

Platelet-Rich Plasma Augmentation for Isolated Arthroscopic Meniscal Repairs Leads to Significantly Lower Failure Rates

A Systematic Review of Comparative Studies

Kyle R. Sochacki,^{*†} MD, Marc R. Safran,[†] MD, Geoffrey D. Abrams,[†] MD, Joseph Donahue,[†] MD, Constance Chu,[†] MD, and Seth L. Sherman,[†] MD

Investigation performed at Stanford University Medical Center, Palo Alto, California, USA

Background: Studies have reported relatively high failure rates of isolated meniscal repairs. Platelet-rich plasma (PRP) has been suggested as a way to increase growth factors that enhance healing.

Purpose: To compare (1) meniscal repair failures and (2) patient-reported outcomes after isolated arthroscopic meniscal repair augmented with and without PRP.

Study Design: Systematic review; Level of evidence, 3.

Methods: A systematic review was performed using the PRISMA (Preferred Reporting Items for Systematic Meta-Analyses) guidelines. Multiple databases were searched for studies that compared outcomes of isolated arthroscopic meniscal repair augmented with PRP versus without PRP in human patients. Failures and patient-reported outcome scores were reported for each study and compared between groups. Study heterogeneity was assessed using I^2 for each outcome measure before meta-analysis. Study methodological quality was analyzed. Continuous variable data were reported as mean and standard deviation from the mean. Categorical variable data were reported as frequency with percentage. All P values were reported with significance set at $P < .05$.

Results: Five articles were analyzed (274 patients [110 with PRP and 164 without PRP]; 65.8% male; mean age, 29.1 ± 4.6 years; mean follow-up, 29.2 ± 22.1 months). The risk of meniscal repair failure ranged from 4.4% to 26.7% for PRP-augmented repairs and 13.3% to 50.0% for repairs without PRP. Meniscal repairs augmented with PRP had significantly lower failure rates than repairs without PRP (odds ratio, 0.32; 95% CI, 0.12-0.90; $P = .03$). One of the 5 studies reported significantly higher outcomes in the PRP-augmented group versus the no-PRP group for the International Knee Documentation Committee (IKDC), Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), and Knee injury and Osteoarthritis Outcome Score (KOOS) ($P < .05$ for all). The remaining 4 studies reported no significant difference between groups with regard to outcomes for the IKDC, Lysholm knee scale, visual analog scale for pain, or Tegner activity level.

Conclusion: Although the studies were of mostly of low quality, isolated arthroscopic meniscal repairs augmented with PRP led to significantly lower failure rates (10.8% vs 27.0%; odds ratio, 0.32; $P = .03$) as compared with repairs without PRP. However, most studies reported no significant differences in patient-reported outcomes.

Keywords: meniscal repair; platelet-rich plasma; PRP; failures

The meniscus functions to provide joint stability, congruency, proprioception, and force distribution across the knee.^{33,34} Meniscal injuries are one of the most common conditions treated by orthopaedic surgeons, with up to 61% of patients demonstrating meniscal pathology on imaging.^{9,15} Once the meniscus is injured, the loss of meniscal

integrity leads to altered mechanics and joint forces with resultant increased contact pressures on the articular cartilage.^{16,27,28,42} As such, meniscal preservation has been increasingly emphasized.¹ Biomechanical studies have demonstrated that meniscal repair restores the tibiofemoral contact pressures to similar levels to that of an intact meniscus while partial meniscectomy leads to significantly higher values.^{2,3,29,39,42} Clinical studies have also found there to be significantly improved patient-reported outcomes and decreased progression to osteoarthritis

The Orthopaedic Journal of Sports Medicine, 8(11), 2325967120964534

DOI: 10.1177/2325967120964534

© The Author(s) 2020

This open-access article is published and distributed under the Creative Commons Attribution - NonCommercial - No Derivatives License (<https://creativecommons.org/licenses/by-nc-nd/4.0/>), which permits the noncommercial use, distribution, and reproduction of the article in any medium, provided the original author and source are credited. You may not alter, transform, or build upon this article without the permission of the Author(s). For article reuse guidelines, please visit SAGE's website at <http://www.sagepub.com/journals-permissions>.

but with relatively high failure rates after meniscal repair.^{8,41,43,47,49}

Multiple risk factors for meniscal repair failure have been identified, including tobacco use, increasing age, location, and surgeon experience.^{4,32} Additionally, some studies have suggested that concomitant anterior cruciate ligament (ACL) reconstruction may lead to improved meniscal healing and outcomes owing to increased bleeding within the joint.^{5,10,30,32} As such, there have been several biologic augmentation techniques described for meniscal repairs, including fibrin clot, marrow stimulation, and platelet-rich plasma (PRP), with varying degrees of success.^{25,40,44} PRP to augment soft tissue reconstruction procedures has been suggested as a way to increase growth factors that enhance healing in the absence of large hemarthrosis.^{13,21,22,50} However, the studies involving PRP augmentation for arthroscopic meniscal repair are limited by small sample sizes and a lack of consensus.

The purpose of this study was to compare (1) meniscal repair failures and (2) patient-reported outcomes after isolated arthroscopic meniscal repair augmented with PRP versus without PRP. We hypothesized that there would be no significant differences in (1) meniscal repair failures or (2) patient-reported outcomes between groups.

METHODS

This systematic review was registered with PROSPERO on January 27, 2020, and the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines were followed.³⁸ We conducted separate searches of the following medical databases: PubMed, SCOPUS, and Cochrane Central Register of Controlled Trials. The searches were performed on January 27, 2020, by a single orthopaedic surgery sports medicine fellow (K.R.S.) and was confirmed by the senior author (S.L.S.). The search terms used were “platelet-rich plasma” and “meniscus” (((“platelet-rich plasma”[Medical Subject Headings (MeSH) Terms] OR (“platelet-rich”[All Fields] AND “plasma”[All Fields])) OR “platelet-rich plasma”[All Fields]) OR (“platelet”[All Fields] AND “rich”[All Fields]) AND “plasma”[All Fields]) OR “platelet-rich plasma”[All Fields]) AND (“meniscus”[MeSH Terms] OR “meniscus”[All Fields]) OR “menisci”[All Fields])).

Eligible studies consisted of evidence levels 1 to 3 (for therapeutic research per the Oxford Centre for Evidence-

Based Medicine), were published in the English language, and compared the outcomes of isolated arthroscopic meniscal repair augmented with and without PRP in human patients. Animal studies, basic science studies, review articles, book chapters, and technique papers were excluded. In the event of different studies with duplicate or overlapping populations, the studies with the greatest number of participants or the greatest clarity of methods and results were included if the participants could not be separated. All references within the included studies were cross-referenced for inclusion if missed by the initial search. Duplicates were removed, and the remaining results were reviewed against inclusion criteria to determine the articles that were included in the final analysis (Figure 1).

Data were extracted from the included studies using the methodology recommended by Harris et al.¹⁹ All study, participant, and surgery parameters, including PRP type, were collected. Study and participant demographic parameters included year of publication, years of participant enrollment, number of participants, number of knees, laterality, age, sex, length of follow-up, meniscal tear location, meniscal tear type, surgical technique, and PRP preparation. Clinical outcomes recorded were meniscal repair failures and all knee-specific patient-reported outcome scores: International Knee Documentation Committee (IKDC), Lysholm knee scale, visual analog scale for pain, Tegner activity level, Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), and Knee injury and Osteoarthritis Outcome Score (KOOS). The primary outcome measure was the rate of meniscal repair failure. Failure was defined by postoperative physical examination, magnetic resonance imaging (MRI), and/or second-look arthroscopy.

The risk of study bias and methodological quality were analyzed using the Modified Coleman Methodology Score (MCMS), with scores reported as excellent (85 to 100), good (70 to 84), fair (55 to 69), and poor (<55).⁶ Meniscal repair failures and patient-reported outcome scores were assessed for heterogeneity using I^2 for each outcome measure before meta-analysis. Outcomes with $I^2 < 40\%$ were deemed to be adequately homogeneous for meta-analysis.²⁰ Where I^2 was $> 40\%$ after pooling, no meta-analysis was performed. Forest plots were created using Review Manager (Version 5.3; Nordic Cochrane Centre, Cochrane Collaboration). Dichotomous data were reported as odds ratios (ORs) using a random-effects model, and continuous data were reported as mean differences and 95% CIs. Continuous variable data were reported as mean and standard

*Address correspondence to Kyle R. Sochacki, MD, Department of Orthopaedic Surgery, Stanford University Medical Center, Palo Alto, CA 94305, USA (email: kylersoachackimd@gmail.com).

†Department of Orthopaedic Surgery, Stanford University Medical Center, Palo Alto, California, USA.

Final revision submitted May 13, 2020; accepted June 8, 2020.

One or more of the authors has declared the following potential conflict of interest or source of funding: M.R.S. has received research support from Smith & Nephew; consulting fees from Anika Therapeutics, Linvatec, Medacta, and Smith & Nephew; speaking fees from Medacta and Smith & Nephew; and royalties from DJO, Saunders/Mosby-Elsevier, Smith & Nephew, Stryker, and Wolters Kluwer Health-Lippincott Williams & Wilkins. M.R.S. also has stock/stock options in Biomimedica. G.D.A. has received educational support from Arthrex, Evolution Surgical, and Stryker; has received consulting fees from Cytonics, Fidia Pharma, RubiconMD, and Sideline Sports Doc; and has stock/stock options in Cytonics. J.D. has received educational support from Arthrex, consulting fees from DePuy Synthes/Medical Device Business Systems, and hospitality payments from Evolution Surgical and has stock/stock options in Stabilynx. C.C. has received honoraria from Fidia Pharma. S.L.S. has received research support from Arthrex and DJO; educational support from Elite Orthopedics; consulting fees from Arthrex, Ceterix, Conmed Linvatec, Flexion Therapeutics, GLG Consulting, JRF Ortho, Moximed, Olympus, RTI Surgical, and Vericel; nonconsulting fees from Arthrex and Vericel; and honoraria from Vericel. A.O.S.S.M. checks author disclosures against the Open Payments Database (OPD). A.O.S.S.M. has not conducted an independent investigation on the OPD and disclaims any liability or responsibility relating thereto.

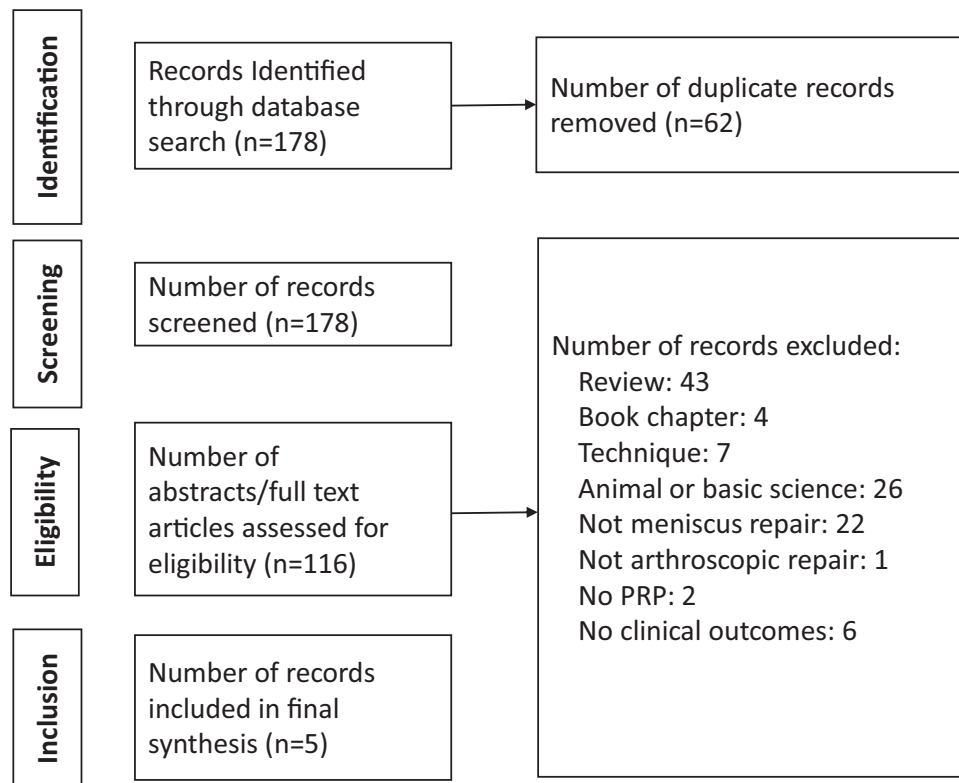


Figure 1. Flow diagram summarizing the literature search, screening, and review using the PRISMA (Preferred Reporting Items for Systematic Meta-Analyses) guidelines. PRP, platelet-rich plasma.

deviations. Categorical variable data were reported as frequency with percentage. All *P* values were reported with significance set at $<.05$.

RESULTS

A total of 178 articles were screened, and 5 articles were included in the final analysis (Table 1).^{7,11,18,24,26} Four articles were level 3 evidence,^{7,11,18,26} and 1 was level 1.²⁴ According to the MCMS, 1 study was excellent,²⁴ 1 was good,²⁶ 1 was fair,⁷ and 2 were poor,^{11,18} with a mean score of 67.0 ± 17.8 .

The number of patients per study ranged from 22 to 151, for a total of 274 patients and 274 knees: 110 augmented with PRP and 164 without PRP. Three studies included more men than women (65.8% men). The patient age in the studies ranged from 26.6 to 31.4 years (mean, 29.1 ± 4.6 years) with a follow-up ranging from 6.0 to 54 months (mean, 29.2 ± 22.1 months). There was no significant difference in demographics between the patients with and without PRP augmentation in all studies, except in 1 study in which the group without PRP was significantly older than the group with PRP (35.0 vs 26.0 years; $P = .045$).¹⁸

All patients were diagnosed with meniscal tears based on physical examination, MRI, and arthroscopy at the time of surgery (Table 1). Four studies^{7,18,24,26} described the location of the meniscal tear, and 3 studies^{7,18,24} reported the tear type. The majority of meniscal tears

were located in the lateral meniscus (59.2%), followed by the medial meniscus (38.4%) and combined medial and lateral menisci (2.4%). The most common meniscal tear morphologies were bucket-handle (46.5%), longitudinal/vertical (30.7%), horizontal (9.9%), complex (9.9%), under-surface (2.0%), and radial (1.0%). Four studies^{7,18,24,26} described the meniscal repair technique. The most common techniques for meniscal repair were inside-out (37.4%), all-inside combined with outside-in (30.1%), all-inside (29.3%), and outside-in (3.3%).

Four studies^{7,11,24,26} utilized leukocyte-rich PRP, with 1 study¹⁸ not specifying leukocyte-rich versus leukocyte-poor formulations. Two studies utilized PRP with a fibrin matrix¹⁸ or clot²⁶ that was inserted into the repair site. The remaining studies injected thrombin-activated leukocyte-rich PRP into the meniscal repair site.^{7,11,24} All participants, regardless of PRP augmentation, underwent similar and standardized meniscal preparation, including debridement and/or rasping of the repair site. No marrow stimulation was utilized in either group.

The IKDC^{18,24,26} and Lysholm knee scale^{7,18,26} were the most frequently used outcome scores (3 of 5 studies each). The visual analog scale^{7,24} was used in 2 studies. Tegner activity level,²⁶ WOMAC,²⁴ and KOOS²⁴ were used in 1 study each. Four studies recorded failure rates after meniscal repair (Table 2).^{7,11,18,24}

Meniscal repair failure was defined by Dai et al⁷ as the recurrence of meniscal symptoms or requirement of repeat

TABLE 1
Summary of Study Characteristics^a

	Griffin (2015) ¹⁸	Kemmochi (2018) ²⁶	Kaminski (2018) ²⁴	Dai (2019) ⁷	Everhart (2019) ¹¹
Level of evidence	3	3	1	3	3
MCMS	49 (poor)	70 (good)	94 (excellent)	69 (fair)	53 (poor)
PRP preparation and use	PRP fibrin matrix sutured into meniscal repair site	Leukocyte-rich PRP fibrin clot inserted into meniscal repair site and PRP injected into knee	Thrombin-activated leukocyte-rich PRP clot injected into meniscal repair site	Thrombin-activated leukocyte-rich PRP clot injected into discoid lateral meniscal repair site	Thrombin-activated leukocyte-rich PRP clot injected into meniscal repair site
Sample size					
PRP	15	17	19	14	45
No PRP	20	5	18	15	106
Laterality, L/R					
PRP	6 L, 9 R	10 L, 7 R	NR	NR	NR
No PRP	11 L, 9 R	2 L, 3 R	NR	NR	NR
Meniscal tear location, M/L					
PRP	8 M, 7 L	6 M, 13 L	16 M, 2 M + L, 1 L	14 L	NR
No PRP	6 M, 14 L	1 M, 4 L	11 M, 1 M + L, 6 L	15 L	NR
Meniscal tear type					
PRP	6 bucket-handle, 2 horizontal, 7 longitudinal/vertical	NR	19 bucket-handle	NR	NR
No PRP	4 bucket-handle, 1 horizontal, 13 longitudinal/vertical, 2 undersurface	NR	18 bucket-handle	NR	NR
Meniscal repair technique					
PRP	13 inside-out, 1 all-inside, 1 outside-in	17 all-inside + outside-in	9 all-inside, 10 all-inside + outside-in	14 inside-out	NR
No PRP	4 inside-out, 13 all-inside, 3 outside-in	5 all-inside + outside-in	13 all-inside, 5 all-inside + outside-in	15 inside-out	NR
Age, y					
PRP	26	32	30	32	NR
No PRP	35	21	26	30	NR
Sex, M/F					
PRP	11 M, 4 F	9 M, 8 F	15 M, 4 F	6 M, 8 F	NR
No PRP	17 M, 3 F	3 M, 2 F	15 M, 3 F	5 M, 10 F	NR
Follow up, mo	48	6	54	21	36
Outcomes	IKDC, Lysholm, ROM, return to sport, return to work, failure	IKDC, Lysholm, Tegner	IKDC, ^b VAS, KOOS, ^b WOMAC, ^b failure ^b	Lysholm, VAS, Ikeuchi grade, failure	Failure ^b

^aIKDC, International Knee Documentation Committee; KOOS, Knee injury and Osteoarthritis Outcome Score; L/R, left/right; MCMS, Modified Coleman Methodology Score; M/F, male/female; M/L, medial/lateral; NR, not reported; PRP, platelet-rich plasma; ROM, range of motion; VAS, visual analog scale for pain; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index.

^bStatistically significant difference between meniscal repair augmented with and without PRP ($P < .05$).

arthroscopy. Two studies considered repair failure if patients developed meniscal symptoms and required reoperation, including meniscectomy, revision meniscal repair, or knee arthroplasty.^{11,18} Kaminski et al²⁴ defined failure per MRI or second-look arthroscopy. Kemmochi et al²⁶ did not evaluate failure, and their study was not included in the meta-analysis.

Two studies reported that meniscal repair with PRP augmentation led to significantly lower failure rates as compared with meniscal repairs without PRP ($P = .002$ and $P = .048$).^{11,24} The remaining 2 studies found no significant difference in failure rates between groups.^{7,18} The risk of meniscal repair failure ranged from 4.4% to 26.7% for PRP-augmented repairs and 13.3% to 50.0% for repairs

TABLE 2
Outcome Measures by Study^a

	Griffin (2015) ¹⁸	Kemmochi (2018) ²⁶	Kaminski (2018) ²⁴	Dai (2019) ⁷	Everhart (2019) ¹¹
IKDC					
PRP	69 ± 26	87.4 ± 10.4	97.56 ± 0.63 ^b	NR	NR
No PRP	76 ± 17	91.5 ± 1.2	84.77 ± 0.92	NR	NR
Lysholm					
PRP	66 ± 31.9	95.8 ± 7.1	NR	79.8 ± 9.6	NR
No PRP	89 ± 9.7	97.2 ± 1.8	NR	74.6 ± 11.6	NR
VAS					
PRP	NR	NR	0.84 ± 0.1	1.2 ± 1.0	NR
No PRP	NR	NR	0.89 ± 0.08	1.6 ± 1.1	NR
Tegner					
PRP	NR	5.9 ± 2.3	NR	NR	NR
No PRP	NR	7.8 ± 1.6	NR	NR	NR
KOOS					
PRP	NR	NR	Pain: 96.06 ± 0.23 ^b Symptoms: 96.23 ± 0.31 ^b ADL: 98.18 ± 0.13 ^b Sport: 89.44 ± 0.86 ^b QOL: 80.90 ± 1.09 ^b	NR	NR
No PRP	NR	NR	Pain: 92.86 ± 0.43 Symptoms: 92.33 ± 0.48 ADL: 95.14 ± 0.38 Sport: 77.65 ± 1.26 QOL: 66.18 ± 1.17	NR	NR
WOMAC					
PRP	NR	NR	0.95 ± 0.13 ^b	NR	NR
No PRP	NR	NR	3.95 ± 0.33	NR	NR
Ikeuchi grade					
PRP	NR	NR	NR	10 (71.4) excellent or good	NR
No PRP	NR	NR	NR	12 (80.0) excellent or good	NR
Failure					
PRP	4 (26.7)	NR	3 (15.8) ^b	1 (7.1)	2 (4.4) ^b
No PRP	5 (25.0)	NR	9 (50.0)	2 (13.3)	27 (25.4)

^aValues are presented as mean ± SD or No. (%). ADL, Activities of Daily Living; IKDC, International Knee Documentation Committee; KOOS, Knee injury and Osteoarthritis Outcome Score; NR, not reported; PRP, platelet-rich plasma; QOL, Quality of Life; VAS, visual analog scale for pain; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index.

^bStatistically significant difference between meniscal repair augmented with and without PRP (*P* < .05).

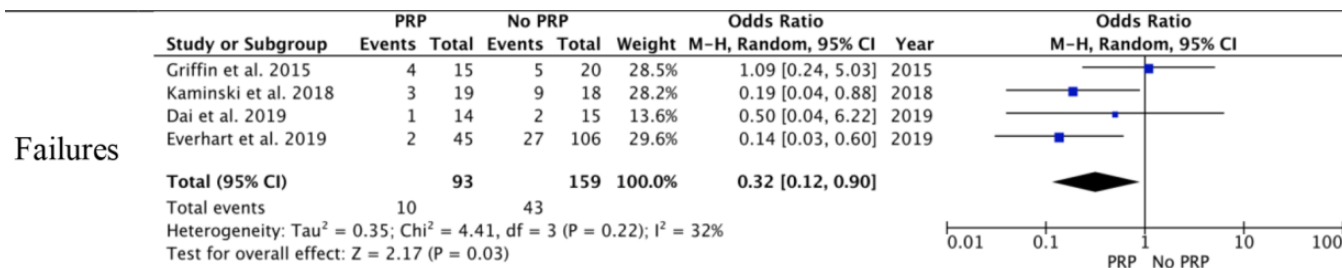


Figure 2. Forest plot of failure differences between meniscal repairs augmented with and without PRP. Failure was defined by postoperative physical examination, magnetic resonance imaging, and/or second-look arthroscopy. M-H, Mantel-Haenszel; PRP, platelet-rich plasma.

without PRP. Meta-analysis showed that meniscal repairs augmented with PRP had significantly lower failure rates than repairs without PRP (10.8% vs 27.0%; OR, 0.32; 95% CI, 0.12-0.90; *P* = .03) (Table 2, Figure 2).

One study reported significantly higher outcome scores in the PRP-augmented group as compared with the no-PRP

group: IKDC (*P* = .001), WOMAC (*P* = .002), and KOOS (*P* < .05 for all subscales).²⁴ Note that the 1 study²⁴ demonstrating the difference in outcomes was the randomized controlled trial, which had the longest follow-up and the second-most patients. All other studies (4 of 5) reported no significant difference between groups with regard to

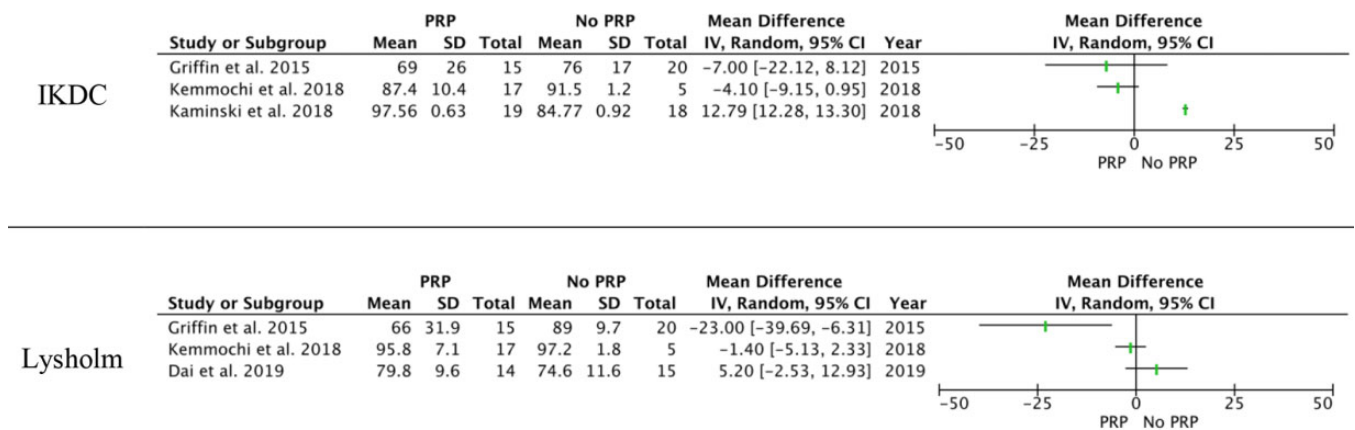


Figure 3. Forest plots of mean outcome differences between meniscal repairs augmented with and without PRP for the International Knee Documentation Committee grade and Lysholm. IV, inverse variance; PRP, platelet-rich plasma.

IKDC, Lysholm, visual analog scale, or Tegner scores (Table 2, Figure 3).

DISCUSSION

It was determined that there are conflicting results in the literature regarding patients undergoing isolated arthroscopic meniscal repair augmented with PRP as compared with no PRP. Meta-analysis of failure rates demonstrated that meniscal repairs augmented with PRP result in significantly lower failure rates than do repairs without PRP. However, only 1 study reported significantly improved patient-reported outcomes (although this was the only level 1 study in this meta-analysis and it had the longest follow-up), with the remaining studies finding no significant differences between groups.

The rate of isolated meniscal repair failure has been reported to range from 0.0% to 30.0% in recent literature, with a cumulative failure rate of 23.1%.^{17,41} This is similar to the studies in the current review, with reported failure rates ranging from 13.3% to 50.0% and a resultant pooled failure rate of 27.0% in patients without PRP. Those patients with PRP augmentation, however, had a significantly reduced pooled failure rate of 10.8% (OR, 0.32; $P = .03$) for isolated meniscal repairs.

This finding may be explained by the upregulation of growth factors with resultant increased viability of meniscal cells from PRP that has been shown in vivo.^{13,21,22,50} However, all PRP formulations are not equal. The concentration of platelets in PRP can range from 200,000 to >1 million platelets per microliter, with varying numbers of leukocytes and growth factors.^{12,36} Additionally, PRP formulations differ by the presence of fibrin architecture and/or need for an activating agent such as calcium or thrombin.^{12,36} In the present work, 2 studies utilized PRP with a fibrin matrix¹⁸ or clot²⁶ that was inserted into the repair site. The remaining studies injected thrombin-activated leukocyte-rich PRP clots into the meniscal repair site.^{7,11,24} Although all PRP formulations were present at the conclusion of the procedure, we were unable to reliably determine

the duration of time that PRP remains at the repair site before dissolution. These different formulations and uses likely contribute to the varying results in the literature regarding patient outcomes and failure rates. However, this has not been adequately studied, and the relationship between PRP formulations and outcomes could not be determined in the present analysis.

The majority of the studies included in this review utilized a PRP clot (fibrin or thrombin activated) that was injected into meniscal repair sites. Previous studies have investigated meniscal repair augmentation with a fibrin clot prepared from venous blood as opposed to PRP. The failure rates from venous fibrin clot augmentation has ranged from 15% to 50% in isolated meniscal repairs.^{23,40,44} This is similar to the failure rates in the present study without PRP augmentation (13.3%-50.0%) and higher than in meniscal repairs with PRP (4.4%-26.7%). As such, venous fibrin clot appears to be inferior to PRP augmentation and may add little value as an augmentation to meniscal repair as compared with repairs without biologic reinforcement. However, this should be investigated in future comparative studies.

It is also important to note that this study examined the effect of PRP in isolated meniscal repairs. Previous studies have demonstrated no benefit to PRP for meniscal repair healing in patients undergoing concomitant ACL reconstruction.^{10,11,32} This is thought to be secondary to increased bleeding in the joint from ACL tunnel drilling, leading to elevated growth factors.^{5,14,51} Marrow stimulation techniques within the notch have thus been used as an adjunct to healing in isolated meniscal repair.²⁵ However, there are currently no data comparing marrow stimulation against PRP. Based on prior studies, PRP augmentation should presently be considered only in patients undergoing isolated meniscal repairs.

In the current study, the majority of meniscal tears were located in the lateral meniscus (59.2%), with 39.1% of these occurring in discoid menisci. This is a unique pathology that had a high recurrent tear rate of 59% and resultant progression to symptomatic osteoarthritis in a large proportion of patients at 8-year follow up.⁴⁵ Dai et al⁷ investigated

PRP augmentation in these patients at almost 2 years postoperatively and found there to be a 7.1% failure rate versus 13.3% for no PRP. As such, PRP augmentation for discoid lateral meniscal repairs may lead to improved healing rates, comparable with those of the normal lateral meniscus.

Medial meniscal tears accounted for 38.4% of all meniscal tears in the present study. This location is particularly challenging to obtain healing, as the medial meniscus has been shown to be an independent risk factor for meniscal repair failures as compared with the lateral meniscus.³² Despite this inherent disadvantage, PRP augmentation resulted in reduced failure rates versus controls. It is therefore possible that by augmenting with PRP, one may be able to improve the healing rates of medial meniscal tears.

Additionally, the meniscal tear morphology differed among patients and studies. The majority of tears were bucket-handle (46.5%) and longitudinal (26.7%), with horizontal (9.9%), complex (9.9%), vertical (4.0%), undersurface (2.0%), and radial (1.0%) tears making up a lesser proportion of meniscal tear patterns. No study demonstrated a significant difference in healing rates among meniscal tear morphology. This is not entirely unexpected, as previous studies have shown there to be equivalent healing rates independent of tear patterns.^{32,37,48} The same trend appears to hold true even with PRP augmentation. There was also no significant difference in failures based on the repair technique in any study included in the review. The most common techniques for meniscal repair were inside-out (37.4%), all-inside combined with outside-in (30.1%), and all-inside (29.3%). This supports previous clinical and biomechanical studies without PRP that showed there to be equivalent outcomes regardless of repair technique.^{31,35,41,46}

Despite the improved failure rate of meniscal repairs augmented with PRP, 1 study reported significantly higher patient-reported outcome scores as compared with no PRP. However, this was the only study included in the review that had significantly reduced failure rates and also recorded patient-reported outcomes. This was also the only evidence level 1 study; it had the longest follow up and second-largest study population; and it involved bucket-handle meniscal tears. The remaining studies that recorded patient-reported outcomes scores demonstrated no significant difference in failure rates, so it is not unexpected that there would be no difference in subjective patient outcome scores. This finding may be due to these studies being underpowered, with no formal power analysis in any study. Unfortunately, a meta-analysis was unable to be performed owing to study heterogeneity, with $I^2 > 90\%$ for all outcome scores. This limited the ability of the current work to determine if improved failure rates translate to improved patient-reported outcome scores after PRP augmentation of meniscal repairs. Future studies should provide standardization of their patient-reported outcome measurements, using the IKDC and Lysholm scores if possible.

There are limitations noted among the studies included in this review. The current design resulted in analysis of

relatively few studies (5 studies) with a limited number of patients (274 patients) and with 1 study not included in the meta-analysis of failure rates. All of the articles were of evidence level 1 or 3. The level of evidence of the studies included in this review limits the strength of the conclusions. The mean methodological quality of the reviewed studies was fair, as assessed by the MCMS. Heterogeneity prevented a meta-analysis of the patient-reported outcome scores and is a significant limitation. Additionally, there was heterogeneity with regard to laterality (medial or lateral), tear morphology, and repair technique used. The definition of failure also varied among studies, with true failure rate probably underreported when relying solely on examination. However, failure rate was sufficiently homogeneous and able to be synthesized using I^2 . In future studies, failure should be standardized and defined by the need for repeat knee arthroscopy and subsequent meniscectomy or revision repair. These limitations reflect the underlying limitations of the literature on this topic, with only 1 randomized study. Future studies should thus be performed in a randomized fashion with more homogeneous meniscal tear types, repair techniques, and follow-up assessments of repair healing at standardized time points.

Additionally, clinical relevance using the minimal clinically important difference and/or Patient Acceptable Symptom State was unable to be obtained. It is an individual-level measure and may not be translatable to group-level statistics. No study reported individual-level data for patient-reported outcomes. Given the lack of patient-level outcomes, the impact of meniscal tear location, morphology, or repair technique was unable to be obtained. Additionally, the type, preparation, and application of PRP varied among the studies. Future studies should report on the characteristics of their PRP. Another possible limitation of this review is that we may have overlooked other relevant studies on this topic, despite conducting a systematic search.

In conclusion, although the studies were of mostly low quality, isolated arthroscopic meniscal repairs augmented with PRP led to significantly lower failure rates (10.8% vs 27.0%; OR, 0.32; $P = .03$) when compared with repairs without PRP. However, most studies reported no significant differences in patient-reported outcome scores.

REFERENCES

1. Abrams GD, Frank RM, Gupta AK, Harris JD, McCormick FM, Cole BJ. Trends in meniscus repair and meniscectomy in the United States, 2005-2011. *Am J Sports Med.* 2013;41(10):2333-2339.
2. Beamer BS, Walley KC, Okajima S, et al. Changes in contact area in meniscus horizontal cleavage tears subjected to repair and resection. *Arthroscopy.* 2017;33(3):617-624.
3. Bedi A, Kelly NH, Baad M, et al. Dynamic contact mechanics of the medial meniscus as a function of radial tear, repair, and partial meniscectomy. *J Bone Joint Surg Am.* 2010;92(6):1398-1408.
4. Blackwell R, Schmitt LC, Flanigan DC, Magnussen RA. Smoking increases the risk of early meniscus repair failure. *Knee Surg Sports Traumatol Arthrosc.* 2016;24(5):1540-1543.
5. Cannon WD Jr, Vittori JM. The incidence of healing in arthroscopic meniscal repairs in anterior cruciate ligament-reconstructed knees versus stable knees. *Am J Sports Med.* 1992;20(2):176-181.

6. Cowan J, Lozano-Calderon S, Ring D. Quality of prospective controlled randomized trials: analysis of trials of treatment for lateral epicondylitis as an example. *J Bone Joint Surg Am.* 2007;89(8):1693-1699.
7. Dai WL, Zhang H, Lin ZM, Shi ZJ, Wang J. Efficacy of platelet-rich plasma in arthroscopic repair for discoid lateral meniscus tears. *BMC Musculoskelet Disord.* 2019;20(1):113.
8. Eberbach H, Zwiggmann J, Hohloch L, et al. Sport-specific outcomes after isolated meniscal repair: a systematic review. *Knee Surg Sports Traumatol Arthrosc.* 2018;26(3):762-771.
9. Englund M, Guermazi A, Gale D, et al. Incidental meniscal findings on knee MRI in middle-aged and elderly persons. *N Engl J Med.* 2008;359(11):1108-1115.
10. Espejo-Reina A, Serrano-Fernandez JM, Martin-Castilla B, Estades-Rubio FJ, Briggs KK, Espejo-Baena A. Outcomes after repair of chronic bucket-handle tears of medial meniscus. *Arthroscopy.* 2014;30(4):492-496.
11. Everhart JS, Cavendish PA, Eikenberry A, Magnussen RA, Kaeding CC, Flanigan DC. Platelet-rich plasma reduces failure risk for isolated meniscal repairs but provides no benefit for meniscal repairs with anterior cruciate ligament reconstruction. *Am J Sports Med.* 2019;47(8):1789-1796.
12. Foster TE, Puskas BL, Mandelbaum BR, Gerhardt MB, Rodeo SA. Platelet-rich plasma: from basic science to clinical applications. *Am J Sports Med.* 2009;37(11):2259-2272.
13. Freymann U, Degraasi L, Kruger JP, Metzloff S, Endres M, Petersen W. Effect of serum and platelet-rich plasma on human early or advanced degenerative meniscus cells. *Connect Tissue Res.* 2017;58(6):509-519.
14. Galliera E, De Girolamo L, Randelli P, et al. High articular levels of the angiogenic factors VEGF and VEGF-receptor 2 as tissue healing biomarkers after single bundle anterior cruciate ligament reconstruction. *J Biol Regul Homeost Agents.* 2011;25(1):85-91.
15. Garrett WE Jr, Swiontkowski MF, Weinstein JN, et al. American Board of Orthopaedic Surgery practice of the orthopaedic surgeon: part-II, certification examination case mix. *J Bone Joint Surg Am.* 2006;88(3):660-667.
16. Goyal KS, Pan TJ, Tran D, Dumpe SC, Zhang X, Harner CD. Vertical tears of the lateral meniscus: effects on in vitro tibiofemoral joint mechanics. *Orthop J Sports Med.* 2014;2(8):2325967114541237.
17. Grant JA, Wilde J, Miller BS, Bedi A. Comparison of inside-out and all-inside techniques for the repair of isolated meniscal tears: a systematic review. *Am J Sports Med.* 2012;40(2):459-468.
18. Griffin JW, Hadeed MM, Werner BC, Diduch DR, Carson EW, Miller MD. Platelet-rich plasma in meniscal repair: does augmentation improve surgical outcomes? *Clin Orthop Relat Res.* 2015;473(5):1665-1672.
19. Harris JD, Quatman CE, Manring MM, Siston RA, Flanigan DC. How to write a systematic review. *Am J Sports Med.* 2014;42(11):2761-2768.
20. Higgins JPT; Cochrane Collaboration. *Cochrane Handbook for Systematic Reviews of Interventions.* 2nd ed. Wiley-Blackwell; 2020.
21. Howard D, Shepherd JH, Kew SJ, et al. Release of growth factors from a reinforced collagen GAG matrix supplemented with platelet rich plasma: influence on cultured human meniscal cells. *J Orthop Res.* 2014;32(2):273-278.
22. Ishida K, Kuroda R, Miwa M, et al. The regenerative effects of platelet-rich plasma on meniscal cells in vitro and its in vivo application with biodegradable gelatin hydrogel. *Tissue Eng.* 2007;13(5):1103-1112.
23. Kamimura T, Kimura M. Meniscal repair of degenerative horizontal cleavage tears using fibrin clots: clinical and arthroscopic outcomes in 10 cases. *Orthop J Sports Med.* 2014;2(11):2325967114555678.
24. Kaminski R, Kulinski K, Kozar-Kaminska K, et al. A prospective, randomized, double-blind, parallel-group, placebo-controlled study evaluating meniscal healing, clinical outcomes, and safety in patients undergoing meniscal repair of unstable, complete vertical meniscal tears (bucket handle) augmented with platelet-rich plasma. *Biomed Res Int.* 2018;2018:9315815.
25. Kaminski R, Kulinski K, Kozar-Kaminska K, Wasko MK, Langner M, Pomianowski S. Repair augmentation of unstable, complete vertical meniscal tears with bone marrow venting procedure: a prospective, randomized, double-blind, parallel-group, placebo-controlled study. *Arthroscopy.* 2019;35(5):1500-1508, e1501.
26. Kemmochi M, Sasaki S, Takahashi M, Nishimura T, Aizawa C, Kikuchi J. The use of platelet-rich fibrin with platelet-rich plasma support meniscal repair surgery. *J Orthop.* 2018;15(2):711-720.
27. Koh JL, Yi SJ, Ren Y, Zimmermann TA, Zhang LQ. Tibiofemoral contact mechanics with horizontal cleavage tear and resection of the medial meniscus in the human knee. *J Bone Joint Surg Am.* 2016;98(21):1829-1836.
28. Koh JL, Zimmermann TA, Patel S, Ren Y, Xu D, Zhang LQ. Tibiofemoral contact mechanics with horizontal cleavage tears and treatment of the lateral meniscus in the human knee: an in vitro cadaver study. *Clin Orthop Relat Res.* 2018;476(11):2262-2270.
29. LaPrade CM, Jansson KS, Dornan G, Smith SD, Wijdicks CA, LaPrade RF. Altered tibiofemoral contact mechanics due to lateral meniscus posterior horn root avulsions and radial tears can be restored with in situ pull-out suture repairs. *J Bone Joint Surg Am.* 2014;96(6):471-479.
30. Lee DW, Jang HW, Lee SR, Park JH, Ha JK, Kim JG. Clinical, radiological, and morphological evaluations of posterior horn tears of the lateral meniscus left in situ during anterior cruciate ligament reconstruction. *Am J Sports Med.* 2014;42(2):327-335.
31. Lee YH, Nyland J, Burden R, Caborn DN. Cyclic test comparison of all-inside device and inside-out sutures for radial meniscus lesion repair: an in vitro porcine model study. *Arthroscopy.* 2012;28(12):1873-1881.
32. Lyman S, Hidaka C, Valdez AS, et al. Risk factors for meniscectomy after meniscal repair. *Am J Sports Med.* 2013;41(12):2772-2778.
33. Maher SA, Rodeo SA, Warren RF. The meniscus. *J Am Acad Orthop Surg.* 2017;25(1):e18-e19.
34. Makris EA, Hadidi P, Athanasiou KA. The knee meniscus: structure-function, pathophysiology, current repair techniques, and prospects for regeneration. *Biomaterials.* 2011;32(30):7411-7431.
35. Marchetti DC, Phelps BM, Dahl KD, et al. A contact pressure analysis comparing an all-inside and inside-out surgical repair technique for bucket-handle medial meniscus tears. *Arthroscopy.* 2017;33(10):1840-1848.
36. Marx RE. Platelet-rich plasma: evidence to support its use. *J Oral Maxillofac Surg.* 2004;62(4):489-496.
37. Moatshe G, Cinque ME, Godin JA, Vap AR, Chahla J, LaPrade RF. Comparable outcomes after bucket-handle meniscal repair and vertical meniscal repair can be achieved at a minimum 2 years' follow-up. *Am J Sports Med.* 2017;45(13):3104-3110.
38. Moher D, Liberati A, Tetzlaff J, Altman DG; PRISMA Group. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: the PRISMA statement. *BMJ.* 2009;339:B2535.
39. Muriuki MG, Tuason DA, Tucker BG, Harner CD. Changes in tibiofemoral contact mechanics following radial split and vertical tears of the medial meniscus an in vitro investigation of the efficacy of arthroscopic repair. *J Bone Joint Surg Am.* 2011;93(12):1089-1095.
40. Nakayama H, Kanto R, Kambara S, Iseki T, Onishi S, Yoshiya S. Successful treatment of degenerative medial meniscal tears in well-aligned knees with fibrin clot implantation. *Knee Surg Sports Traumatol Arthrosc.* 2020;28(11):3466-3473.
41. Nepple JJ, Dunn WR, Wright RW. Meniscal repair outcomes at greater than five years: a systematic literature review and meta-analysis. *J Bone Joint Surg Am.* 2012;94(24):2222-2227.
42. Ode GE, Van Thiel GS, McArthur SA, et al. Effects of serial sectioning and repair of radial tears in the lateral meniscus. *Am J Sports Med.* 2012;40(8):1863-1870.
43. Paxton ES, Stock MV, Brophy RH. Meniscal repair versus partial meniscectomy: a systematic review comparing reoperation rates and clinical outcomes. *Arthroscopy.* 2011;27(9):1275-1288.

44. Ra HJ, Ha JK, Jang SH, Lee DW, Kim JG. Arthroscopic inside-out repair of complete radial tears of the meniscus with a fibrin clot. *Knee Surg Sports Traumatol Arthrosc.* 2013;21(9):2126-2130.
45. Sabbag OD, Hevesi M, Sanders TL, et al. High rate of recurrent meniscal tear and lateral compartment osteoarthritis in patients treated for symptomatic lateral discoid meniscus: a population-based study. *Orthop J Sports Med.* 2019;7(7):2325967119856284.
46. Samuelsen BT, Johnson NR, Hevesi M, et al. Comparative outcomes of all-inside versus inside-out repair of bucket-handle meniscal tears: a propensity-matched analysis. *Orthop J Sports Med.* 2018;6(6):2325967118779045.
47. Stein T, Mehling AP, Welsch F, von Eisenhart-Rothe R, Jager A. Long-term outcome after arthroscopic meniscal repair versus arthroscopic partial meniscectomy for traumatic meniscal tears. *Am J Sports Med.* 2010;38(8):1542-1548.
48. Wu IT, Hevesi M, Desai VS, et al. Comparative outcomes of radial and bucket-handle meniscal tear repair: a propensity-matched analysis. *Am J Sports Med.* 2018;46(11):2653-2660.
49. Xu C, Zhao J. A meta-analysis comparing meniscal repair with meniscectomy in the treatment of meniscal tears: the more meniscus, the better outcome? *Knee Surg Sports Traumatol Arthrosc.* 2015;23(1):164-170.
50. Yadav S, Storrie B. The cellular basis of platelet secretion: emerging structure/function relationships. *Platelets.* 2017;28(2):108-118.
51. Yasuda K, Sakai T, Kondo E, Onodera S. Bleeding from the bone marrow enhances remodeling of the in situ frozen-thawed anterior cruciate ligament. *Clin Biomech (Bristol, Avon).* 2007;22(8):941-949.