



No influence of patellar fixation technique on clinical outcomes of double-bundle medial patellofemoral ligament reconstruction: a systematic review

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Abstract

Purpose To compare clinical outcomes of double-bundle medial patellofemoral ligament (MPFL) reconstruction with different patellar fixation techniques including Kujala score, functional failure and complications.

Methods Pubmed, Embase, and Cochrane Library databases were searched for studies with clinical results of double-bundle MPFL reconstruction. The hamstring tendon autografts were used, and femoral fixation was performed with bone tunnel and an interference screw, and knee fixation angle was less than or equal to 45°. Patellar fixation methods were broadly categorized into 3 treatment groups: suture anchor (SA), bone tunnel (BT) and suture techniques (SU). Pooled means for Kujala score and pooled estimates for functional failure rate and complication rate were compared.

Results 21 studies (23 groups) consisting of 691 knees met the inclusion criteria. 12 groups with 344 knees were in SA group, 5 groups of 161 knees were in BT group and 6 groups with 186 knees were in SU group. Statistically significant differences in Kujala score were found among three groups, 90.2 (95% CI 88.7–91.7) in SA group, 88.7 (95% CI 85.3–92.2) in BT group and 89.4 (95% CI 84.2–94.6) in SU group (all $P < 0.001$), but these differences were not clinically significant. No statistically significant differences were found in the positive apprehension sign rate, recurrent subluxation or dislocation rate, and major or minor complication rate among three groups.

Conclusion Patellar fixation with bone tunnel, suture anchor or suture techniques were all effective in the double-bundle MPFL reconstruction. The present systematic review failed to show that one technique was better than the others. More high-quality trials and randomized controlled trials are needed.

Keywords Patellar dislocation · Medial patellofemoral ligament · Patellar fixation · Bone tunnel · Suture anchor

Introduction

Lateral patellar dislocation is a complex clinical condition including multifactorial osseous and soft-tissue abnormalities [1]. Recently, medial patellofemoral ligament (MPFL)

reconstruction has become an established treatment option for recurrent patellar dislocation, isolated or combined with other surgical procedures. MPFL has been regarded as the primary passive restraint to lateral patellar translation at the early knee flexion [2–6], and its wide patellar insertion consisted of two functional bundles to synergistically restrain lateral force throughout the range of knee flexion [7, 8]. Therefore, double-bundle reconstruction was popular with the purpose to restore the wide patellar insertion.

However, patellar fixation techniques in double-bundle MPFL reconstruction were still in controversy, with multiple techniques used in current clinical practice. Tunnel technique has shown the similar strength with the native MPFL, but bone tunnels across the patella hold the risk of patellar fracture [9]. Suture anchor fixation can be introduced to reduce the risk of patellar fracture, but it may cause pain and irritation at the insertion side [10]. Transosseous suture

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or suture with soft-tissue as an implant-free technique can avoid the symptoms relative to hardware, but its strength is still in concern [11]. In the literature, the surgical procedures of MPFL reconstruction have been reported with a great number of variations in type of graft, fixation method and knee flexion angle of graft fixation. This vast variations in surgical techniques make it difficult to compare the clinical results in various studies meaningfully [12, 13].

Therefore, this study was the first systematic review to compare the clinical outcomes of double-bundle MPFL reconstruction with different patellar fixation methods based on the similar other surgical conditions: the hamstring tendon autograft, femoral fixation of bone tunnel technique with an interference screw, and knee flexion angle of less than or equal to 45°. We hypothesized that double-bundle MPFL reconstruction with different patellar fixation methods would yield similar clinical outcomes in subjective knee function, functional failure rate and complications.

Methods

Literature search

To comprehensively identify studies presenting clinical results of MPFL reconstruction, two authors independently performed online literature searches through the databases of the Pubmed, Embase, and Cochrane Library on July 31, 2017, using the terms “(medial patellofemoral ligament [Title]) OR MPFL [Title]”.

Eligibility and study selection

Two reviewers screened the titles and abstracts of the retrieved papers, and selected relevant studies for full review on the basis of following inclusion and exclusion criteria. Inclusion criteria were as follows: (1) Studies presenting clinical results of double-bundle MPFL reconstruction using hamstring tendon autografts, femur fixation with bone tunnel and an interference screw, and knee fixation angle of less than or equal to 45°; (2) Studies with or without minor secondary soft-tissue surgery (e.g., release of lateral retinaculum or advancement of vastus medialis); (3) The study with groups of ten or more knees; (4) The study with a minimum mean follow-up of 12 months; (5) The study reported a minimum mean or median age of 18 years; (6) The article was available in the English language. The exclusion criteria were as follows: (1) The study addressed acute patellar dislocation or MPFL repair; (2) The study described the technique of tendon transfer for MPFL reconstruction including hamstring tendon, adductor magnus tendon, quadriceps or patellar tendon; (3) Concomitant surgical procedure including:

trochleoplasty, tibial tubercle osteotomy, medial patellofemoral ligament reconstruction, or anterior cruciate ligament reconstruction. (4) The animal and cadaveric studies; (5) The case reports, technical notes, and reviews.

Quality assessment

The Centre for Evidence-Based Medicine’s level of evidence was used to evaluate the quality of the current analysis. The methodological quality of each study was evaluated using the modified Coleman methodology score (Appendix 1). In cases of disagreement, the two authors debated the controversial score until reaching a consensus.

Data extraction

To extract data from the papers, a predefined form was used including patient demographics, details of surgical technique and clinical outcomes. The details of surgical technique included graft type, patellar and femoral fixation method, and fixation angle. To make meaningful comparison of patellar fixation method, we broadly categorized patellar fixation technique into 3 treatment groups: bone tunnel, suture anchor and suture technique. The graft type was limited to hamstring tendon autografts, the femoral fixation was performed with bone tunnel and an interference screw and knee flexion angle was of less than or equal to 45°.

The clinical outcomes were the postoperative Kujala score, functional failure and complications. Functional failures included positive apprehension sign and recurrent subluxation or dislocation. Postoperative complications were collected from each publication and divided into major and minor complications according to the modified Stupay’s method (Appendix 2) [13].

Statistical analysis

Systematic review was performed using OpenMeta [Analyst] (Centre for Evidence-Based Medicine). Homogeneity was tested by the Q statistic (significance level at $P < .1$) and the I^2 statistic (significance level at $I^2 > 50\%$). A random-effects model was used if the Q or I^2 value was statistically significant; otherwise, a fixed-effects model was used. Continuous variable such as Kujala score with the pooled estimated mean was analyzed by one-way analysis of variance (ANOVA) and Student 2-tailed t test. The categorical variables as pooled estimates for functional failure rate and complication rate were assessed by Pearson Chi-square test. $P < .05$ was considered to be statistically significant, and 95% confidence intervals (CIs) were reported.

Results

Demographics

The literature search identified 927 relevant articles initially. Based on the inclusion and exclusion criteria, 21 articles were included in the present analysis. The flow diagram was shown in Fig. 1. For two studies included 2 separate groups of MFPL reconstruction for the analysis [14, 15], in total 23 groups with a total of 666 patients (691 knees) were included in this review, with a weighted average age of patients was 25.2 years, and a weighted mean follow-up was 36.9 months (Table 1).

For the patellar fixation methods, 12 groups with 322 patients (344 knees) used suture anchor (SA group) [15–25], 5 groups of 158 patients (161 knees) used bone tunnel (BT group) [26–30] and 6 groups with 186 patients (186 knees) used suture technique (SU group) [14, 31–34].

Level of evidence and methodology assessment

In assigning levels of evidence, no study was level I, 3 studies were level II, 5 studies were level III, and 13 studies were level IV. The average modified Coleman methodology score was 69.4 ± 9.0 (Appendix 1).

Clinical outcomes

Postoperative Kujala scores were calculated from 12 groups of 90.2 (95% CI 88.7–91.7) in SA group, 4 groups of 88.7 (95% CI 85.3–92.2) in BT group, and 5 groups of 89.4 (95% CI 84.2–94.6) in SU group (Fig. 2) (Table 2). The statistically significant difference was found among three groups with each other (all $P = 0.000$), but the difference among three groups was 1.5 points, less than a minimal clinical important difference of the Kujala sore of 7 points [35].

There was no statistically significant difference in positive apprehension sign rate (Fig. 3) and in recurrent subluxation or dislocation rate (Fig. 4) among three groups (Table 2).

No statistically significant difference in major (Fig. 5) or minor (Fig. 6) complication rate was found among three groups (Table 2).

Discussion

The most important finding of present study was that patellar fixation using bone tunnel, suture anchor, and suture techniques would achieve similar clinical outcomes for double-bundle MPFL reconstruction in subjective knee Kujala score, positive apprehension sign, recurrent subluxation or dislocation and complications. The present analysis failed to show that one technique was better than the others for patellar fixation in double-bundle MPFL reconstruction.

Fig. 1 The flowchart of the literature search process. TTT tibial tubercle transfer

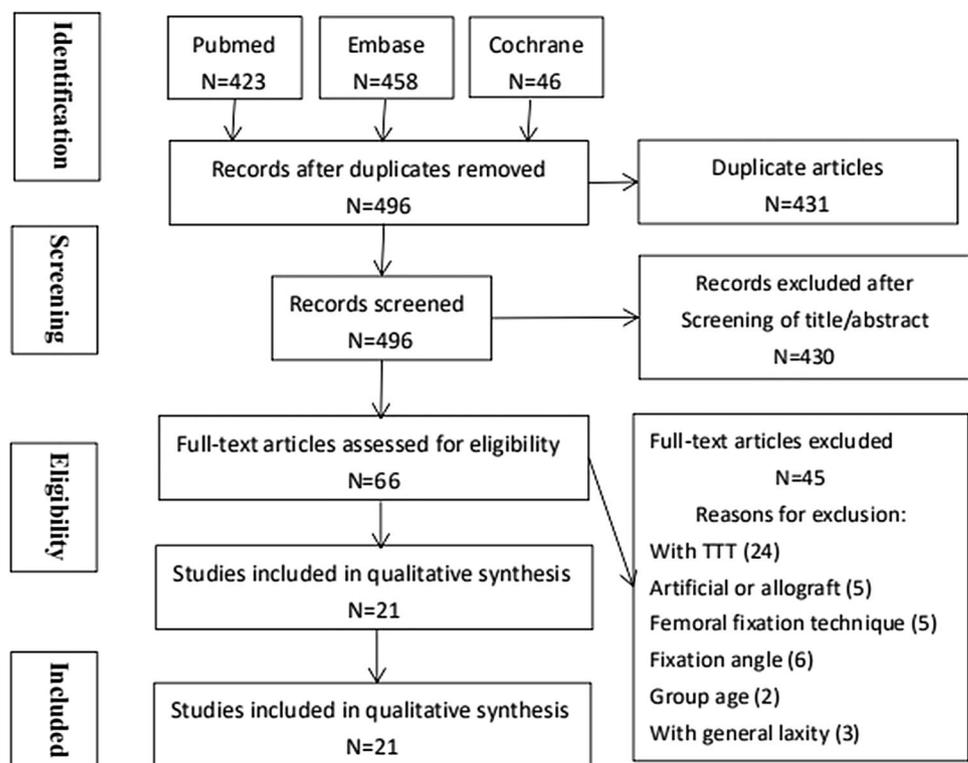


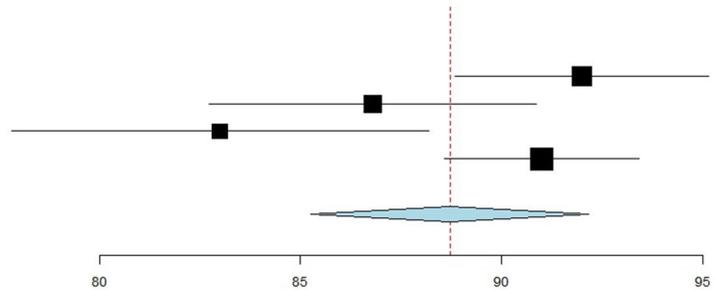
Table 1 Characteristics of included studies for double-bundle MPFL reconstruction

General information		Surgical technique					Clinical results									
Author	Year	Level of evidence	No. of patient	No. of knee	Mean age	Follow up	Graft	Patellar fixation	Femoral fixation	Fixation angle	Mean Kujala score	Functional failures		Complications		
											Pre	Post	App	Sub/dis	Major	Minor
Ambrozic [16]	2016	IV	29	31	26.2	76.8	GR	SA	BT	30	75+10	95+10	1	0	0	0
Astur [17]	2015	II	28	28	28.32	60	GR	SA	BT	30–45	N/A	87.0+12.6	0	0	1	0
Becher [18]	2014	III	15	15	21.3	26	GR	SA	BT	30	N/A	82±17	0	0	3	1
Feller [26]	2014	III	31	31	23.9	37.2	HA	BT	BT	20	N/A	N/A	0	0	0	0
Hinterwimmer [27]	2013	IV	19	19	23	12	GR	BT	BT	30	N/A	92±7	0	0	1	4
Kang-A [14]	2013	II	40	40	28.3	32.0	ST	SU	BT	0 and 30	53.5±5.6	95.9±4.7	0	0	0	0
Kang-B [14]	2013	II	42	42	29.4	33.9	ST	TS	BT	30	52.5±5.5	91.3±9.7	0	0	0	0
Kang [31]	2014	IV	45	45	26.6	33.7	ST	SU	BT	0 and 30	53.4±5.3	90.9±6.6	0	0	0	0
Lobner [32]	2017	III	17	17	23.8	25.4	GR	TS	BT	30	N/A	84±11.4	0	1	0	5
Matsushita-A [15]	2014	III	19	21	22.1	44	ST	SA	BT	20–30	75.5±18.5	92.3±11.7	4	1	0	3
Matsushita-B [15]	2014	III	15	18	23.5	38	ST	SA	BT	20–30	67.8±19.0	92.1±6.3	1	0	0	0
Matsushita [19]	2017	IV	46	54	22.8	63.6	ST	SA	BT	20–30	64.0+22.1	84.9+11.5	3	0	0	0
Matthews [33]	2010	IV	21	21	24	31	HA	TS	BT	20	N/A	87	0	0	2	5
Niu [20]	2016	II	22	22	27.46	48	HA	SA	BT	30	61.73±4.88	92.46±2.25	0	0	0	0
Panni [28]	2011	IV	48	51	28	33	ST	BT	BT	20	56.7±17.7	86.8±14.4	0	0	7	4
Ronga [29]	2009	IV	28	28	32.5	37.2	GR	BT	BT	20	45±17	83±14	0	3	0	4
Song [21]	2014	IV	20	20	21	34.5	ST	SA	BT	30–45	52.6±12.4	90.9±4.5	0	0	0	0
Torkaman [22]	2015	IV	15	15	26.53	12	ST	SA	BT	30	59.8±6.41	88.6±3.29	0	0	0	0
Wagner [23]	2013	IV	50	50	19	12	GR	SA	BT	30	70±23	87±13	0	1	2	0
Wang [24]	2013	III	37	44	26	48	ST	SA	BT	30	61.00±5.17	92.86±2.47	2	0	0	1
Wang [25]	2016	IV	26	26	26.3	38.2	GR	SA	BT	30	53.2±8.3	89.4±7.6	0	0	0	0
Wang [34]	2012	IV	21	21	23	37.5	ST	TS	BT	45	53.9±5.02	84.1±3.72	1	0	0	0
Zhou [30]	2014	IV	32	32	21.34	18	ST	BT	BT	30	63.0±9.0	91.0±7.0	0	0	0	0

GR gracilis, ST semitendinosus, HA hamstrings, SA suture anchor, BT bone tunnel, SU suture, TS transosseous suture, N/A not available, App apprehension, Sub/dis subluxation/dislocation

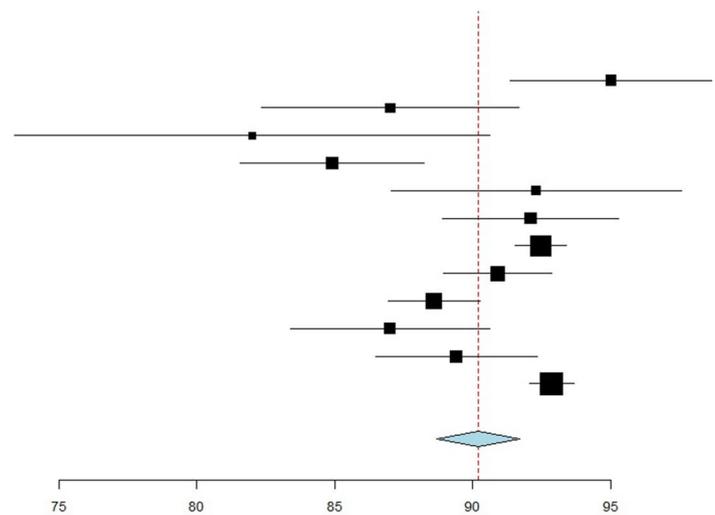
A

Studies	Estimate (95% C.I.)
Hinterwimmer 2013	92.000 (88.852, 95.148)
Panni 2011	86.800 (82.726, 90.874)
Ronga 2009	83.000 (77.814, 88.186)
Zhou 2014	91.000 (88.575, 93.425)
Overall (I²=73.93 % , P=0.009)	88.718 (85.261, 92.175)



B

Studies	Estimate (95% C.I.)
Ambrozic 2016	95.000 (91.360, 98.640)
Astur 2015	87.000 (82.333, 91.667)
Becher 2014	82.000 (73.397, 90.603)
Matsushita 2017	84.900 (81.577, 88.223)
Matsushita-A 2014	92.300 (87.039, 97.561)
Matsushita-B 2014	92.100 (88.912, 95.288)
Niu 2016	92.460 (91.520, 93.400)
Song 2014	90.900 (88.928, 92.872)
Torkaman 2015	88.600 (86.935, 90.265)
Wagner 2013	87.000 (83.397, 90.603)
Wang HD 2016	89.400 (86.479, 92.321)
Wang CH 2013	92.860 (92.064, 93.656)
Overall (I²=82.16 % , P< 0.001)	90.201 (88.683, 91.719)



C

Studies	Estimate (95% C.I.)
Kang 2014	90.900 (88.972, 92.828)
Kang-A 2013	95.900 (94.443, 97.357)
Kang-B 2013	91.300 (88.366, 94.234)
Lobner 2017	84.000 (78.581, 89.419)
Wang JL 2012	84.100 (82.509, 85.691)
Overall (I²=96.69 % , P< 0.001)	89.411 (84.212, 94.610)

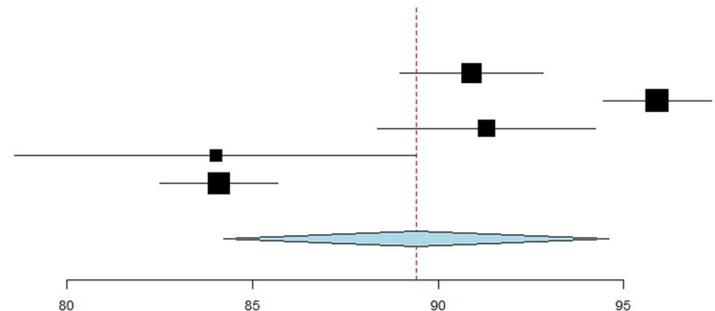


Fig. 2 Individual study means and pooled estimated postoperative means in Kujala scores for bone tunnel (a), suture anchor (b) and suture technique (c)

The superiority of present study was to analyze the effect of patellar fixation method on clinical outcomes of double-bundle MPFL reconstruction based on the uniformity of graft type, femoral fixation method and knee flexion angle.

In the present study, the pooled mean Kujala score in the bone tunnel technique was statistically lower than that in the suture anchor and suture techniques. The pooled mean Kujala score was 88.7 for the bone tunnel technique, 90.2 for the suture anchor technique and 89.4 for the suture fixation. The result is similar to a previous systematic review, which the mean Kujala score was 88.6 (SD 4.7) for the bone tunnel

fixation and 90.0 (SD 3.7) for the soft-tissue attachments [13]. Even though this difference was statistically significant, the difference did not approach clinical significance based on a minimal clinically important difference of the Kujala score of 7 points [35].

No significant difference was found in positive apprehension sign rate and recurrent subluxation or dislocation rate among different patellar fixation techniques from the present analysis. In the literature, there was no clinical studies, only few biomechanical studies to compare the outcomes of different patellar fixations. Hapa et al. reported that aperture

Table 2 Results of MPFL reconstruction with different patellar fixation methods

	SA group	BT group	SU group		<i>P</i> value
Kujala score					
<i>N</i> Groups	12	4	5		
<i>N</i> Subjects	322	127	165		
Postoperative score	91.2	88.7	89.4	$F=21.585$	0.000
Functional failures					
<i>N</i> Groups	12	5	6		
<i>N</i> Subjects	344	161	186		
Apprehension rate	2.4%	1.4%	1.4%	$\chi^2=0.797$	0.671
Sub/dislocation rate	1.6%	1.6%	1.4%	$\chi^2=0.032$	0.984
Complications					
<i>N</i> Groups	12	5	6		
<i>N</i> Subjects	344	161	186		
Major rate	1.8%	2.6%	1.5%	$\chi^2=0.425$	0.809
Minor rate	1.6%	3.3%	2.6%	$\chi^2=1.055$	0.590

SA suture anchor, BT bone tunnel, SU suture

fixation techniques such as suture anchor and interference screw fixation were as strong as the tunnel technique in the ultimate load [11]. Using transosseous 1-mm braided polyester Ethibond suture, Lenschow et al. reported that transosseous sutures provided similar load to failure (539.5 Nm) and elongation (3.0 mm) with that of two anchors fixation (401.5 Nm and 3.7 mm) [36]. With four 2–0 Ethibond sutures, He et al. reported the tensile strength (234.86 N) was stronger than that of the normal MPFL (146.91 N) and anchors-single suture technique (159.17 N) [37]. From the biomechanical point of view, all the fixation methods as bone tunnel, suture anchor and transosseous suture technique can effectively fix the graft to native patellar margin.

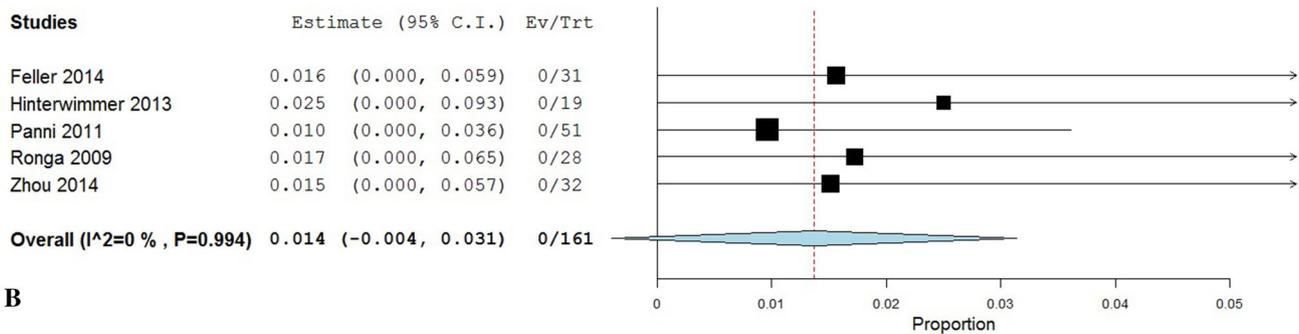
From the present study, the complication was classed into the major and minor complication according to modified Stupay's method [13] (Appendix 2). No statistically significant differences in major or minor complication rate were found among different patellar fixation techniques. With regard to the type of complication, the most common type of complication was knee flexion deficit (21/43), followed by the residual anterior knee pain (14/43). This may be related to the firm fixation of double-bundle reconstruction causing more "tensioning" the MPFL graft and restraint to the normal mobility of patella and resulting more stress to the injured chondral injury in the patellofemoral joint [9]. Patellar fracture was a serious but not common problem. In present study, two patellar fractures were reported in MPFL reconstruction with bone tunnel technique ($n=161$), and no patellar fractures were reported in studies with anchor or suture techniques ($n=530$). This reminded the surgeon of the inherent risk of fracture for the bone tunnel technique. In all, bone tunnel, suture anchor and suture techniques were

all safe alternatives for the patellar fixation in double-bundle MPFL reconstruction.

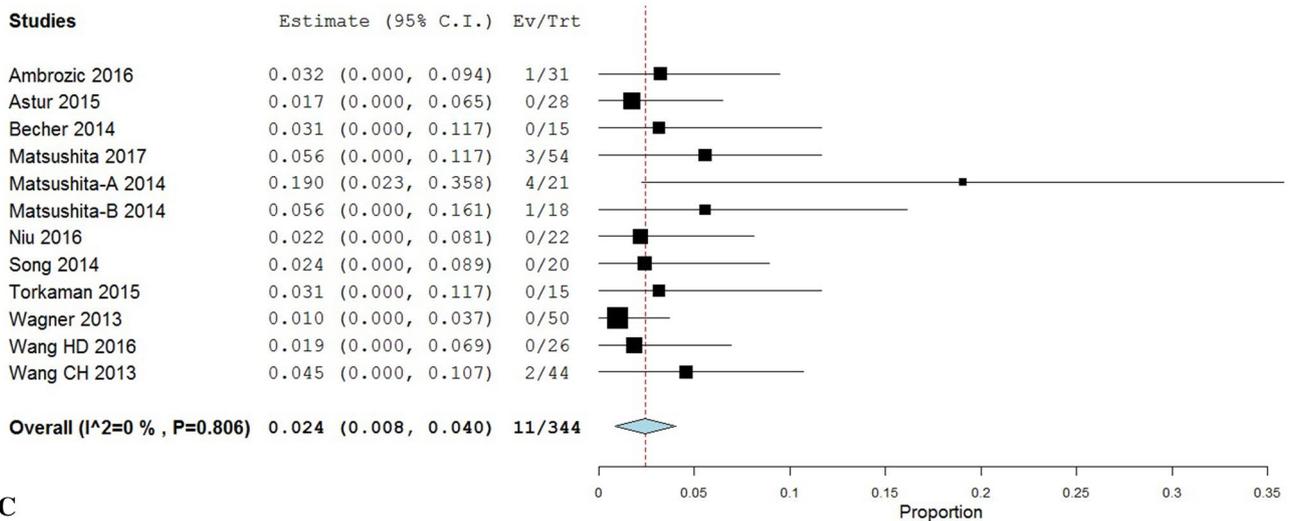
From the present study, knee flexion angle of less or equal to 45° was chosen based on the length change pattern of native ligament that MPFL tightens in early to midflexion and slackens during deeper flexion [2, 38, 39]. Victor et al. showed that the length of the MPFL was longer at 0° to 40° of flexion than at over 40° of flexion [39]. Recently, in vivo analysis shown that the MPFL can be functionally divided into superior and inferior portions, which act synergistically to restrain lateral force throughout the range of knee flexion, with the superior fibers being taut in low flexion and the inferior fibers in mid flexion, respectively [8]. The appropriate knee angle for graft fixation is at or close to 30°, most commonly fixed in clinical practice at lower flexion angles between 20° and 45°.

The present study also has some limitations. First, the main problem was the clinical complexity of recurrent patellar dislocation to limit the generalizability of the results of MPFL reconstruction. We tried to focus on the isolated MPFL reconstruction without any additional bony procedures, but the subjects with bony risk factors such as an increased TT-TG distance, trochlear dysplasia, or patella alta were not excluded for the analysis. Second, the surgical procedure of MPFL reconstruction was described to be of great variety in graft choice, fixation method, fixation angle and so on. We attempted to minimize confounding effects by limiting the graft choice, femoral fixation and knee flexion angle to study the effect of patellar fixation method on the outcomes of MPFL reconstruction [40, 41]. Although the patellar fixation method were broadly classified into tunnel technique, suture anchor and suture technique, the factors such as the size, shape and the exit of the tunnel, fixation for the graft within the tunnel were

A



B



C

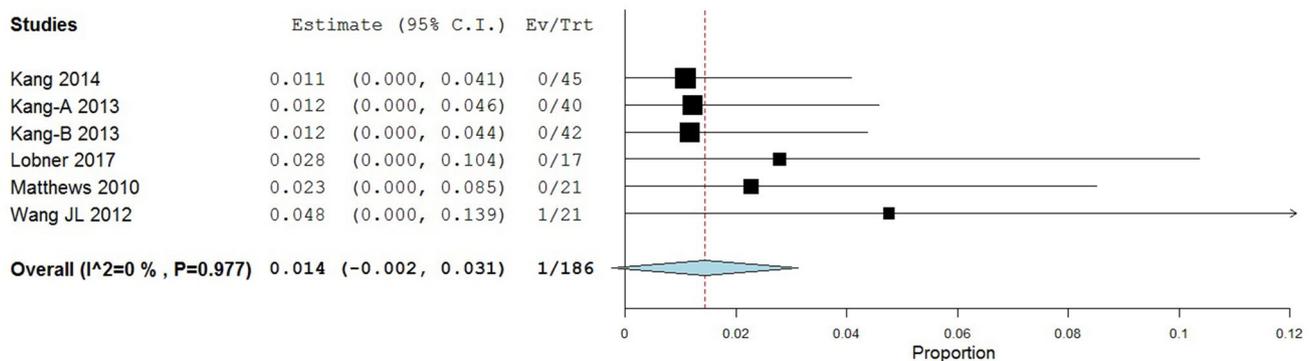


Fig. 3 Individual study proportions and pooled estimated positive apprehension sign for bone tunnel (a), suture anchor (b) and suture technique (c)

not analyzed, all these factors may have an effect on the clinical outcomes. Third, there is a paucity of high-level evidence in the current literature on recurrent patellar dislocation, only

3/21 studies were classified as level II studies and no level I studies. More high-quality trials and randomized controlled trials are needed in the future.

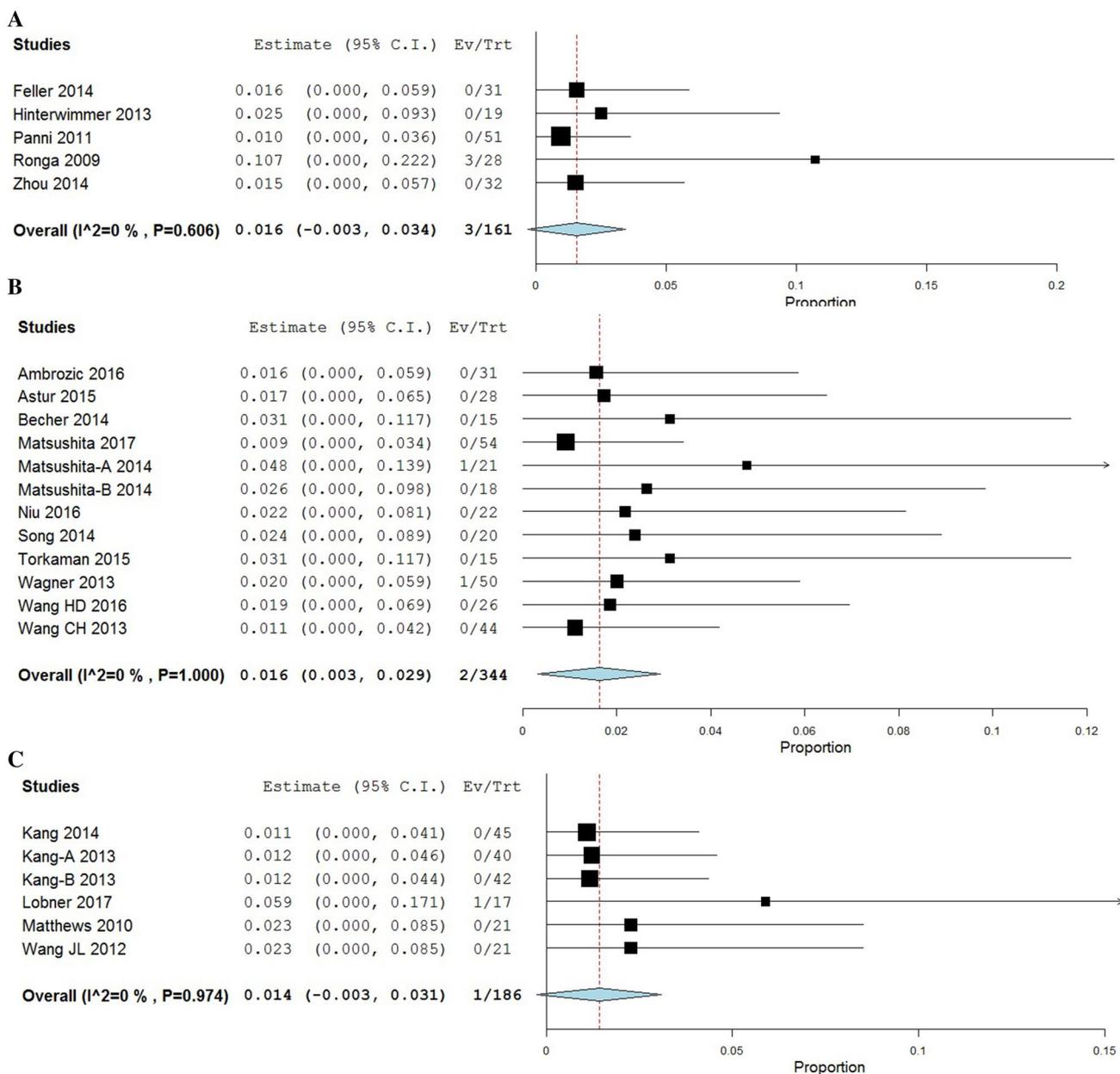


Fig. 4 Individual study proportions and pooled estimated recurrent subluxation or dislocation for bone tunnel (a), suture anchor (b) and suture technique (c)

Conclusion

Patellar fixation using bone tunnel, suture anchor, and suture techniques would achieve similar clinical outcomes for double-bundle MPFL reconstruction in the subjective

knee Kujala score, positive apprehension sign, recurrent subluxation or dislocation and complications based on the similar other surgical conditions: the hamstring tendon autograft, femoral fixation of bone tunnel technique with

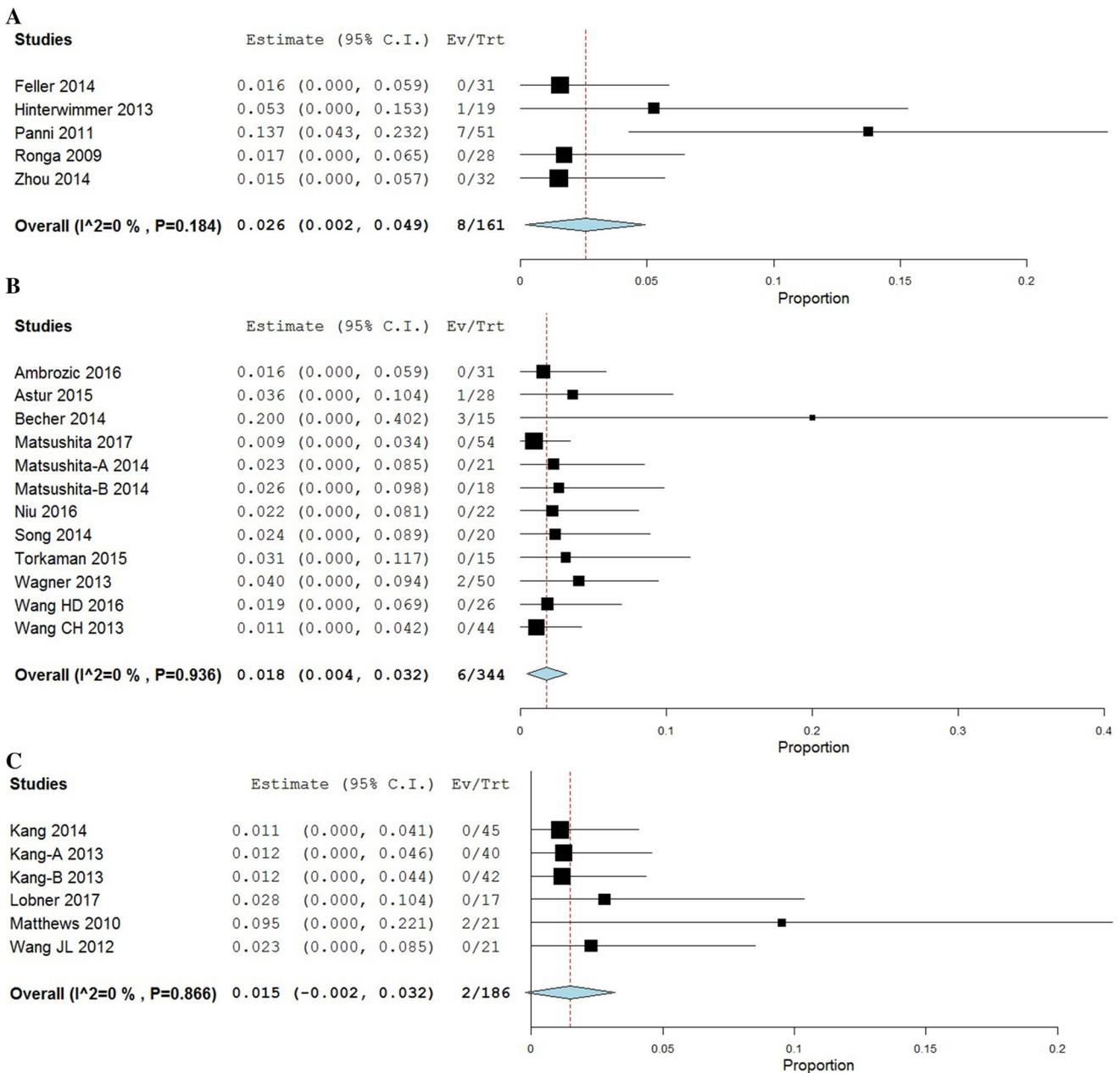


Fig. 5 Individual study proportions and pooled estimated major complication for bone tunnel (a), suture anchor (b) and suture technique (c)

an interference screw, and knee flexion angle of less than or equal to 45°. The present analysis failed to show that one technique was better than others for patellar fixation

in double-bundle MPFL reconstruction. More high-quality trials and randomized controlled trials are needed in the future.

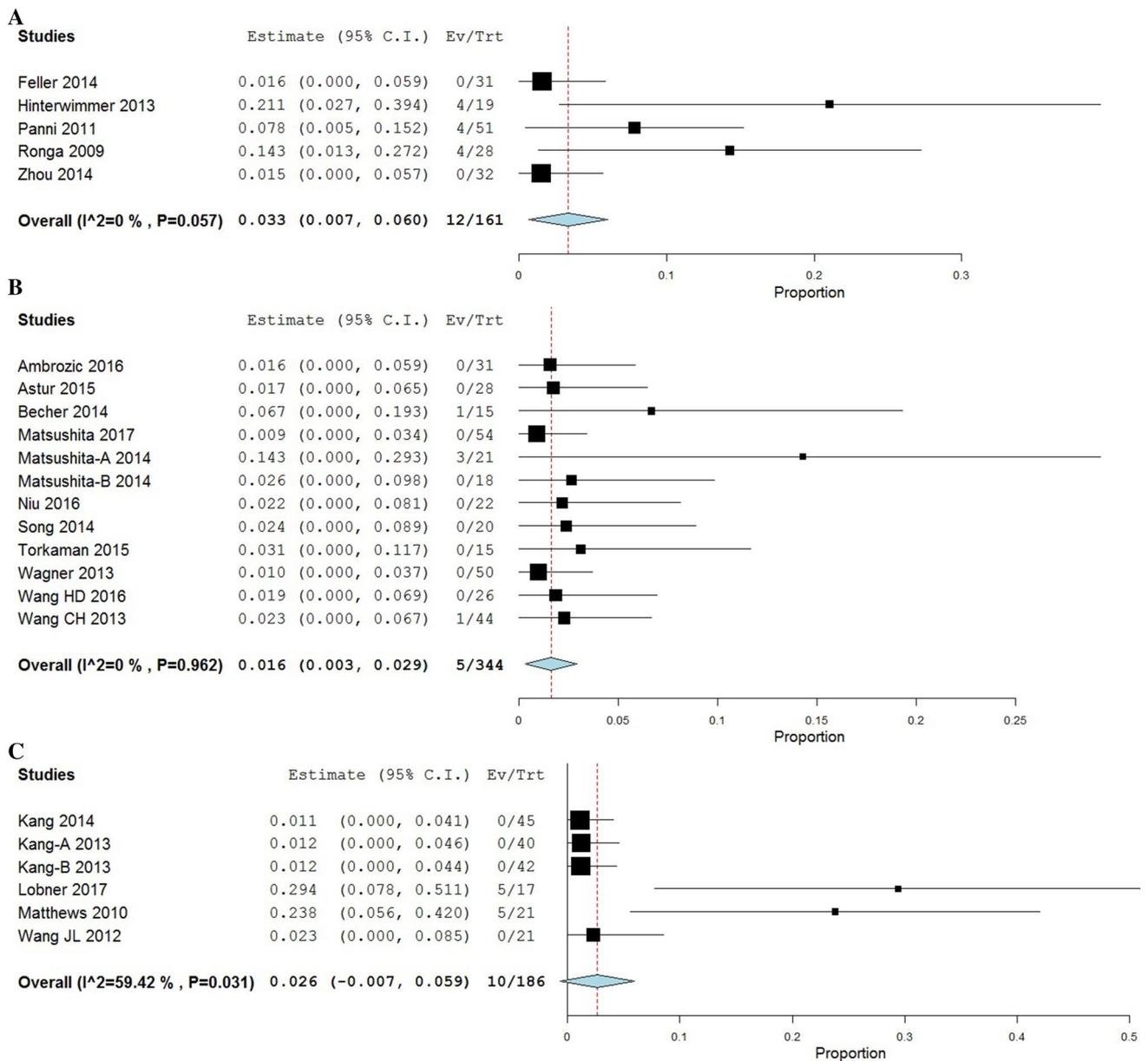


Fig. 6 Individual study proportions and pooled estimated minor complication for bone tunnel (a), suture anchor (b) and suture technique (c)

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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

References

1. Froesch KH, Schmeling A (2016) A new classification system of patellar instability and patellar maltracking. *Arch Orthop Trauma Surg* 136(4):485–497
2. Amis AA, Firer P, Mounthey J, Senavongse W, Thomas NP (2003) Anatomy and biomechanics of the medial patellofemoral ligament. *Knee* 10(3):215–220
3. Desio SM, Burks RT, Bachus KN (1998) Soft tissue restraints to lateral patellar translation in the human knee. *Am J Sports Med* 26(1):59–65
4. Hautamaa PV, Fithian DC, Kaufman KR, Daniel DM, Pohlmeier AM (1998) Medial soft tissue restraints in lateral patellar instability and repair. *Clin Orthop Relat Res* 349:174–182

5. Philippot R, Boyer B, Testa R, Farizon F, Moyon B (2012) The role of the medial ligamentous structures on patellar tracking during knee flexion. *Knee Surg Sports Traumatol Arthrosc* 20(2):331–336
6. Sandmeier RH, Burks RT, Bachus KN, Billings A (2000) The effect of reconstruction of the medial patellofemoral ligament on patellar tracking. *Am J Sports Med* 28(3):345–349
7. Song SY, Pang CH, Kim CH, Kim J, Choi ML, Seo YJ (2015) Length change behavior of virtual medial patellofemoral ligament fibers during in vivo knee flexion. *Am J Sports Med* 43(5):1165–1171
8. Yoo YS, Chang HG, Seo YJ, Byun JC, Lee GK, Im H, Song SY (2012) Changes in the length of the medial patellofemoral ligament: an in vivo analysis using 3-dimensional computed tomography. *Am J Sports Med* 40(9):2142–2148
9. Singhal B, Rogers S, Charalambous CP (2013) Double-bundle medial patellofemoral ligament reconstruction with hamstring tendon autograft and mediolateral patellar tunnel fixation: a meta-analysis of outcomes and complications. *Bone Joint J* 95B(7):900–905
10. Shah JN, Howard JS, Flanigan DC, Brophy RH, Carey JL, Lattermann C (2012) A systematic review of complications and failures associated with medial patellofemoral ligament reconstruction for recurrent patellar dislocation. *Am J Sports Med* 40:1916–1923
11. Hapa O, Akşahin E, Özden R, Pepe M, Yanat AN, Doğramac Y, Bozdağ E, Sünbuloğlu E (2012) Aperture fixation instead of transverse tunnels at the patella for medial patellofemoral ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc* 20(2):322–326
12. Schneider DK, Grawe B, Magnussen RA, Ceasar A, Parikh SN, Wall EJ, Colosimo AJ, Kaeding CC, Myer GD (2016) Outcomes after isolated medial patellofemoral ligament reconstruction for the treatment of recurrent lateral patellar dislocations: A systematic review and meta-analysis. *Am J Sports Med* 44(11):2993–3005
13. Stupay KL, Swart E, Shubin Stein BE (2015) Widespread implementation of medial patellofemoral ligament reconstruction for recurrent patellar instability maintains functional outcomes at midterm to long-term follow-up while decreasing complication rates: a systematic review. *Arthroscopy* 31(7):1372–1380
14. Kang H, Cao J, Yu D, Zheng Z, Wang F (2013) Comparison of 2 different techniques for anatomic reconstruction of the medial patellofemoral ligament: a prospective randomized study. *Am J Sports Med* 41(5):1013–1021
15. Matsushita T, Kuroda R, Oka S, Matsumoto T, Takayama K, Kurosaka M (2014) Clinical outcomes of medial patellofemoral ligament reconstruction in patients with an increased tibial tuberosity-trochlear groove distance. *Knee Surg Sports Traumatol Arthrosc* 22(10):2438–2444
16. Ambrožič B, Novak S (2016) The influence of medial patellofemoral ligament reconstruction on clinical results and sports activity level. *Phys Sportsmed* 44(2):133–140
17. Astur DC, Gouveia GB, Borges JH, Astur N, Arliani GG, Kaleka CC, Cohen M (2015) Medial patellofemoral ligament reconstruction: a longitudinal study comparison of 2 techniques with 2 and 5-years follow-up. *Open Orthop J* 9:198–203
18. Becher C, Kley K, Lobenhoffer P, Ezechieli M, Smith T, Ostermeier S (2014) Dynamic versus static reconstruction of the medial patellofemoral ligament for recurrent lateral patellar dislocation. *Knee Surg Sports Traumatol Arthrosc* 22(10):2452–2457
19. Matsushita T, Oka S, Araki D, Nishida K, Tanaka T, Kanzaki N, Nishida K, Kuroda R (2017) Patient-based outcomes after medial patellofemoral ligament reconstruction. *Int Orthop* 41(6):1147–1153
20. Niu C, Fu K, Lu J, Chen X, Liu J, Niu Y, Li Y, Yang X, Wang F (2016) A medium-term follow-up outcome of medial retinaculum plasty versus double-bundle anatomical medial patellofemoral ligament reconstruction for recurrent patellar dislocation in adults. *Int J Clin Exp Med* 9(6):9064–9072
21. Song SY, Kim IS, Chang HG, Shin JH, Kim HJ, Seo YJ (2014) Anatomic medial patellofemoral ligament reconstruction using patellar suture anchor fixation for recurrent patellar instability. *Knee Surg Sports Traumatol Arthrosc* 22(10):2431–2437
22. Torkaman A, Monshizadeh S, Shabanpour M (2015) Medial patellofemoral ligament (MPFL) reconstruction surgery in Iranian patients with recurrent patellar dislocation: report of three years' experiences. *Biomed Pharmacol J* 8(1):165–170
23. Wagner D, Pfalzer F, Hingelbaum S, Huth J, Mauch F, Bauer G (2013) The influence of risk factors on clinical outcomes following anatomical medial patellofemoral ligament (MPFL) reconstruction using the gracilis tendon. *Knee Surg Sports Traumatol Arthrosc* 21(2):318–324
24. Wang CH, Ma LF, Zhou JW, Ji G, Wang HY, Wang F, Wang J (2013) Double-bundle anatomical versus single-bundle isometric medial patellofemoral ligament reconstruction for patellar dislocation. *Int Orthop* 37(4):617–624
25. Wang HD, Dong JT, Gao SJ (2016) Medial patellofemoral ligament reconstruction using a bone groove and a suture anchor at patellar: a safe and firm fixation technique and 3-year follow-up study. *J Orthop Surg Res* 11(1):138
26. Feller JA, Richmond AK, Wasiak J (2014) Medial patellofemoral ligament reconstruction as an isolated or combined procedure for recurrent patellar instability. *Knee Surg Sports Traumatol Arthrosc* 22(10):2470–2476
27. Hinterwimmer S, Imhoff AB, Minzlaff P, Saier T, Rosenstiel N, Hawe W, Feucht MJ (2013) Anatomical two-bundle medial patellofemoral ligament reconstruction with hardware-free patellar graft fixation: technical note and preliminary results. *Knee Surg Sports Traumatol Arthrosc* 21(9):2147–2154
28. Panni AS, Alam M, Cerciello S, Vasso M, Maffulli N (2011) Medial patellofemoral ligament reconstruction with a divergent patellar transverse 2-tunnel technique. *Am J Sports Med* 39(12):2647–2655
29. Ronga M, Oliva F, Longo UG, Testa V, Capasso G, Maffulli N (2009) Isolated medial patellofemoral ligament reconstruction for recurrent patellar dislocation. *Am J Sports Med* 37(9):1735–1742
30. Zhou JW, Wang CH, Ji G, Ma LF, Wang J, Zhang F, Dong JT, Wang F (2014) A minimally invasive medial patellofemoral ligament arthroscopic reconstruction. *Eur J Orthop Surg Traumatol* 24(2):225–230
31. Kang HJ, Cao JH, Pan S, Wang XJ, Yu DH, Zheng ZM (2014) The horizontal Y-shaped graft with respective graft tension angles in anatomical two-bundle medial patellofemoral ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc* 22(10):2445–2451
32. Lobner S, Krauss C, Reichwein F, Patzer T, Nebelung W, Venjakob AJ (2017) Surgical treatment of patellar instability: clinical and radiological outcome after medial patellofemoral ligament reconstruction and tibial tuberosity medialisation. *Arch Orthop Trauma Surg* 137(8):1087–1095
33. Matthews JJ, Schranz P (2010) Reconstruction of the medial patellofemoral ligament using a longitudinal patellar tunnel technique. *Int Orthop* 34(8):1321–1325
34. Wang JL, Li HP, Liu YJ, Wang N, Li ZL, Wang ZG, Wei M (2012) Reconstruction of the medial patellofemoral ligament with a suture-tie technique of patellar side fixation. *Chin Med J (Engl)* 125(11):1884–1888
35. Singer B, Singer K (2009) Anterior knee pain scale. *Aust J Physiother* 55(2):140

36. Lenschow S, Schliemann B, Gestring J, Herbort M, Schulze M, Kösters C (2013) Medial patellofemoral ligament reconstruction: fixation strength of 5 different techniques for graft fixation at patella. *Arthroscopy* 29(4):766–773
37. He W, Yang YM, Liu M, Wang AY, Liu YJ (2013) Reconstruction of the medial patellofemoral ligament using hamstring tendon graft with different methods: a biomechanical study. *Chin Med Sci J* 28(4):201–205
38. Smirk C, Morris H (2003) The anatomy and reconstruction of the medial patellofemoral ligament. *Knee* 10(3):221–227
39. Victor J, Wong P, Witvrouw E, Sloten JV, Bellemans J (2009) How isometric are the medial patellofemoral, superficial medial collateral, and lateral collateral ligaments of the knee? *Am J Sports Med* 37(10):2028–2036
40. Schüttler KF, Hoeger A, Heyse TJ, Figiel J, Timmesfeld N, Stein T, Ziring E, Efe T (2018) Femoral tunnel widening is associated with tunnel malposition but not with clinical failure after medial patellofemoral ligament reconstruction with a free gracilis tendon graft. *Arch Orthop Trauma Surg*. <https://doi.org/10.1007/s00402-018-2923-z>
41. McNeilan RJ, Everhart JS, Mescher PK, Abouljoud M, Magnussen RA, Flanigan DC (2018) Graft choice in isolated medial patellofemoral ligament reconstruction: a systematic review with meta-analysis of rates of recurrent instability and patient-reported outcomes for autograft, allograft, and synthetic options. *Arthroscopy* 34(4):1340–1354