Single *Versus* Double Tunnel Fixation in Medial Patellofemoral Ligament Reconstruction: A Meta-Analysis

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ABSTRACT

The purpose of this meta-analysis was to conduct a comparative analysis of clinical scores and complication rates among patients experiencing recurrent patellar dislocation who underwent medial patellofemoral ligament (MPFL) reconstruction using both single and double tunnel techniques. A comprehensive search was conducted across electronic databases including PubMed, the Cochrane Library, Web of Science, and Google Scholar to retrieve articles relevant to MPFL reconstruction utilising the tunnel technique. Subsequently, meta-analyses were undertaken to assess complication rates and changes in clinical scores before and after surgery. Following this, sensitivity analysis and meta-regression analysis were performed to scrutinise potential confounding variables. A total of thirty-two studies were included in the analysis, comprising twenty-seven non-comparative studies and five comparative studies. The findings revealed a similarity in postoperative complication rates between the single and double tunnel fixation techniques: [9.0% (95%CI, 4.0%-15.6%) *versus* 8.9% (95%CI, 4.7%-14.1%, p = 0.844)]. Likewise, no statistically significant differences were observed in Lysholm scores [34.1 (95%CI, 26.7-41.5) *versus* 33.8 (95%CI, 27.7-40.0, p = 0.956)], Kujala scores [29.4 (95%CI, 22.3-36.4) *versus* 27.3 (95%CI, 22.3-32.3, p = 0.637)], and Tegner score change [1.1 (95%CI, 0.8-1.4) *versus* 0.7 (95%CI, -0.2-1.6, p = 0.429)] before and after MPFL reconstruction, respectively, using these two techniques. In conclusion, the authors found that the clinical functional improvement and complication rates in MPFL reconstruction using the single tunnel fixation technique are comparable to those achieved with the double tunnel fixation approach. However, to further advance the understanding in this field, additional randomised controlled studies must be conducted to provide further insights.

Key Words: *MPFL reconstruction, Bone tunnel, Patellar dislocation, Meta-analysis.*

How to cite this article: Zhan H, Jiang J, Yi Z, He J, Wu M, Xia Y. Single *Versus* Double Tunnel Fixation in Medial Patellofemoral Ligament Reconstruction: A Meta-Analysis. *J Coll Physicians Surg Pak* 2024; **34(05)**:584-594.

INTRODUCTION

Recurrent patellar dislocation represents a common disorder in sports orthopaedics. Its incidence exhibits a gradual rise, particularly among physically active young women.[1] In recent years, anatomical and biomechanical inquiries focused on the ligaments surrounding the patellofemoral joint have unequivocally established the paramount importance of the medial patellofemoral ligament (MPFL) as the principal stabiliser against lateral patellar dislocation, especially within the context of a 30-degree range of knee flexion.[2,3] Additionally, anatomical variables exert a significant influence on the genesis of recurrent patellar dislocation. These variables encompass patellar alta, an elevated tibial tubercle to trochlear groove (TT-TG) value, trochlear dysplasia, and patellar deformities.[4,5]

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Received: February 09, 2023; Revised: August 14, 2023; Accepted: January 25, 2024
DOI: https://doi.org/10.29271/jcpsp.2024.05.584

Approximations suggest that MPFL tears afflict as many as 94% of patients undergoing their inaugural patellar dislocation.[6] This underscores the prominence of MPFL reconstruction as the primary surgical recourse for managing recurrent patellar dislocation, with demonstrated enhancements in clinical outcomes. Notably, this procedure has garnered widespread adoption, both as a standalone intervention and in tandem with osseous procedures.[7-9]

Graft fixation techniques predominantly encompass femoral and patellar fixation methods. The bone tunnel and interface anchor techniques are employed for graft fixation at Schottle's point on the femur, and this has been established as the optimal femoral fixation approach.[10] The techniques employed for patellar graft fixation in MPFL reconstruction are categorised into suture anchor and bone tunnel methods. Biomechanical investigations have demonstrated that bone tunnel fixation yields superior fixation strength compared to the suture anchor, and it exhibits equivalent tensile load to failure as the native MPFL.[11,12] The bone tunnel technique is commonly categorised into single and double tunnel fixation approaches, with the selection between the two techniques sparking controversy.[13,14] Biomechanical analyses have unveiled that the double tunnel fixation method possesses akin stiffness, ultimate load, elongation, and absorbed energy characteristics as the single tunnel fixation approach. However, it also carries a heightened risk of patellar fracture.[13,15] Additionally, Ercan *et al.* and Qiao *et al*. conducted prospective randomised controlled independent studies encompassing patients afflicted with recurrent patellar dislocation.[14,16] Both investigations yielded congruent findings, suggesting that both single and double tunnel fixation resulted in comparable clinical, radiological, and functional outcomes. This finding contrasts with the conclusions drawn from earlier investigations.[17,18] To enhance comprehension regarding the comparative effectiveness of single tunnel and double tunnel fixation for MPFL reconstruction in cases of recurrent patellar dislocation, and to offer valuable insights for clinical decision making, an imperative is discerned to undertake a meta analysis encompassing pertinent antecedent studies.

The purpose of this meta-analysis was to conduct a comparative assessment of the complication rates and clinical scores observed in patients with recurrent patellar dislocation who underwent treatment *via* single tunnel and double tunnel fixation. Our working hypothesis posited that the double tunnel fixation would yield comparable clinical outcomes to those achieved with single tunnel fixation.

METHODOLOGY

This study was executed in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) statement.[19] Comprehensive literature searches were conducted across multiple databases including PubMed, Cochrane Library, Web of Science, and Google Scholar to identify studies assessing the clinical outcomes of MPFL reconstruction for recurrent patellar dislocation through tunnel fixation methods, spanning the period from January 1996 to December 2022. The search terms encompassed various fields, including title, abstract, MeSH, and keywords, with specific terms such as 'patellar dislocation' or 'patellar instability' and 'single tunnel' or 'double tunnel' and 'MPFL reconstruction' or 'Medial patellofemoral ligament reconstruction'. Furthermore, additional searches were conducted across the reference lists of the included articles to identify potentially overlooked publications.

Two researchers screened the titles and abstracts of the included articles based on the following inclusion and exclusion criteria, and reviewed the full text if necessary. In instances of discrepancy, a consensus was achieved with the involvement of a senior author. The inclusion criteria encompassed investigations focusing on hamstrings-based patellar tunnel fixation MPFL reconstruction in patients with recurrent patellar dislocation, regardless of the performance of secondary soft tissue procedures such as, lateral retinaculum release or vastus medialis advancement; articles reporting clinical outcomes (comprising clinical scores or complications) of MPFL reconstruction for recurrent patellar dislocation, wherein recurrent patellar dislocation was defined as the occurrence of two or more lateral patellar dislocations; a minimum average follow-up duration of 12 months; and studies involving a cohort size exceeding 10 cases. The stipulated exclusion criteria encompassed: The inclusion of cases involving acute patellar dislocation; articles written in languages other than English; studies coupled with concurrent bony procedures such as trochleoplasty or tibial tubercle osteotomy; patients who had undergone prior or supplementary interventions on the same knee; and materials classified as case reports, abstracts, technical notes, editorials, cadaveric investigations, or reviews.

Two senior researchers independently utilised a predefined data extraction template to methodically retrieve pertinent information from articles satisfying the predetermined inclusion and exclusion criteria. Any discrepancies arising between the two researchers were judiciously addressed through a process of deliberation to reach a consensus. The extracted data encompassed salient study attributes, comprising the first author's identity, year of publication, and study design; particulars regarding the patients, including age, sample size, duration of symptoms, follow-up time, and the presence of trochlear dysplasia; surgical methodologies encompassing patellar fixation, femoral fixation, graft selection, and fixation angles; mean values ± standard deviation of postoperative clinical scores, encompassing Lysholm, Kujala, and Tegner scores; and mention of postoperative complications, encompassing patellar instability, patellar subluxation, patellar fracture, positive apprehension sign, re-operation, and postoperative pain (Table I and II).[20-50]

Two researchers conducted an independent evaluation of the methodologic quality of each study in accordance with the methodological index for nonrandomised studies (MINORS) criteria. The degree of concordance between the two evaluators was determined using the Kappa coefficient. MINORS has demonstrated its efficacy in assessing the reporting quality of both comparative and noncomparative studies, featuring eight items (with a maximum score of 16) applicable to noncomparative studies and twelve items (with a maximum score of 24) applicable to comparative studies. Any instances of disparity between the two researchers were effectively resolved through thorough discourse or, if necessary, adjudicated by a third reviewer.

Statistical analyses were conducted using R software (Version 4.1.0). To enhance consistency within the study, included comparative studies were divided into two distinct groups and treated as independent units for meta-analysis purposes. The primary focus of meta-analysis centred on elucidating the mean disparities in complication rates and clinical scores between MPFL reconstruction employing single tunnel and double tunnel fixation in patients grappling with recurrent patellar dislocation. Continuous variables, such as Lysholm scores, Kujala scores, and Tegner scores, were presented as mean differences (MD) accompanied by 95% confidence intervals, utilising a random-effects model. Conversely, binary variables encompassing complication rates were reported as risk ratios (RR) with corresponding 95% confidence intervals, also employing a random-effects model. However, due to instances where clinical scores were presented solely as medians, quartiles, or extreme values, the authors resorted to the approach advocated by Wan *et al*. This methodology facilitated the estimation of sample means and standard deviations, drawing upon sample sizes, medians, ranges, and/or interquartile ranges.[51]

Table I: Included Noncomparative Studies (n = 27).

Author Year	MINORS score	Mean age	Sample size	Mean follow-up	Dysplasia included?	Graft	Patellar fixation	Femoral fixation	Fixation angle	Lysholm score		Kujala score		Tegner score		Complication
										Pre	Post	Pre	Post	Pre	Post	
Csintalan 2014[20]	12	24	56	51.6	N/A	semiT	DT	BT	N/A	N/A	N/A	N/A	N/A	6.1 ± 2.7	5.6 ± 2.5	5
Feller 2014[21]	11	23.9	31	37.2	N/A	semiT or gracilis	DT	BT	20	N/A	N/A	N/A	N/A	N/A	N/A	0
Foda 2017[22]	11	23	18	24	No	semiT	DT	BT	30	N/A	N/A	N/A	N/A	N/A	N/A	3
Gao 2020[23]	11	21.3	80	66.1	Yes	gracilis	DT	BT	90	73.5 ± 14.6	95.3 ± 3.4	69.4 ± 7.9	96.1 ±1.9	3.1 ± 1.3	5.9 ± 1.3	2
Goncaives 2011[24]	10	28.6	22	26.1	Yes	semiT	ST	BT	60	53.7 ± 12.6	93.4 ± 8.1	59.8 ± 14.7	83.54 ± 6.6	N/A	N/A	0
Habeeb 2021[25]	10	25.9	20	14.9	No	semiT or gracilis	DT	BT	30	54.9 ± 19.8	78.9 ± 16.5	52.3 ± 15.5	73.1 ± 14.6	N/A	N/A	3
Han 2011[26]	12	24.3	59	68.4	No	semiT or gracilis	DT	BT	60	N/A	N/A	N/A	N/A	N/A	N/A	7
Hinterwimmer 2013[27]	10	23	19	16	No	gracilis	DT	BT	30	N/A	N/A	N/A	N/A	N/A	N/A	3
Kang 2014[28]	10	26.6	45	33.7	No	semiT	DT	BT	30	51.8 ± 6.2	91.7 ± 4.1	53.4 ±5.3	90.9 ± 6.6	N/A	N/A	0
Kita 2012[29]	9	22.7	25	13.2	N/A	semiT	DT	BT	45	N/A	N/A	73.8 ± 4.3	93.8 ± 3.8	N/A	N/A	4
Kita 2015[30]	12	25.4	44	38.4	Yes	semiT	DT	BT	45	N/A	N/A	66.6 ± 8.9	93.6 ± 4.4	N/A	N/A	18
Kumar 2014[31]	11	18	30	25	No	gracilis	ST	BT	45	42.6 ± 11.5	85.5 ± 5.9	43.8 ± 15.7	84.7 ± 6.9	N/A	N/A	3
Kumar 2017[32]	11	20	48	24	No	semiT	DT	BT	20-60					N/A	N/A	6
Lee 2014[33]	14	21.2	12	28.5	Yes	semiT	ST	BT	60	75.0 ± 8.3	92.2 ± 5.5	71.1 ± 6.8	91.2 ± 6.7	N/A	N/A	1
Lippacher 2014[34]	11	18.3	72	24.7	No	gracilis	DT	BT	30	N/A	N/A	64.5 ± 13	78 ± 13.2	4.8 ± 1.3	4.3 ± 1.1	12
Matthews 2010[35]	10	24	25	31	No	semiT or gracilis	DT	BT	20	N/A	N/A	N/A	N/A	3 ± 1.5	4.2 ± 1.5	7
Mikashima 2006[36]	11	22.3	12	41	N/A	semiT	ST	BT	45	N/A	N/A	N/A	N/A	N/A	N/A	3
Monllau 2015[37]	14	25.6	36	37.6	Yes	gracilis	DT	AP	30	53 ± 5.7	95 ± 2.4	63 ± 5	90 ± 4.5	4 ± 0.2	5 ± 1	0
Nelitz 2013[38]	12	12.2	21	33.6	Yes	gracilis	DT	BT	30	N/A	N/A	72.9 ± 13.2	92.8 ± 6.9	6 ± 1.6	5.8 ± 1.6	1
Nomura 2006[39]	12	24.8	12	50.4	N/A	semiT	ST	BT	60	N/A	N/A	56.3 ± 15.6	96 ± 5.2	N/A	N/A	5
Panni 2011[40]	11	28	51	24	No	semiT	DT	BT	20	57.6 ± 19.6	88.1 ± 16.2	56.7 ± 8.9	86.8 ± 14.4	N/A	N/A	6
Ronga 2009[41]	14	32.5	28	37.2	No	semiT or gracilis	DT	BT	20	N/A	N/A	45 ± 17	83 ± 14	N/A	N/A	10
Smith 2014[42]	15	23.1	30	12	No	semiT or gracilis	ST	BT	70	N/A	N/A	65.3 ± 17.6	84.1 ± 20.6	N/A	N/A	1
Sufyan 2022[43]	11	24.2	48	12	N/A	semiT or gracilis	DT	BT	30	N/A	N/A	N/A	N/A	N/A	N/A	3
Sundararajan 2015[44]	12	29	22	30	No	semiT	ST	BT	45	62.1 ± 3.7	94.3 ± 2.6	49.6 ± 8.9	92.2 ± 2.6	2.3 ± 0.3	3.3 ± 0.3	1
Engelhardt 2018[45]	11	18	30	24	No	gracilis	DT	BT	30	59 ± 11	95 ± 6	57 ± 15	92 ± 10	N/A	N/A	5
Zhou 2014[46]	12	21.3	32	18	NA	semiT	DT	BT	30	N/A	N/A	63.0 ± 9.0	91.0 ± 7.0	N/A	N/A	0

N/A, not available; semiT, Semitendinosus; ST, Single tunnel; DT, Double tunnel; BT, Bone tunnel; SA, Suture anchor; AP, Adductor pedicle; Pre, Preoperatively; Post, Postoperatively.

In terms of effect heterogeneity, the variability in effect sizes across the included studies was gauged utilising the 12 statistic. Interpretatively, values of 25%, 50%, and 75% corresponded to low, moderate, and high degrees of heterogeneity, respectively.[52] Evaluation of publication bias in scenarios involving ten or more studies was executed *via* funnel plots and the Egger's statistical test. For additional robustness, sensitivity analysis was carried out by accounting for varying follow-up times, years of publication, patients' ages, graft selection, and the presence of trochlear dysplasia. Ultimately, a meta-regression analysis was undertaken to assess the influence of patient-specific characteristics (age and follow-up time), on complication rates and clinical scores.

Table II: Included comparative studies (n = 5).

Author Year	MINORS score	Group	Mean age	Sample size	Mean follow-up	Dysplasia included?	Graft	Patellar fixation	Femoral fixation	Fixation angle	Lysholm score		Kujala score		Complication
											Pre	Post	Pre	Post	
Astur 2015[47]	20	Single tunnel fixation (Anchor fixation was excluded)	31.06	30	60	No	gracilis	ST	BT	30-45	N/A	N/A	N/A	N/A	2
Ercan-A 2021[14]	22	Single tunnel fixation	15	40	46.5	No	semiT	ST	BT	30	48.3 ± 20.4	89.2 ± 9.2	38.1 ± 21.4	86.6 ± 12	0
Ercan-B 2021[14]		Double tunnel fixation	19	40	40	No	semiT	DT	BT	30	45 ± 25.4	85 ± 13.2	40.5 ± 22	88.2 ± 9.3	0
Li 2018[48]	23	Single-double reconstruction (Double anchor reconstruction was excluded)	27.4	43	41.3	No	semiT	ST	BT	30	52.88 ± 5.30	85.16 ± 3.89	64.74 ± 4.91	83.96 ± 3.7	9
Lind-A 2014[49]	17	Children	12.5	20	39	Yes	gracilis	ST	BT	30	N/A	N/A	61 ± 13	71 ± 15	5
Lind-B 2014[49]		Adult	23	179	41	Yes	gracilis	DT	BT	30	N/A	N/A	63 ± 17	76 ± 20	5
Wang-A 2010[50]	19	Isolated MPFL reconstruction	29	28	42	No	semiT	ST	AP	30	N/A	N/A	51.3 ± 4.5	79.9 ± 6.2	2
Wang-B 2010[50]		Combination of MPFL reconstruction with vastus medialis advancement	31	41	42	No	semiT	ST	BT	30	N/A	N/A	53.7 ± 5.2	83.9 ± 6.5	4

N/A, Not available; semiT, Semitendinosus; ST, Single tunnel; DT, Double tunnel; BT, Bone tunnel; AP, Adductor pedicle; Pre, Preoperatively; Post, Postoperative

Table III: Quality assessment of included studies (MINORS score).

Authors	Clearly stated aim	Inclusion of consecutive patients	Prospective collection of data	Endpoints appropriate for aim	Unbiased assessment of endpoints	Appropriate follow-up period	Lost to follow-up <5%	Prospective calculation of study size	Adequate control group	Contemporary groups	Baseline equivalence of groups	Adequate statistical analysis	Total score
Astur 2015[47]	2	2	1	1	2	2	1	2	2	2	1	2	20
Csintalan 2014[20]	2	2	2	2	0	2	2	0					12
Ercan 2021[14]	2	2	2	2	2	2	2	1	2	1	2	2	22
Feller 2014[21]	2	2	2	2	0	2	1	0					11
Foda 2017[22]	2	2	2	1	0	2	2	0					11
Gao 2020[23]	2	2	2	2	0	2	1	0					11
Goncaives 201[24]	2	1	2	1	0	2	2	0					10
Habeeb 2021[25]	2	2	2	1	0	1	2	0					10
Han 2011[26]	2	2	2	2	0	2	1	1					12
Hinterwimmer 2013[27]	2	2	2	1	0	2	1	0					10
Kang 2014[28]	2	1	2	2	0	2	1	0					10
Kita 2012[29]	2	1	2	2	0	1	1	0					9
Kita 2015[30]	2	2	2	2	0	2	2	0					12
Krishna Kumar 2014[31]	2	2	2	1	0	2	2	0					11
Kumar 2017[32]	2	2	2	1	0	2	2	0					11
Lee 2014[33]	2	2	2	2	2	2	2	0					14
Li 2019[48]	2	2	2	2	2	2	2	2	2	1	2	2	23
Lind 2014[49]	2	2	2	2	0	2	1	0	2	1	1	2	17
Lippacher 2014[34]	2	2	2	2	0	2	1	0					11
Matthews 2010[35]	2	2	2	1	0	1	2	0					10
Mikashima 2006[36]	2	2	2	1	0	2	2	0					11
Monllau 2015[37]	2	2	2	2	2	2	2	0					14
Nelitz 2012[38]	2	2	2	2	0	2	2	0					12
Nomura 2006[39]	2	2	2	2	0	2	2	0					12
Panni 2011[40]	2	2	2	2	0	2	1	0					11
Ronga 2009[41]	2	2	2	2	2	2	2	0					14
Smith 2014[42]	2	2	2	2	2	2	1	2					15
Sufyan 2022[43]	2	2	2	1	0	2	2	0					11
Sundararajan 2015[44]	2	2	2	2	0	2	2	0					12
von Engelhardt 2018[45]	2	2	2	2	0	1	2	0					11
Wang 2010[50]	2	2	2	2	0	2	2	0	2	1	2	2	19
Zhou 2014[46]	2	2	2	2	0	2	2	0					12

RESULTS

Initial electronic searches conducted on PubMed, Cochrane Library, Web of Science, and Google Scholar yielded respective totals of 95, 4, 207, and 129 articles. Of these, 75 articles were identified as duplicates within the databases. Subsequent to applying the predetermined inclusion and exclusion criteria, a total of 360 articles underwent meticulous scrutiny based on their titles and abstracts. Ultimately, excluding 93 articles, the remaining pool was distilled. A thorough examination of the full texts of these 93 articles led to the exclusion of 61, primarily due to insufficient vital data. The culminating outcome comprised 32 studies, encompassing 27 noncomparative studies, and 5 comparative studies. Finally, a total of 32 studies were subsequently incorporated into the process of data extraction and meta-analysis.

The agreement between two independent investigators for the MINORS score demonstrated a high level of concordance (kappa = 0.89). The mean MINORS score was 11.5 (range, 9-15) for noncomparative studies and 20.2 (range, 17 - 23) for comparative studies (Table III). Points deducted from the MINORS score primarily pertained to the evaluation of endpoints without a blind method, absence of sample size calculation, and the non-simultaneous execution of two study groups in comparative studies. Acknowledging the established practice, the authors undertook an evaluation for publication bias in studies with >10 outcomes.

Table IV: Sensitivity analysis comparing the single and double tunnel fixation techniques.

	No. of studies	Sample size	Complication rate (95% CI), %	I^2, %	p-value
All					0.844
Single tunnel	13	342	9.0 (4.0, 5.6)	65	
Double tunnel	22	1007	8.9 (4.7, 14.1)	82	
Follow-up >24 mouths					0.575
Single tunnel	12	312	9.7 (4.1, 17.0)	66	
Double tunnel	13	716	7.8 (2.2, 15.8)	88	
Published after 2012					0.639
Single tunnel	8	227	7.9 (2.5, 15.3)	64	
Double tunnel	17	819	6.5 (2.5, 11.7)	82	
Age >20 years					0.790
Single tunnel	10	252	9.5 (4.1, 16.5)	56	
Double tunnel	17	796	9.0 (4.0, 15.6)	84	
Gracilis					0.253
Single tunnel	3	80	12.1 (4.1, 23.0)	38	
Double tunnel	7	437	6.2 (1.6, 13.0)	76	
semiT					0.839
Single tunnel	9	232	9.0 (2.3, 18.4)	72	
Double tunnel	9	359	8.5 (2.0, 18.3)	86	
Trochlear dysplasia excluded					0.181
Single tunnel	8	264	6.8 (2.7, 12.4)	54	
Double tunnel	12	455	12.4 (6.4, 19.8)	75	
	No. of studies	**Sample size**	**Kujala score mean difference (95% CI), %**	**I^2, %**	**p-value**
All					0.637
Single tunnel	11	300	29.4 (22.3, 36.4)	95	
Double tunnel	14	703	27.3 (22.3, 32.3)	95	
Follow-up >24 mouths					0.614
Single tunnel	10	270	30.3 (22.9, 37.8)	96	
Double tunnel	9	545	27.6 (20.2, 35.0)	96	
Published after 2012					0.771
Single tunnel	7	197	28.7 (17.7, 39.7)	97	
Double tunnel	11	599	26.9 (20.9, 32.8)	95	
Age >20 years					0.777
Single tunnel	8	210	27.9 (21.6, 34.2)	95	
Double tunnel	10	540	26.7 (22.1, 31.4)	95	
Gracilis					0.842
Single tunnel	2	50	25.6 (-4.7, 55.9)	97	
Double tunnel	6	418	22.4 (15.7, 29.2)	94	
semiT					0.986
Single tunnel	8	220	31.3 (23.8, 38.7)	96	
Double tunnel	6	237	31.4 (24.0, 38.8)	96	
Trochlear dysplasia excluded					0.882
Single tunnel	7	234	32.7 (24.3, 41.1)	97	
Double tunnel	7	286	31.8 (23.2, 40.3)	95	

semiT, semitendinosus

Table V: Meta-regression analysis comparing the associations of age and follow-up period.

	Coefficient	Standard error	p-value	95% CI
Complication rate				
Age	0.004	0.007	0.532	(-0.009, 0.017)
Follow-up period	-0.001	0.002	0.762	(-0.005, 0.004)
Kujala score improvement				
Age	0.270	0.397	0.497	(-0.509, 1.048)
Follow-up period	0.182	0.172	0.290	(-0.156, 0.520)
Lysholm score improvement				
Age	-0.285	0.557	0.609	(-1.376, 0.807)
Follow-up period	-0.104	0.205	0.611	(-0.202, 0.297)

The assessment focused on studies reporting complication rates, Lysholm scores, and Kujala scores, revealing a notable leftward skew in the complication rate distribution through funnel plots. Contrarily, the funnel plots for Lysholm and Kujala scores depicted no significant skewness, as depicted in Figure 1. Further validation was provided by Egger test, indicating publication bias in complication rates (p = 0.042), yet no such bias for Lysholm scores and Kujala scores (p = 0.632 and p = 0.335, respectively).

Thirty-two studies, encompassing 1,349 knees, documented postoperative complications in cases of recurrent patellar dislocation subjected to MPFL reconstruction. These complications included patellar instability, subluxation, fracture, positive apprehension sign, re-operation, and postoperative pain. Among these studies, thirteen involved 342 knees undergoing single tunnel fixation, while twenty-two studies featured 1,007 knees subjected to double tunnel fixation in MPFL reconstruction. The average postoperative complication rates for these groups were 9.0% (95% CI, 4%-15.6%) and 8.9% (95% CI, 4.7%-14.1%), respectively. Importantly, the inter group difference lacked statistical significance (p = 0.844), as illustrated in Figure 2.

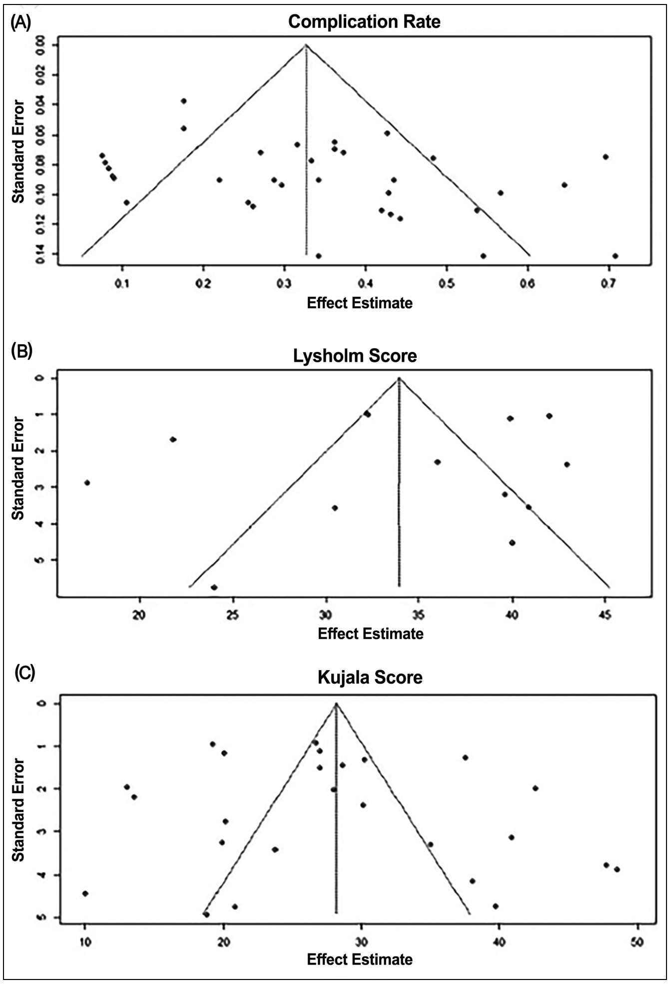

Figure 1: Funnel plots testing for publication bias in complication rates (A), Lysholm scores (B), and Kujala scores (C).

A total of 12 studies reported enhancements in Lysholm scores post-surgery. Among these, six studies involved 169 knees treated with single tunnel fixation, while seven studies encompassed 302 knees treated with double tunnel fixation in MPFL reconstruction. The mean changes in Lysholm scores for these groups were 34.1 (95% CI, 26.7-41.5) and 33.8 (95% CI, 27.7-40.0), respectively. Importantly, the variation between groups did not achieve statistical significance (p = 0.956), as depicted in Figure 3.

A total of nine studies documented enhancements in Tegner scores post-surgery. Among these, three studies encompassed 105 knees treated with the single tunnel fixation technique, while seven studies involved 330 knees subjected to the double tunnel fixation technique in MPFL reconstruction. The mean changes in Tegner scores before and after MPFL reconstruction for these groups were 1.1 (95% CI, 0.8-1.4) and 0.7 (95% CI, -0.2-1.6) respectively. Importantly, no statistically significant disparity was observed between the two groups (p = 0.429), as depicted in Figure 4 (A).

Twenty-two studies documented alterations in Kujala scores subsequent to MPFL reconstruction. Among these, eleven studies encompassed 300 knees subjected to single tunnel fixation, while fourteen studies involved 703 knees treated with double tunnel fixation in MPFL reconstruction. The mean changes in Kujala scores before and after MPFL reconstruction for these groups were 29.4 (95% CI, 22.3-36.4) and 27.3 (95% CI, 22.3-32.3), respectively. Notably, no statistically significant difference existed between the two groups (p = 0.637), as illustrated in Figure 4 (B).

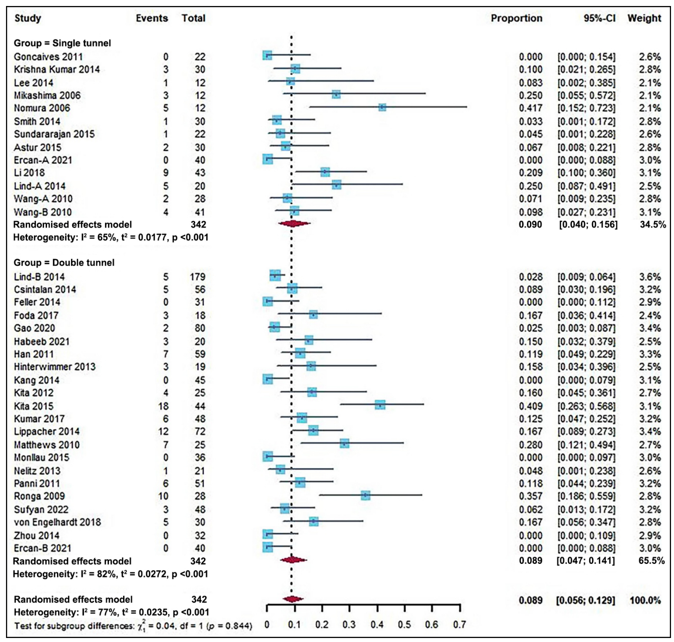

Figure 2: Forest plots of studies showing complication rates after MPFL reconstruction using single and double tunnel fixation techniques, the squares represent the mean postoperative complication rates, and the size of the squares indicates the sample size of study (CI, confidence interval).

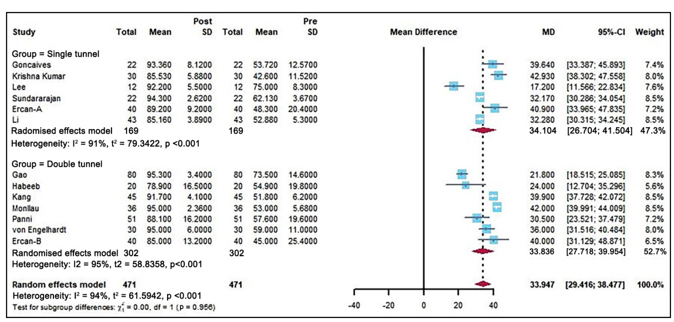

Figure 3: Forest plots showing changes in Lysholm score before and after MPFL reconstruction using single and double tunnel fixation techniques (CI, confidence interval; MD, mean difference).

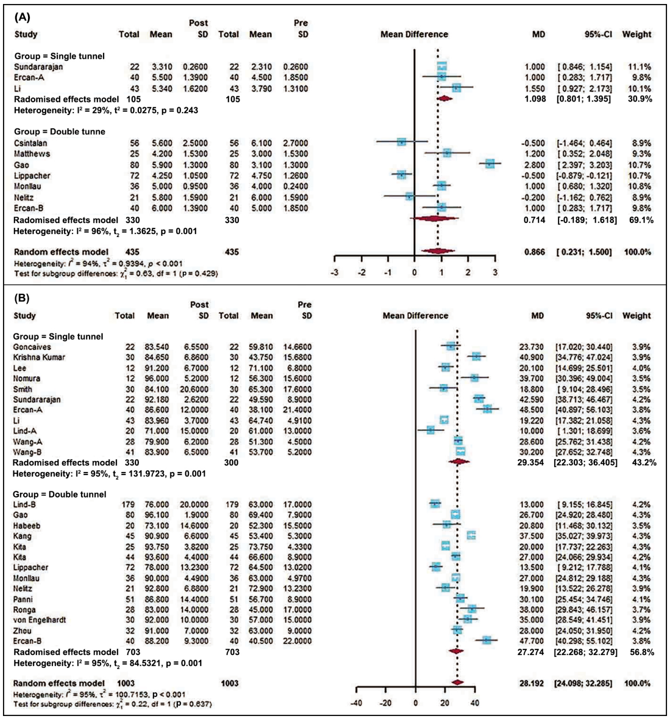

Figure 4: Forest plots showing changes in Tegner score (A) and Kujala score (B) before and after MPFL reconstruction using single and double tunnel fixation techniques (CI, confidence interval; MD, mean difference).

Sensitivity analysis revealed that variables such as follow-up time, publication year, age, graft selection, and femoral trochlear dysplasia did not exert a significant influence on the incidence of complications and the changes in Kujala scores before and after MPFL reconstruction utilising both single and double tunnel fixation techniques ($p > 0.05$), as illustrated in Table IV.

The meta-regression analysis demonstrated that patients' age and follow-up time had no significant correlation with clinical scores and postoperative complication rates ($p > 0.05$), as indicated in Table V.

DISCUSSION

The primary discovery of this study underscores the efficacy of both single and double tunnel fixation techniques in MPFL reconstruction for recurrent patellar dislocation, manifesting in enhanced knee functionality. Notably, no statistically significant distinctions were observed in postoperative complication rates and clinical scores between these two approaches.

A biomechanical investigation conducted by Mountney *et al.* demonstrated that the failure load of grafts reconstructed through transosseous tunnel fixation surpassed that of suture anchor fixation, resembling the load capacity of the native MPFL.[53] Similarly, Russo *et al*. arrived at a congruent conclusion, revealing that the maximal and yield loads achieved with the converging tunnel technique exceeded those associated with suture anchor fixation.[54] Both single and double tunnel fixation techniques exhibit additional merits. Primarily, the bone tunnel approach secures the graft *via* bone, obviating the need for supplemental biomaterials. This accelerates anatomical healing and reduces treatment costs. Moreover, the utilisation of autologous tendons (gracilis or semitendinosus) within the bone tunnel method circumvents implant-specific complications linked to suture anchor fixation. These observations substantiate the superiority of bone tunnel techniques, encompassing both single and double tunnel configurations, for addressing recurrent patellar dislocation compared to alternative surgical strategies.

A cadaveric investigation encompassing 18 knees by Placella *et al.*[15] revealed comparable ultimate load and stiffness in single-bundle MPFL reconstructions (with single tunnel fixation on the patella side) and double-bundle MPFL reconstructions (with double tunnel fixation on the patella side).[16] However, the former exhibited an 11% incidence of patellar fractures, while the latter did not. Conversely, a study by Schiphouwer *et al*. suggested a higher likelihood of patellar fracture with the double tunnel technique, attributing it to greater patellar damage compared to the single tunnel approach.[55] In contrast, this meta-analysis of primary data unveiled no significant disparity in postoperative complication rates between the two techniques. Across the meta-analysis, 13 studies (involving 342 knees) utilising single tunnel fixation reported 3 cases of patellar fractures, while 22 studies (encompassing 1,007 knees) utilising double-tunnel fixation reported 1 case of patellar fracture. Evidently, the incidence of patellar fracture remained low in both methods, demonstrating equivalence between them.

A recent biomechanical investigation revealed no significant disparities in the mechanical and structural properties of grafts between single tunnel fixation and double tunnel fixation.[13] In comparison to the native MPFL, both techniques exhibit increased ultimate elongation and absorbed energy but reduced stiffness. The authors posit that regardless of the number of bone tunnels employed, the instantaneous load at the point of patellar fracture far exceeds the force generated by lateral knee dislocation during routine activities, thereby lowering the incidence of patellar fractures associated with the bone tunnel technique. Theoretically, augmented absorption energy and failure load better counteract the lateral patellar dislocation resistance, thereby mitigating the potential for recurrent dislocation. Furthermore, reduced stiffness can favourably influence the dynamic knee extension and flexion environment, enhancing comfort during physical activities and diminishing the risk of anterior knee pain stemming from overly taut MPFL reconstruction. Moreover, the research underscores the significance of graft length change patterns in successful MPFL reconstruction, indicating a reliance on the femoral insertion site as opposed to the patellar insertion site.[56,57] Consequently, the use of bio-absorbable interference screws for femoral fixation, regardless of the patellar fixation approach, yields akin postoperative complication rates for both single tunnel and double tunnel fixation techniques in MPFL reconstruction addressing recurrent patellar dislocation.

The present study identified no statistically significant differences in Lysholm scores, Kujala scores, and Tegner scores between the single tunnel fixation and double tunnel fixation techniques. A prospective randomised controlled investigation comparing these two techniques over a two-year follow-up period reported analogous findings. The clinical scores [Kujala, Lysholm, Tegner, and international knee documentation committee (IKDC)], and radiological measurements demonstrated equivalence, with the isokinetic force intensity test at the 24-month postoperative mark yielding congruent outcomes.[14] Generally, single tunnel fixation employs single-bundle (SB) reconstruction of the MPFL, whereas the double tunnel technique employs double-bundle (DB) reconstruction.[17,58] This research indicates that the DB technique aligns more closely with the principles of anatomical reconstruction, restoring the fan-shaped structure of the native MPFL and consequently delivering enhanced biomechanical and clinical function compared to SB reconstruction. However, a recent systematic review assessing SB and DB MPFL reconstructions concluded that DB procedures yielded outcomes similar to SB procedures in terms of improved knee function and patellar redislocation rates.[59] Correspondingly, a separate long-term follow-up study detected no significant differences between SB and DB groups in postoperative Kujala, Fulkerson, and SF-36 scores.[47]

Femoral trochlear dysplasia is a crucial factor in recurrent patellar dislocation.[4] The research has demonstrated that type B and D trochlear dysplasia (according to the Dejour classification system) alters the patellofemoral joint's motion trajectory, increasing joint instability and causing uneven stress on the articular surface.[60] Currently, some authors have indicated that MPFL reconstruction in patients with severe trochlear dysplasia and patellar dislocation results in higher patellar redislocation rates and poorer clinical function.[61,62] A systematic review evaluating MPFL reconstruction alone or in conjunction with trochleoplasty for patellar dislocation revealed that the latter approach effectively reduces patellar redislocation rates and yields improved clinical outcomes.[63] Sensitivity analysis to explore the inclusion of severe trochlear dysplasia revealed no significant disparity in complication rates or clinical scores between the single tunnel fixation and double tunnel fixation techniques. This finding suggests that the clinical outcomes of these two techniques remain similar, regardless of the presence of severe trochlear dysplasia.

Graft options for MPFL reconstruction encompass allografts, autografts, and synthetic grafts. This study substantiated that autograft-based MPFL reconstruction yields superior knee function compared to allograft, albeit with comparable recurrence rates. Thus, this study exclusively focused on MPFL reconstructions employing hamstring autografts. Furthermore, the sensitivity analysis of graft selection unveiled no statistically significant variance in clinical function and postoperative complication rates between single tunnel and double tunnel fixation MPFL reconstructions. This underscores that the choice of autograft (semitendinosus or gracilis) does not exert a substantial influence on tunnel fixation MPFL reconstructions.

While this study employs a meta-analysis approach, several limitations merit consideration. Primarily, the quality of evidence within the included studies tends to be suboptimal, with most being retrospective investigations and a paucity of randomised controlled trials. Consequently, cautious interpretation of the meta-analysis findings is warranted, and future validation *via* multiple randomised controlled trials is imperative. Secondly, the variations in tunnel orientation and diameter on the patellar side across the included studies, which may correlate with higher complication rates, introduce a level of complexity. A pivotal limitation lies in the heterogeneous sample sizes and graft fixation angles, contributing to marked statistical heterogeneity in the meta-analyses of clinical scores and complication rates, thus enhancing confounding factors. Notably, the elevated complication rate in smaller sample studies merits scrutiny and consideration. Therefore, studies with a sample size of less than 10 were excluded to mitigate confounding influences. The diversity of knee flexion angles during graft fixation introduces variability in graft length and tension during knee motion, potentially leading to knee flexion contracture and discomfort from excessive graft tension. The optimal graft fixation angle to achieve stability and minimise the risk of undue graft tension remains undetermined. Furthermore, heterogeneity stemming from variations in participant's age and follow-up duration may contribute to potential confounders. As such, a meta-regression analysis incorporating age and follow-up time was conducted, revealing their non-significant association with complication rates and improvement in clinical scores.

CONCLUSION

In conclusion, the authors found that the clinical functional improvement and complication rates in MPFL reconstruction using the single tunnel fixation technique are comparable to those achieved with the double tunnel fixation approach. However, to further advance our understanding, additional randomised controlled studies must be conducted to provide further insights.

COMPETING INTEREST:
The authors declared no conflict of interest.

AUTHORS' CONTRIBUTION:
HZ, JJ, ZY: Writing original draft, data curation, investigation, and statistical analyses.
YX, MW: Conceptualisation, supervision, writing review, and editing.
HZ, JJ, JH: Quality assessment.
All authors approved the final version of the manuscript to be published.

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