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Influence of graft source and configuration on revision rate and patient-reported outcomes after MPFL reconstruction: a systematic review and meta-analysis

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Abstract
Purpose The purpose of this systematic review and meta-analysis was to determine the influence of graft source (allograft vs. autograft) and configuration (single-limbed vs. double-limbed) on failure rate and disease-specific patient-reported outcome (Kujala score) after medial patellofemoral ligament (MPFL) reconstruction for patellar instability.
Methods A systematic review of PubMed, Scopus, and the Cochrane Library was performed. A total of 31 studies met inclusion/exclusion criteria and were used to extract cohorts of patients who underwent ligament reconstruction with various allograft, autograft, single-limbed, and double-limbed constructs. Failure rates and postoperative improvements in Kujala scores were compared between cohorts using inverse-variance weighting in a random-effects analysis model and appropriate comparative statistical analyses (Chi-squared and independent samples *t* tests).
Results A total of 1065 MPFL reconstructions were identified in 31 studies. Autograft reconstructions were associated with greater postoperative improvements in Kujala scores when compared to allograft (32.2 vs. 22.5, $p < 0.001$), but there was no difference in recurrent instability (5.7 vs. 6.7 %, $p = 0.74$). Double-limbed reconstructions were associated with both improved postoperative Kujala scores (37.8 vs. 31.6, $p < 0.001$) and lower failure rate (10.6 vs. 5.5 %, $p = 0.030$).
Conclusion MPFL reconstructions should be performed using double-limbed graft configurations. While autograft tendon may be associated with higher patient-reported outcomes in the absence of associated connective tissue disorders or ligamentous laxity, patient factors and allograft processing techniques should be carefully considered when selecting an MPFL graft source, as revision rates were no different between graft sources.
Level of evidence IV.

Keywords Knee · Patellar instability · Patellar dislocation · Autograft · Allograft · Patellofemoral

Introduction

The medial patellofemoral ligament (MPFL) is the primary stabilizing soft tissue restraint to lateral patellar translation during early knee flexion (0–30°) [16, 20]. Acute patellar dislocation can result in significant intraarticular chondral injury and concurrent MPFL disruption in a large percentage of patients [18, 21]. In appropriately indicated patients with recurrent instability, MPFL reconstruction is an effective surgical treatment [7, 8, 10, 12, 19, 38, 48, 58, 68] with re-dislocation rates reported in less than 5 % of patients in some series [22, 39, 53]. While multiple surgical techniques for MPFL reconstruction have been described in the literature, there is no current consensus as to which technique or graft source optimizes clinical outcomes [32, 50, 60].

The ideal surgical construct and graft source for MPFL reconstruction is not widely accepted, due in part to the general lack of large prospective comparative studies. Few case series directly compare the use of autograft versus allograft sources nor single versus double-limb reconstruction techniques, thereby failing to identify best practices

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[9, 55, 65]. The purpose of this study was therefore to perform a systematic review and meta-analysis of existing literature in order to determine the influence of graft source (allograft vs. autograft) and configuration (single-limbed vs. double-limbed) on failure rate and disease-specific patient-reported outcomes (Anterior Knee Pain Scale, or "Kujala score") after MPFL reconstruction. We hypothesized that autograft and double-limbed constructs would each result in improved clinical outcomes (defined by Kujala scores) and lower failure rates (defined by recurrent patellar instability).

Materials and methods

The methodology for meta-analysis of observational studies used in the current study has been widely utilized in the orthopaedic surgery literature [4, 24, 36, 42, 44, 45, 49]. A systematic review of PubMed, Scopus, and the Cochrane Library was performed (search date: 15 July 2014). Search terms were "patellar instability [AND] MPFL reconstruction" and subsequently expanded to "MPFL reconstruction", along with associated MeSH terms.

Following the primary search, a title and abstract review was performed in accordance with the standard PRISMA checklist, to identify articles that contained relevant information. [34] If relevant information was identified, articles were then assessed in order to determine compliance with the following inclusion criteria:

1. A minimum of 5 subjects (i.e. no case reports or small case series)
2. Recurrent patellar instability as a reported outcome measure: defined by constituent studies as subluxation or dislocation. Determination of instability was heterogeneous across studies, but included both patient-reported episodes and confirmation by examination under anaesthesia.
3. Minimum 1-year clinical follow-up
4. Study published in either English or Mandarin language

Articles meeting these inclusion criteria were then manually reviewed in their entirety. Exclusion criteria were:

1. Use of a synthetic ligament
2. Concomitant surgical procedure (i.e. same surgical setting) including: tibial tubercle osteotomy, trochleoplasty, total knee arthroplasty. Concomitant soft tissue procedures were *not* excluded (e.g. lateral retinacular release).
3. A cadaveric study
4. Article solely describing a new surgical technique
5. Failure to specify graft source material: allograft or autograft
6. Insufficient data reporting. Corresponding authors were contacted on three separate attempts to ascertain missing data. Studies were excluded if missing data were not available.

A PRISMA flow chart (Fig. 1) outlines the application of meta-analysis inclusion and exclusion criteria to the 216 articles that were identified for potential inclusion. A total of 31 studies met inclusion/exclusion criteria and were used to extract cohorts of patients who underwent ligament reconstruction with allograft, autograft, single-limbed, and double-limbed constructs (Table 1). Relevant patient demographics (age, sex), length of follow-up, incidence of postoperative patellar dislocations, and improvements in Kujala scores were recorded.

Subject cohorts were extracted from the studies that met inclusion/exclusion criteria and subsequently combined using Comprehensive Meta-Analysis Software Package (Biostat Inc., Englewood, NJ, USA). A meta-analysis utilizing inverse-variance weighting in a DerSimonian–Laird random-effects model was then created [15, 33, 34]. Study heterogeneity was quantitatively assessed using I^2 statistic and indicated the potential for heterogeneity of the included studies (range 0–96 %). A random-effects model was chosen because it is the most appropriate and conservative method for assessment in the setting of study heterogeneity. It also accounts for both within-study and between-study variance. Furthermore, random-effects modelling is considered to be more appropriate in medical decision making contexts [1, 15]. Weighted failure rates and postoperative improvements in Kujala scores were compared between cohorts using Chi-squared and independent samples Student's t tests. Funnel plots were generated, and the Egger intercept method was used to assess for publication bias [17].

Results

Study selection

A total of 1065 MPFL reconstructions were performed in 31 studies. Patient demographics and weighted results for each study are displayed in Table 1. Cohort size across graft source and configuration is detailed in Table 2.

The weighted mean follow-up across all studies was 35.0 months. Mean patient age at the time of operation was 23.4 years. Twelve studies exclusively used semitendinosus tendon autograft. Other autograft tissue sources included gracilis, patellar tendon, adductor magnus, quadriceps, and

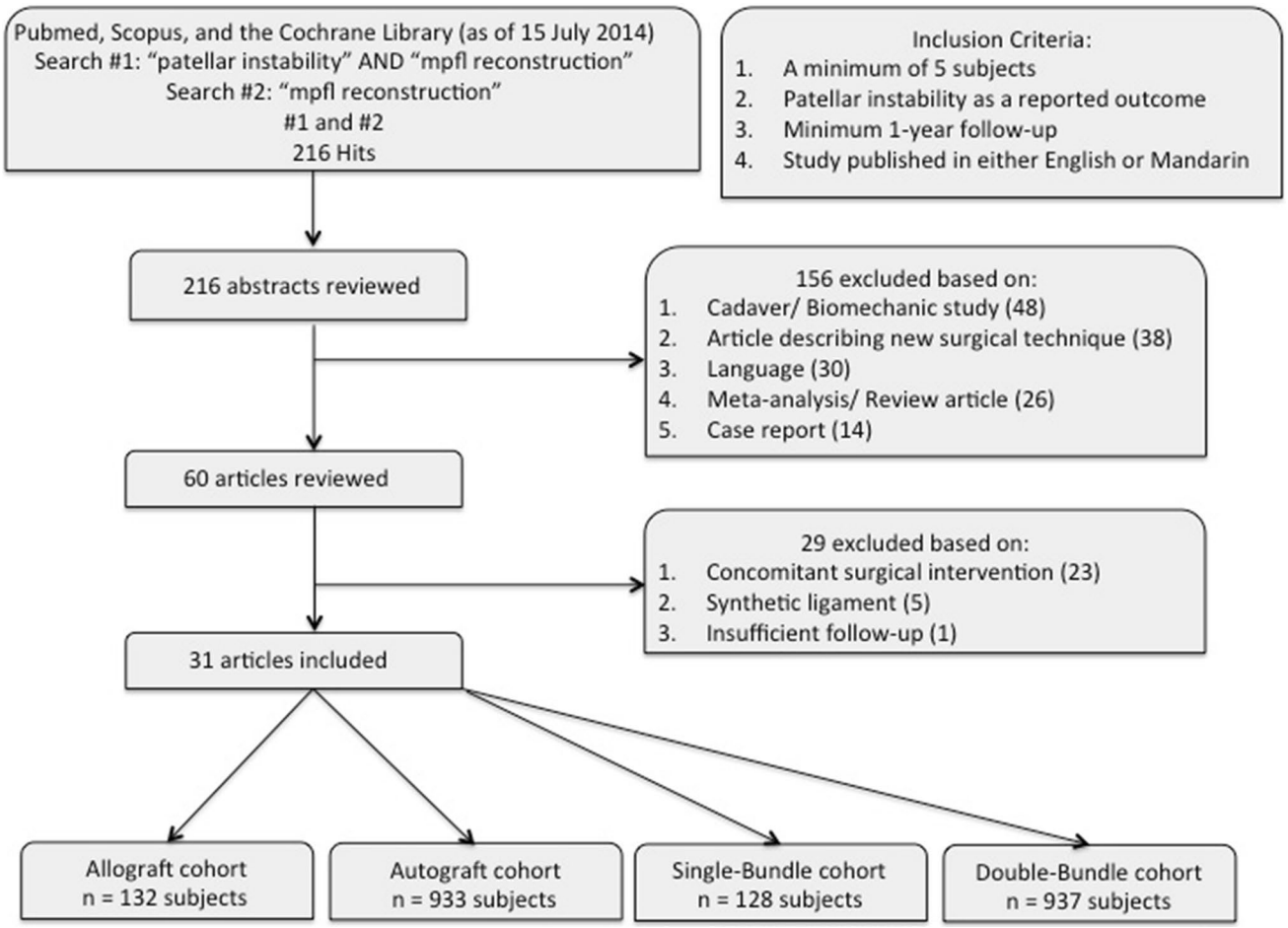

Fig. 1 PRISMA diagram outlining the application of the inclusion and exclusion criteria of this systematic review [41]

unspecified hamstring tendon. The allograft tendon sources that were utilized included semitendinosus, tibialis anterior, patellar tendon, and unspecified hamstring. Two studies did not specify the allograft source used [37, 72].

Preoperative and postoperative collection of the Kujala score was completed for 75 of 128 (58.6 %) reconstructions in the single-limbed group and 451 of 937 (48.1 %) in the double-limbed group. Similarly, 47 of 132 (35.6 %) Kujala scores were assessed in the allograft cohort and 445 of 933 (47.7 %) were provided in the autograft cohort. Overall, 4 of the 31 studies (13 %) did not utilize the Kujala score as an outcome measure [6, 12, 37, 62]. Twelve of the remaining studies reported incomplete data with regard to the Kujala scores (e.g. point estimates only without data distribution such as standard deviation, postoperative Kujala score only), and the corresponding authors did not respond to inquiries for original data or compliant descriptive statistics. These Kujala scores were therefore not included in the final analyses.

Egger's intercept method revealed an intercept of -4.41 ($P = 0.046$) for Kujala score (indicating borderline potential for publication bias). Subsequent inspection of the funnel plot (Fig. 2a) indicated an equally wide variation in results for studies with low standard error (e.g. larger studies), rather than true publication bias. With regard to failure rate, Egger's intercept method revealed an intercept of -1.78 ($P = 0.01$), indicating there was some evidence of publication bias in the included studies. Inspection of the funnel plot (Fig. 2b) indicated a "file drawer effect", or a likely preferential publication of studies with more favourable (lower) failure rates. Subsequent analysis of subgroup funnel plots for failure rate revealed an identical effect for all subgroups: single-limbed (Egger's intercept -2.01, $p < 0.01$); double-limbed (Egger's intercept -1.60, $p < 0.01$); autograft (Egger's intercept -1.78, $p < 0.01$); allograft (Egger's intercept -1.77, $p = 0.01$).

Graft configuration

Double-limbed reconstructions were associated with both improved postoperative Kujala scores and a lower

Table 1 Articles included in systematic review

References	N	Male	Female	Mean age	Level of evidence, study methodology	Graft configuration		Graft tissue	
						Single	Double	Allograft	Autograft
Becher [5]	30	10	20	21.7	Level III, case–control study		✓		✓
Berard [6]	59	14	37	24.2	Level III, case–control study		✓		✓
Csintalan [12]	56	12	37	24	Level IV, case series		✓		✓
Hopper [28]	72	18	50	23.9	Level IV, case series		✓		✓
Kang [31]	45	13	27	26.6	Level IV, case series		✓		✓
Lippacher [38]	72	24	44	18.3	Level IV, case series		✓		✓
Matsushita [40]	34	6	28	22.2	Level III, case–control study		✓		✓
Song [56]	20	10	10	21	Level IV, case series		✓		✓
Hinterwimmer [27]	19	5	13	23	Level IV, case series		✓		✓
Kang [32]	82	32	50	28.3	Level II, randomized control trial		✓		✓
Nelitz [46]	21	6	15	12.2	Level IV, case series		✓		✓
Slenker [55]	35	12	23	20.6	Level IV, case series	✓		✓	✓
Wagner [64]	50	17	33	19	Level IV, case series		✓		✓
Wang [65]	70	23	35	25	Level IV, case series	✓	✓		✓
Witoński [69]	10	4	6	27.2	Level IV, case series	✓			✓
Kumahashi [35]	5	2	3	13.6	Level IV, case series	✓			✓
Raghuveer [52]	15		11	29.2	Level IV, case series		✓		✓
Wang [66]	22	6	15	23	Level IV, case series		✓		✓
Bitar [7]	18	NR	NR	24.2	Level 1, randomized control trial	✓			✓
Deie [14]	31	5	26	22.2	Level IV, case series		✓		✓
Han [25]	52	NR	NR	24.3	Level IV, case series		✓		✓
Li [37]	52	10	28	13.4	Level IV, case series		✓	✓	
Panni [51]	48	11	37	28	Level IV, case series		✓		✓
Toritsuka [61]	20		11	23	Level IV, case series		✓		✓
Zhang [71]	27	NR	NR	20.3	Level IV, case series		✓	✓	
Zhang [72]	20	4	16	19	Level IV, case series		✓	✓	
Ahmad [2]	20	NR	NR	23	Level IV, case series		✓	✓	✓
Trentacosta [62]	12		10	15.3	Level IV, case series		✓	✓	✓
Christiansen [11]	32	15	29	22	Level IV, case series		✓		✓
Nomura [47]	12	4	1	24.8	Level IV, case series		✓		✓
Steiner [59]	34	12	22	27	Level IV, case series	✓		✓	✓

The original articles included in this systematic review, along with graphical representation of graft configuration and tissue sources

NR not reported

failure rate. Chi-squared analysis of postoperative failure, as defined by recurrent patellar instability, favoured double-limbed configurations (5.5 vs. 10.6 %, $p = 0.03$). Furthermore, autograft reconstructions were associated with greater postoperative improvements in Kujala scores when compared to allograft using independent samples *t* test (37.8 ± 0.4 vs. 31.6 ± 1.1, $p < 0.001$). This finding (difference in improvement of 6.2 points between groups) approached clinical importance based on a minimal clinical important difference (MCID) of the Kujala score of 7 points [54].

Graft source

Chi-squared analysis revealed that failure rate was no different between autograft and allograft reconstructions (5.70 vs. 6.70 %, respectively, $p = 0.74$). However, autograft reconstructions were associated with greater postoperative improvements in Kujala scores when compared to allograft using independent samples *t* test (32.2 ± 2.5 vs. 22.5 ± 2.0, $p < 0.001$). Moreover, this difference (9.7 points) was clinically important, as it exceeded the MCID of the Kujala score (7 points).

Table 2 Results across cohorts

	N cohorts	N subjects	Failure rate (%)	*p* value[†]
Failure				
Autograft	30	933	5.70	0.74
Allograft	6	132	6.70	
Single-limb	8	123	10.60	0.03*
Double-limb	28	937	5.50	
	N cohorts	N subjects	Post–pre difference (SD)	*p* value[‡]
Kujala score				
Autograft	16	445	32.2 (2.5)	<0.001*
Allograft	2	47	22.5 (2.0)	
Single-limb	8	41	31.6 (1.1)	<0.001*
Double-limb	15	451	37.8 (0.4)	

The summary results of outcomes across combined subject cohorts. Previously reported minimally clinically important difference (MCID) of Kujala score is 7 points [54]

*$p < 0.05$

† Chi-squared analysis was used to compare failure rates

‡ A Student's *t* test was used to compare Kujala scores

Discussion

The most important findings of the present study were that the rate of recurrent patellar instability postoperatively as well as improvements in Kujala score were superior for the double-limb graft configuration. Similarly, improvements in Kujala scores were superior in the autograft cohort; however, rates of recurrent instability were no different. Similar concepts in the ACL literature have garnered increased attention. ACL reconstruction has demonstrated a higher rate of graft failure in young active patients when allograft sources are utilized. [26, 30, 67] Furthermore, some authors have proposed functional and biomechanical benefits of double-bundle reconstruction; however, it has not been shown to be wholly superior to single-bundle ACL reconstruction. [23, 29, 63] The MPFL has a broad, fan-shaped patellar insertion, and cadaveric studies demonstrate a mean patellar insertion width of 27.9 mm, which may be more precisely replicated with double-limbed grafts [3]. Despite these apparent conceptual similarities, it is important to note that the ACL and MPFL may not be comparable due to their differing anatomy and function. While the ACL is a stout intraarticular structure that provides stability in all ranges of knee flexion, the MPFL is a thin, extraarticular structure which acts as a checkrein in early knee flexion only. The 208-N tensile strength of the MPFL is significantly less than the 2160-N tensile strength of the native ACL, so extrapolations of ACL reconstruction theory may not be appropriate and the MPFL literature must be examined independently, further underscoring the importance of the current study [43, 70].

A study by Wang et al. [65] retrospectively compared double-limbed reconstruction ($n = 44$) with single-limbed reconstruction ($n = 26$) [65]. The authors observed a 4.3 % recurrent dislocation rate (3/70) in the study population, all in the single-limb group. The Kujala score also favoured use of the double-limb technique. Kujala scores continued to improve from 12 months to 48 months postoperatively, indicating long-term stability and graft longevity following MPFL reconstruction may be associated with the use of a double-limbed graft. Anatomic studies by Aragåo et al. [3] and Steensen et al. [57] defined the anatomic dimensions of the patellar attachment of the MPFL as fan-shaped, thereby facilitating distribution of ligament tension along the superior and middle portions of the patella [3, 57]. These observations provide an anatomic basis for double-limb constructs' best approximation of the anatomic configuration of the MPFL, thereby resulting in improved stability compared to single-limb reconstructions.

Slenker et al. [55] compared recurrence of instability and Kujala scores by graft source following MPFL reconstruction in a small retrospective series, for patients who received hamstring autograft ($n = 12$) and soft tissue allograft ($n = 23$) [55]. The authors found no statistically significant difference in postoperative Kujala score, likely due to limited sample size and statistical power. While no patellar dislocations were reported after surgery, three patients (3/35; 8.6 %) reported episodes of patellar subluxation, all in the allograft cohort. This observation lends minimal support to the use of autograft; however, in the light of the results of the current study autograft may result in better patient-reported outcomes but not significantly lower risk of recurrent instability.

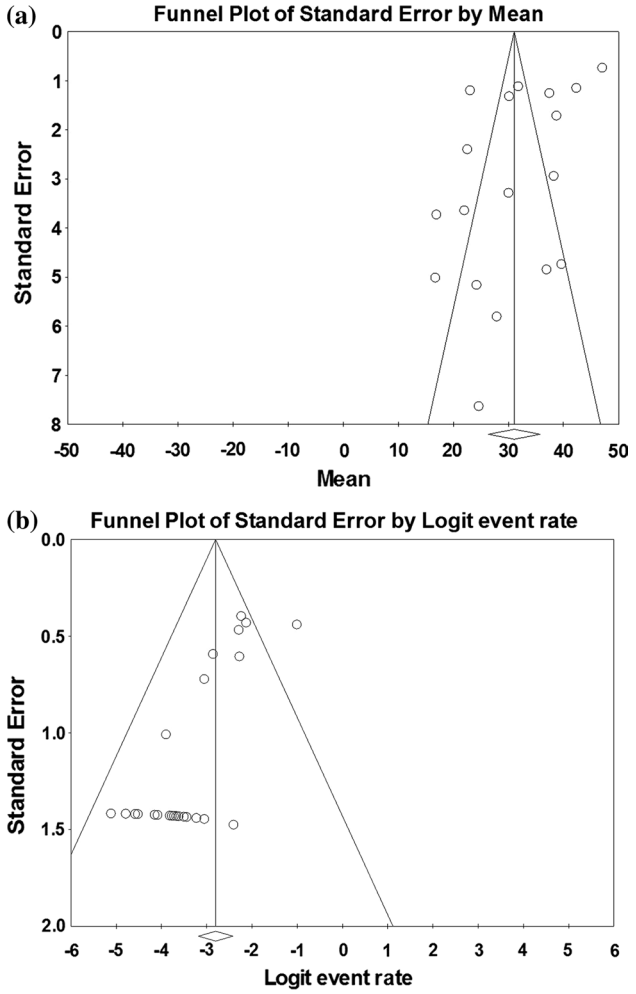

Fig. 2 Funnel plots testing for publication bias in the reporting of Kujala score and failure rate. Analysis of Kujala score (**a**) indicated an equally wide variation in results for studies with low standard error (e.g. larger studies), rather than true publication bias. Analysis of failure rate (**b**) indicated a "file drawer effect", or a likely preferential underreporting of failure rates across the orthopaedic surgical literature

Limitations of the current meta-analysis reflect those of the constituent studies. Specifically, the reliance on retrospective observational studies makes selection bias unavoidable. Some studies evaluating Kujala score did not offer preoperative scores and had to be excluded from this portion of the analysis. Furthermore, most studies that utilized allograft tissue did not specify the tissue source or processing procedures, despite the understanding that graft irradiation can lead to structural compromise. [13] An additional limitation of the constituent studies included in this meta-analysis is that graft configuration and tissue source are unable to be analysed concurrently, because subjects have been extracted from observational cohort studies and analyses performed independently. Therefore, conclusions cannot be combined to indicate a superior combination of graft source and configuration. However, we are able to draw conclusions regarding superiority of graft configuration (single- vs. double-limbed) and tissue source (autograft vs. allograft) independently. Finally, most of these studies did not aim to evaluate graft source or configuration as the primary independent variable. As a result, authors did not specify age or sex within study populations. Therefore, we were unable to further stratify our cohorts and thus cannot definitively conclude one graft source or configuration is superior across patient populations. Nonetheless, despite some of the methodological flaws of the constituent studies, we believe the aggregation of multiple study cohorts provides the best available evidence for this topic to date. The underreporting of surgical failure rates likely lead to publication bias; however, there was no evidence of differential reporting bias between cohorts, indicating that the comparative results from the current study remain valid.

Few studies have directly compared allograft with autograft or single-limb versus double-limb constructs, and to our knowledge, no studies have assessed both graft source and configuration simultaneously. Strengths of the current study lie in the increased statistical power gained through cohort extraction and meta-analysis. Based upon failure rate and Kujala scores, clinicians should strongly consider restoring the anatomy of the MPFL with a double-limb graft configuration for recurrent patellar instability. In addition, clinicians should remain mindful that Kujala scores favour the selection of autograft tissue (in the absence of ligamentous laxity or a connective tissue disorder); however, there was no difference in revision rate between autograft and allograft sources and allograft processing techniques were not elucidated in the constituent studies.

Conclusion

Both the rate of recurrent postoperative patellar instability and Kujala scores were superior in the double-limb graft configuration cohort, and Kujala scores were superior with the use of autograft tendon. MPFL reconstructions should be performed using double-limbed configurations. While autograft tendon may be associated with higher patient-reported outcomes in the absence of associated connective tissue disorders or ligamentous laxity, patient factors and allograft processing techniques should be carefully considered when selecting an MPFL graft source, as revision rates were no different between graft sources.

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