative effect of ACL repair. Except for Tegner and Lysholm scores, which showed that the ACLR group had better recovery of postoperative motor function, the above results were promising. At the same time, subgroup analysis showed that the short-term follow-up results of arthroscopic ACL repair group were indeed better than those of open ACL repair group and generally comparable to those of the ACLR group.

▶ **Table 2** Postoperative Rehabilitation Protocols

Included studies	Cast immobilization	brace immobilization	Weight bearing		Knee ROM	Guided physiotherapy			
			Partial	full		Closed Chain	Proprioceptive exercises	running	return to sports
Engebretsen et al. (1990) [24]	2 wk	30° of flexion for 6 wk	After 8 wk		30–60° at 3–4wk	After 12 wk		NA	12mo
					30–90° at 5–8wk				
Grontvedt et al. (1996) [25]	2 wk	30° of flexion for 6 wk	After 8 wk		30–60° at 3–4wk	After 12 wk		NA	12mo
					30–90° at 5–8wk				
Sporsheim et al. (2019) [26]	2 wk	30° of flexion for 6 wk	After 8 wk		NA	NA		NA	12mo
Schliemann et al. (2018) [17]	4 d	NA	After 2 wk		Unrestricted after 2 wk	2wk-3wk	3wk-6wk	After 6wk	5 mo
Hoogeslag et al. (2019) [20]	DIS: A long-leg cast for 5d; ACLR: immediate Unrestricted; then received a near-identical, structured, criteria-based rehabilitation protocol								
Murray et al. (2020) [18]	NA	locking for 6 wk *	4 wk	After 4 wk	0–50° at 2wk	physical therapy protocol from MOON			NA
		movable at 6–12wk *			0–90° at 2–6 wk				
Sters et al. (2020) [19]	NA	5d	20 kg at 0–2wk	After 2 wk	Unrestricted after 5d	5d to 4 wk	After 4 wk	NA	6 mo

The rehabilitation protocols depicted in the table are for the patients who underwent primary ACL repair or reconstruction.; ROM, range of motion; NA, not applicable; d, day; wk, week; mo, month; ACLR, anterior cruciate ligament reconstruction; DIS, dynamic intraligamentary stabilization; MOON, Multicenter Orthopaedics Outcomes Network; Kg, kilograms.; *Use of locked hinge knee brace for 6 weeks, then use of functional ACL brace for 6 to 12 weeks.

Open primary repair of ACL injury was gradually abandoned many years ago, Part of the reason is that the follow-up results for patients were not satisfactory, which showed that pain, joint swelling, instability, persistent symptoms were not relieved, and the incidence of reoperation rate was high. The research reported by Feagin showed that although the early curative effect was satisfactory, in the following 5 years of follow-up, only 5 of the initial 64 patients had symptoms relieved. 91 % of the patients had unstable conditions, and 15 patients need reoperation [4]. Although other literatures had reported that the success rate could reach 75 % in 6 years, there were still a large number of literatures confirming the above unsatisfactory results. This study included three research on open ACL repair. After integrating the data of open ACL repair with or without LAD, we found that in the short-term follow-up (2–5year), the results showed that the failure rate was higher in the open ACL repair group, the instability gradually increased with time and stabilized after 5 years, with lower activity and function levels. The BPTB group was indeed much better than the open ACL repair group. This may be one of the reasons why meta-analysis results showed that Tegner and Lysholm scores of open ACL repair group were lower than those of ACLR group. This was also consistent with the results of the above historical literature. Although the 5-year follow-up results showed that there was no significant difference in knee ROM, and the reoperation rate of open ACL repair was basically the same as that of BPTB group, LARS and other scholars still suggested that non-enhanced ACL repair should not be performed again. On the other hand, the results of 30-year follow-up of ACL-repair patients by Anne showed that with the increase of follow-up time, the stability of knee joint in each group was increasing, and few patients still had substantial relaxation. The unstable patients who appeared during the follow-up period of 5–16 years also obtained more stable year by year. Meta-analysis also showed that there was no significant difference in knee stability and ROM among the groups. The average age of 30-year follow-up patients reported by ANNE was 60 years old, which was another reason for the lower Tegner and Lysholm scores of the two groups, as the activity level of the elderly is usually lower. In addition, the development of osteoarthritis (OA) was also a factor to be considered for the recovery of knee stability.

Another point to note is that the reoperation rate of ACL repair group after 30-year follow-up reported by ANNE was higher than that of ACLR group. This was not appeared during short-term follow-up. The main defect of ACL repair is in the difficulty of healing. The repair of ACL is relatively difficult in the synovial environment. After the fibrin plug in the synovial space is destroyed by fibrinolytic enzyme, fibroblasts will cover the surface of ACL, and the early healing will be prevented [32]. This undoubtedly makes ACL repair more difficult. Cabaud er al. had confirmed that early ACL repair would always fail completely, and the use of LAD has better results [33]. LAD was first invented by Kennedy to enhance the repair or reconstruction of ACL injuries [34]. Schabus first applied LAD and reported good clinical results [35]. Engebretsen et al. had confirmed in cadaver research that LAD can provide about 75 % of the extension and flexion activity load of ACL tissue in the early stage, which protects the early repair of ACL from being damaged until the tissue fully grows and the repair is completed [36]. This is consistent with our meta-analysis results. In short-term follow-up (2–5 years), the clinical outcomes, stability and activity function in LAD group were indeed better than those without LAD. But the protective function of LAD can only last for about 1 year. So, with the increase of follow-up time, this advantage gradually disappeared. As mentioned before, the reoperation rate of ACL repair was significantly higher than that of BPTB group, which was consistent with the similar results reported by some scholars: supporting the disadvantage of LAD compared with autologous BPTB or hamstring tendon transplantation [37, 38]. This is not only related to the degeneration and aging of tissues after ACL repair, but also related to the wear of LAD and the mechanical deterioration of synthetic material fragments [39].

Therefore, through analysis, it was not difficult to figure out why open ACL repair was abandoned by surgeons at that time: the invasive and rough technology of open arthrotomy, long time fixation and high revision rate were the important reasons. Although some scholars put forward the view that the disappointing effect of open ACL repair was largely due to the wrong choice of patients. After reviewing historical literature, Van et al. found that the location of ACL rupture seems to play an important role in the prognosis of open ACL repair [40]. Some studies had confirmed that selective open ACL repair for proximal ACL rupture had a very good prognosis and would not deteriorate with time, while the prognosis for middle ACL rupture was disappointing [41]. Unfortunately, there was no more high-quality research to explore this issue. The RCTs we included also did not statistically analyze the location of ACL rupture. Therefore, we could not make more judgments.

With the rapid development of arthroscopy and arthroscopic surgery in recent years, there is a renewed interest in the primary repair of ACL injury. Especially, the research on the proprioceptive effect of ACL tissue is deepening. Some studies had shown that preserving the injured stump of ACL can improve the mechanical stability of knee joint after operation and allow earlier and more active rehabilitation exercise, which is very important for athletes with ACL injury [1]. Therefore, the main concern of modern joint surgeons is how to keep this function in patients with ACL injury, especially athletes. The intervention measures of arthroscopic ACL repair included in this study were DIS and BEAR. The above two approaches can effectively preserve their own ACL stumps while enhancing the biomechanical properties of repaired ACL through augmentation devices [42–45]. Biery et al. reported the 2-year follow-up results showed that DIS patients returned to work and exercise earlier than the traditional ACLR, while there was no difference in treatment cost, revision rate and clinical outcomes [46]. Eggli et al. followed up DIS patients for 5 years and found that the postoperative success rate could reach 80 % [42]. The results of the above historical literature were consistent with this study. Through systematic analysis, we found that patients in arthroscopic ACL repair group, including DIS and BEAR group, not only had no significant difference in clinical score, physical examination, reoperation rate and postoperative muscle strength recovery from ACLR group, but also achieved better results in IKDC score during short-term follow-up. By subgroup analysis, it was not difficult to find that compared with open ACL repair, arthroscopic ACL repair did show greater advantages: higher postoperative activity function level and less reoperation rate.

Another great advantage of arthroscopic ACL repair is that it can resume activity earlier. We noticed that the rehabilitation program in the early decades included long-leg cast fixation for at least 5–6 weeks, and then partial weight bearing was allowed after 8 weeks. As we all know, long-time knee joint fixation is one of the main causes of knee joint pain, decreased mobility and functional loss [47]. However, the concept of early rapid rehabilitation gradually emerged around 1990 [48]. Therefore, the lagging postoperative rehabilitation program was also one of the important factors for the poor activity function outcome in patients after open ACL repair. Genelin et al. had confirmed that the use of continuous passive movement machines in the early postoperative period of patients with primary ACL repair combined with braces providing limited knee joint movement could further improve the postoperative effect [49]. The rehabilitation programs of the arthroscopic ACL repair studies we included basically did not use the continuous fixation after operation, which was used by open ACL repair, instead of the early partial or completely unlimited joint movement and the advance of weight-bearing time. The time for returning to sports reported by several included studies was basically about 5–6 months. This undoubtedly played an important role in the recovery of activity function after operation. Unfortunately, we had not found a study to evaluate the difference in activity recovery speed between ACL repair and ACLR group, which needs further study.

Limitations

There are some limitations in this study. No RCT study had discussed and analyzed the location of ACL injury. Considering that the ACL repair effect of patients with proximal ACL rupture is better, an in-depth study is necessary for patient selection and refinement of surgical indications. Secondly, because only RCT research is included, the number of related literatures, the total number of patients, and the included analysis indicators were few, which might have some impacts on the combined results. Besides, Except for a 30-year follow-up literature, the follow-up time of other literatures was short, which might not better judge the long-term effect of ACL repair patients. In addition, all included studies did not report the follow-up results of postoperative complications and clinical symptoms of patients. And there was no clear comparative evaluation on the recovery speed of early activity.

Conclusion

This systematic review using meta-analysis found that at short-term follow-up, the postoperative clinical efficacy of arthroscopic ACL repair was comparable to ACLR, but the prognosis of open ACL repair was relatively unsatisfactory. Therefore, we can make the conclusion that the arthroscopic ACL repair technique is an optional and promising surgical method to treat ACL injury. Of course, we still need more prospective controlled studies with long follow-up time to confirm our conclusions.

Conflict of Interest

The authors declare that they have no conflict of interest.

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