Bone marrow stimulation decreases retear rates after primary arthroscopic rotator cuff repair: a systematic review and meta-analysis

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Background: Despite the optimization of biomechanical and patient factors in the setting of rotator cuff repair (RCR), postoperative retear rates remain high in many series reported in the literature. Preclinical studies have suggested bone marrow stimulation (BMS) at the rotator cuff footprint may reduce the rate of retear after RCR. The objective of this meta-analysis was to analyze the clinical evidence investigating the effect of arthroscopic RCR, with and without BMS, on rotator cuff healing and functional outcomes.
Methods: PubMed, MEDLINE, Embase, and the Cochrane Library were searched through December 2017. Two reviewers selected studies based on the inclusion criteria and assessed methodologic quality. Pooled analyses were performed for continuous and binomial variables where appropriate.
Results: Four studies (365 patients), including 2 Level I randomized controlled trials and 2 Level III retrospective comparative cohort studies were included. There was no statistical difference in the Disabilities of the Arm, Shoulder and Hand score, University of California Los Angeles Shoulder Rating Scale score, or the Constant score between the BMS and conventional repair groups. The pooled retear rates were 18.4% (28 of 152) and 31.8% (56 of 176) for patients treated with and without BMS, respectively. The pooled analysis of rotator cuff retear rates from the 4 studies (328 patients) showed a statistically significant difference favoring BMS over conventional repair (odds ratio, 0.42; 95% confidence interval, 0.25-0.73; $P = .002$; $I^2 = 0\%$).
Conclusion: BMS reduces the retear rate after RCR but shows no difference in functional outcomes compared with conventional repair. This study provides evidence for the use of BMS as a potential cost-effective biological approach toward improving rotator cuff healing.
Level of evidence: Level III; Systematic Review/Meta-analysis
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Keywords: Bone marrow stimulation; microfracture; multiple channeling; rotator cuff repair; rotator cuff; rotator cuff tear

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Rotator cuff tears are common shoulder pathologies that occur more frequently with age[87] and typically undergo surgical intervention when conservative therapy fails.[59] Arthroscopic rotator cuff repair (RCR) continues to be the preferred method for many surgeons because it preserves the deltoid muscle, improves mobilization, and decreases postoperative scarring, stiffness, and pain.[7,47,83,86] However, despite the satisfactory-to-high clinical success with arthroscopic RCR[24,68,86] and the recent advances in biomechanical constructs for tendon fixation,[50,60,78] recurrent tearing of the rotator cuff remains a persistent problem.

Rotator cuff retear rates have historically ranged between 5% and 40% for small- to medium-sized tears and as high as 40% to 94% for large- to massive-sized tears,[9,11,33,44,78,89] depending on surgical technique.[40] Higher retear rates have been associated with older age,[10,54] larger tear size,[54,93,94] significant fatty infiltration,[35,54] muscle atrophy,[1] presence of comorbidities,[1,23] and the use of a single-row technique.[1,27,29] Considering that retear rates remain a substantial confounder of outcomes after RCR,[78] exploring alternative strategies to enhancing structural healing is important.

One approach to enhance tendon-to-bone healing that is gaining popularity among surgeons is biological augmentation, which includes the use of platelet-rich plasma (PRP) injections, growth factors, and mesenchymal stem cells (MSCs), including adipose-derived MSCs and bone marrow (BM) aspirate concentrate.[36,56,66] Among these, MSCs have received significant attention due to their potential clinical application in tendon repair and regeneration by influencing the biological environment through producing an array of bioactive molecules that stimulate angiogenesis, regeneration, cellular recruitment, remodelling, immune cell activation or suppression, and inhibit apoptosis.[12,18,28,37,48,58] However, access to exogenous MSCs remains limited in most countries due to ongoing clinical investigation and stringent regulatory requirements.

Despite being in the early stages of clinical application, studies administering BM aspirate concentrate and adipose-derived MSCs for RCR have indicated favorable patient-reported outcomes and structural healing.[41,52,53] Further studies are needed to better understand the long-term effect of these biological agents. Although evidence is conflicting, several systematic reviews[17,81,84] have demonstrated that PRP may reduce retear rates after RCR, specifically for small to medium tears[17,20,72,81]; however, this approach has not been found to be cost-effective.[73,81]

BM stimulation (BMS) is known to be an effective in situ modality to treat chondral lesions in the knee and ankle.[22,64,77] BMS is believed to provide for the egress of marrow elements containing cytokines, growth factors, and possibly a limited number of MSCs, which form a surgically induced super clot that may enrich the local biological healing milieu.[19,63,76,85] In the context of RCR, previous studies using BMS in animal models[8,49] have consistently shown increased ultimate load to failure in RCR, indicating that BMS may be a simple, yet effective technique to promote tendon-to-bone healing. In addition, there are conflicting clinical results regarding the effectiveness of BMS at improving healing and outcomes after RCR.[27,46,61,89]

The primary aim of this study was to identify, summarize, and synthesize the currently available clinical data on BMS treatment for primary arthroscopic RCR. We hypothesized that applying BMS at the footprint during RCR would significantly lower retear rates and result in similar functional outcomes compared with conventional RCR without BMS.

Materials and methods

Literature search

A systematic search was conducted in the electronic databases MEDLINE, Embase, PubMed, Cochrane Central Register of Controlled Trials, and www.clinicaltrials.gov for completed comparative randomized controlled trials (RCTs) and cohort studies during the first week of December 2017. Additional screening of poster presentations and abstracts from the American Academy of Orthopaedic Surgeons (AAOS) and the Canadian Orthopaedic Association (COA) were also reviewed for any relevant unpublished studies. This systematic search was performed using a text-based search strategy with the following keyword combinations: [rotator cuff repair *or* rotator cuff tear] *and* [microfracture *or* bone-marrow stimulation]. We restricted our search strategy to only human studies; however, no language or publication date restrictions were applied. References of all included studies were manually cross-referenced by the primary author (J.C.) for further review to ensure search completeness of relevant studies not located in the original systematic search. This literature search was also repeated on several occasions over the course of manuscript preparation to ensure no new eligible studies were available.

Eligibility criteria

We identified and included all studies that fulfilled the following inclusion criteria: (1) published studies that were randomized trials or prospective and retrospective cohort studies (Level I-III) with a comparative control group that reported clinical outcomes after primary arthroscopic repair of a full-thickness rotator cuff tear; (2) used the BMS technique in one of the respective study groups; (3) a minimum clinical follow-up of 12 months; and (4) patients aged 18 years or older. We excluded case studies, review, and basic science articles that did not report patient-specific clinical outcomes. Studies in which RCR was completed as a revision procedure were also excluded.

Study selection

The primary author scanned through the title and abstracts of all the articles that were generated by the literature search. After duplicates were removed, 2 independent reviewers (P.A. and M.A.) assessed the remaining studies to determine their eligibility based on the inclusion criteria. If any uncertainty of study eligibility was encountered, the study was included until the full-text review could be performed from each independent reviewer to determine eligibility. Any disagreement during the full-text review was resolved

by discussion between the 2 reviewers until a final consensus was reached. The titles of journals and names of authors or supporting institutions were not blinded for any reviewer at any screening stage.

Data extraction and management

Two independent reviewers (P.A. and M.A.) extracted general study information (author, year of publication, study design, and level of evidence), population demographic data (sample size, mean age, and sex), follow-up data (mean duration, rate, and number of patients lost to follow-up), surgical intervention information (anchors used, surgical procedures performed, and BMS protocol), results (outcome measures and complications), and study weaknesses. In cases where additional study data were required from the respective study that was not published in the manuscript, the corresponding author was contacted. Data pertaining to retear rates and patient-reported functional outcome measures from all available studies were imported into RevMan 5.3 meta-analysis software (The Cochrane Collaboration, Oxford, United Kingdom) for statistical pooling and analysis.

Methodologic quality assessment of included studies

The methodologic quality of all included studies was assessed and reviewed by 2 independent reviewers. The CLEAR-NPT (Checklist to Evaluate a Report of a Non-Pharmacological Trial), a validated 10-element checklist, was used to assess the methodologic quality of RCTs.[15] The higher the score obtained from a respective study with CLEAR-NPT was indicative of a higher methodologic study quality. MINORS (Methodologic Index for Non-Randomized Studies) a 12-item criteria, was used to determine the risk of bias for the included nonrandomized comparative studies.[75] The global ideal score from the MINORS criteria for comparative studies is 24, which represents a low risk of bias and is given the grade letter A. Scores ranging from >20 to <24 are also considered to have a low risk of bias, but are graded as B. Lastly, a score that is ≤20 is considered to have high risk of bias and is graded as C.

Outcomes

The outcomes of interest for this study were rotator cuff retear rates (as evaluated by magnetic resonance imaging, ultrasound, or computed tomography arthrography) and functional outcome measures, including the Disabilities of the Arm, Shoulder, and Hand Questionnaire (DASH),[6,26] University of California, Los Angeles Shoulder Rating Scale (UCLA),[2] Constant-Murley outcome score,[25] Pennsylvania Shoulder Score,[55] visual analog scale,[13,39] Simple Shoulder Test,[34] American Shoulder and Elbow Surgeons Score,[61] and the Shoulder Pain and Disability Index,[16,57] all at the latest follow-up.

Statistical analysis

For continuous outcomes, the mean difference was obtained and calculated from the inverse variance method. When the standard deviation was not provided for specific continuous outcomes, the corresponding author from the respective article was contacted to obtain the possible raw data. If there was no response from the author and the appropriate statistical range was provided, then the standard deviation was calculated to impute these values from a well-established

statistical formula described by Hozo et al.[43] For dichotomous outcomes, the odds ratio (OR) was calculated using the Cochran-Mantel-Haenzel method.

For all outcome variables, we tested heterogeneity between studies using a standard χ^2 test, and the calculation of an I^2 statistic[42] was used to quantify heterogeneity. A fixed-effects model was used to pool results from comparable studies in the absence of significant heterogeneity ($I^2 < 50\%$), and the random-effects model was used to pool results when significant heterogeneity was present ($I^2 > 50\%$). We calculated 95% confidence intervals (CI) from all point estimates, and a P value of <.05 was considered statically significant for all outcome measures.

Results

Literature search

The results of our systematic search and the number of studies excluded at each stage are outlined in Fig. 1. After title and abstract screening, 8 articles remained eligible for full-text review. Of these 8 studies, 4 were excluded, and 2 authors (P.A. and M.A.) independently reviewed the remaining 4 studies[45,62,67,79] that met the inclusion criteria for this study. This included 2 RCTs (Level I)[62,67] and 2 retrospective comparative cohort studies (Level III).[45,79]

General study characteristics

The 4 studies[45,62,67,79] comprised 365 patients, of whom 197 (54%) were men. A total of 164 patients received BMS along with conventional RCR, whereas 201 patients only received conventional RCR. The frequency-weighted age of the patients across all studies was 61.7 years (range, 58.8-64.7 years). The overall median clinical follow-up period for all studies was 27 months (range, 12-36 months). Complete clinical and imaging follow-up was reported in 328 of 365 patients, with an overall follow-up rate of 90% from all included studies.[45,62,67,79]

Three studies[45,62,67] reported an average duration of symptoms preceding surgery of 20.1 months (range, 12.5-26.2 months) for the BMS group and 17.5 months (range, 13-22.3 months) for the conventional group. A single-row technique was used to treat 134 patients, and a double-row technique was used in 231 patients.[45,62,67,79] Among patients undergoing BMS, 101 of 231 (44%) received a double-row/transosseous equivalent repair,[45,79] and 63 of 134 (47%) were treated with single-row repairs.[45,62,67] In the conventional repair group, 130 of 231 (56%) and 71 of 134 (53%) received double-row/transosseous equivalent and single-row repair, respectively.[45,62,67,79]

Rotator cuff tear diagnosis and severity

The rotator cuff tear size was recorded in 3[45,62,79] of the 4 studies using the Cofield classification[45,79] or the Patte classification[62] of rotator cuff tear retraction (frontal plane) grading system.
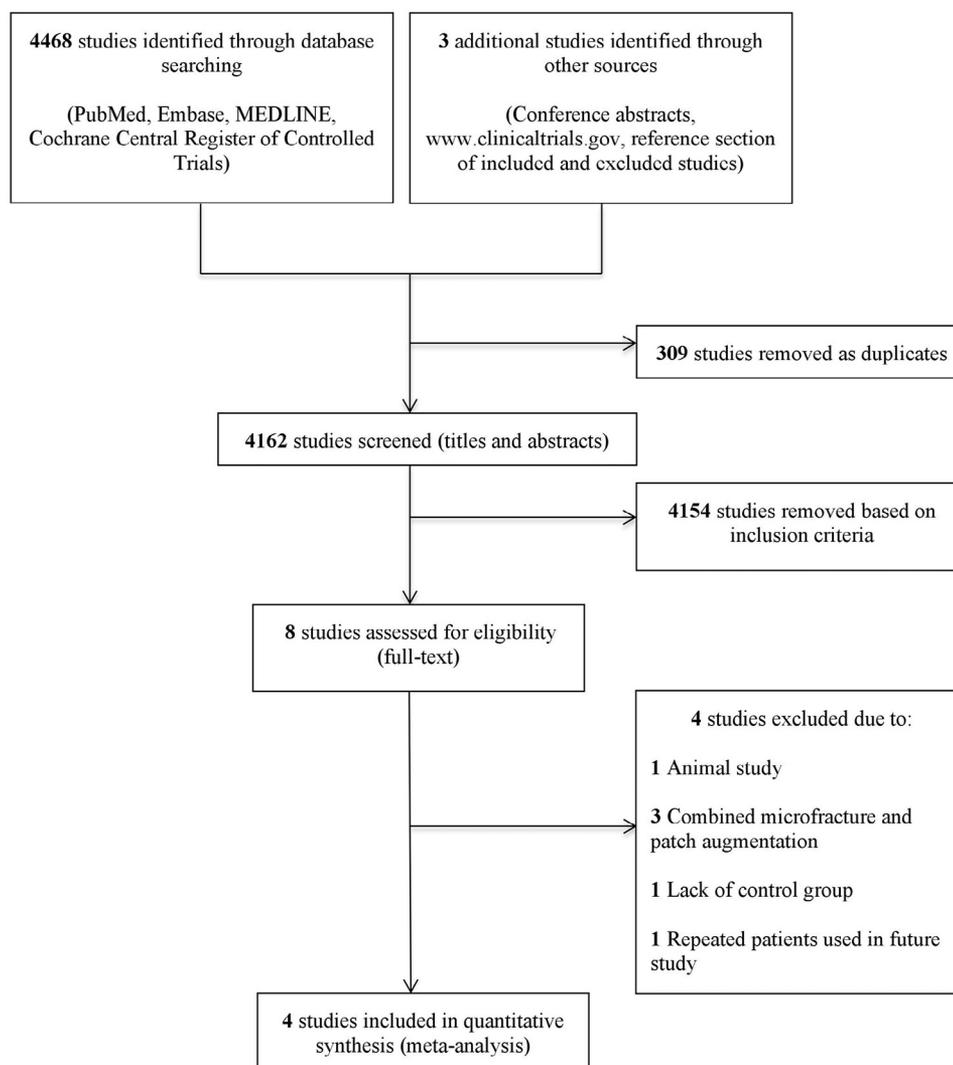
Figure 1 Search strategy results.

Two[45,62] studies included patients with small, medium, large, or massive rotator cuff tears, and 1 study[79] excluded patients with small rotator cuff tears due to the use of the arthroscopic surface holding technique. Therefore, the number of patients with small, medium, and large to massive tears were 6.6% (9 of 136), 56.6% (77 of 136), and 36.8% (50 of 136), respectively, in the BMS group. Conversely, the number of small, medium, and large to massive tears in the conventional group was 6.4% (11 of 172), 53% (91 of 172), and 40.6% (70 of 172), respectively. Although 3 studies[45,62,79] recorded fatty infiltration, only 2 studies[45,62] clearly reported it for each group as evaluated by the Goutallier grading system. Collectively, from these 2 studies, fatty infiltration did not differ significantly between the BMS group and conventional repair group.

Concomitant procedures

Additional surgical procedures that were performed alongside RCR were reported in 4 of the 5 studies.[45,62,67,79] Treatment procedures for any long head of the biceps (LHB) pathology were reported in 2 of the 4 studies.[62,67] Osti et al[56] performed a LHB tenotomy in all instances, whereas Milano et al[62] addressed the treatment of the LHB in relation to the patient's age, with patients aged 60 years and older receiving a biceps tenotomy and those younger than 60 years receiving a tenodesis. Acromioplasty was performed in patients in 2[45,79] of the 4 studies. Specifically, Jo et al[45] indicated that 26.5% (15 of 57) of BMS patients received an acromioplasty compared with 73.1% (49 of 67) in the conventional group.

Rotator cuff retear classification and outcomes reported

All included studies[45,62,67,79] reported the retear rate, which was measured by magnetic resonance imaging and the Sugaya classification[62,67,79] or computed tomography arthrography and the Boileau grading system,[45] to describe the incidence and severity of rotator cuff retear. However, Jo et al[45] used the combination of magnetic resonance imaging or computed

tomography arthrography to report the incidence of retear rates. The most commonly reported shoulder-specific functional outcome measures used across all studies were the Constant-Murley score,[45,62,67] DASH score,[45,62] UCLA score,[45,67] visual analog scale,[45,67] and the American Shoulder and Elbow Surgeons Score.[45,67]

Study methodologic quality

Quality appraisal of the 2 included RCTs[62,67] found that both RCTs attained a good score ranging between 7 and 9 of 10 according to the CLEAR-NPT checklist. In general, sequence generation was reported in both RCTs; however, allocation concealment was inadequate in the study by Osti et al.[67] Surgical experience and skill level was appropriate in both trials. In one of the trials,[67] patient blinding was not adequate, and given the nature of the intervention, the treating surgeon could not be blinded for both trials.[62,67] However, both RCTs reported that the clinical outcome assessor was blinded during all assessments. Lastly, both trials failed to state whether an intention-to-treat analysis was performed.

The 2 nonrandomized studies[45,79] were given the grade letter C as evaluated by the MINORS criteria, indicating a high risk of bias and poor to moderate study quality. Specifically, both studies provided a clearly stated aim, end points of the study, adequate statistical analysis of outcomes, appropriate follow-up periods, and sufficient control groups.[45,79] However, both studies failed to perform a prospective study calculation of sample size and did not refer to the use of an unbiased outcome assessor.[45,79] The study by Jo et al[45] also failed to collect study data prospectively. Overall, the 2 nonrandomized studies[45,79] received a score of 17 of 19 of a possible 24.

BMS technique

Two different BMS techniques, microfracture[62,67,79] and multiple channeling,[45] were applied across the 5 included studies. These 2 techniques differed in the surgical instrumentation used to induce BM venting and in the depth and associated measurements of BM vents (Table I).

Table I Description of bone marrow stimulation technique within each study

Study	Bone marrow stimulation technique
Milano[62]	• Used an awl for microfractures • 5 mm deep, 1.5 mm wide, 4 mm apart
Taniguchi[79]	• Used a metal bar for microfractures • 3 mm wide, 3-5 mm apart
Osti[67]	• Used an awl for microfractures • 2-4 mm deep, 3-4 mm apart
Jo[45]	• Used a rasp for multiple channeling • 10 mm deep, 2.1 mm wide, 4-5 mm apart

Outcomes

Retear rates

The pooled retear rate at a minimum of 12 months postoperatively (range, 12-36 months) for all patients across the 4 included studies[45,62,67,79] was 25.6% (84 of 328). The pooled retear rates were 18.4% (28 of 152) and 31.8% (56 of 176) for patients treated with BMS and those treated without, respectively. A meta-analysis of the 4 included studies (328 patients)[45,62,67,79] indicated a statistically significant difference in the overall retear rate that favored BMS (OR, 0.42; 95% CI, 0.25-0.73; $P = .002$, $I^2 = 0\%$; Fig. 2, A). When pooling the 2 nonrandomized studies (198 patients)[45,79] alone, sensitivity analysis indicated a statistically significant difference in the retear rate favoring BMS (OR, 0.33; 95% CI, 0.16-0.69; $P = .003$, $I^2 = 0\%$). However, sensitivity analysis showed no significant difference in the overall retear rate when the results from the 2 randomized studies[62,67] (130 patients) were pooled alone (OR, 0.60; 95% CI, 0.26-1.39; $P = .23$, $I^2 = 0\%$].

Shoulder-specific functional outcomes

Only the Constant-Murley score, UCLA score, and DASH score were eligible for statistical pooling. A meta-analysis of the Constant-Murley score[45,62,67] in patients treated with or without BMS showed no statistical difference between the 2 groups (3 studies [254 patients]; mean difference, 1.18; 95% CI, −1.63 to 3.99; $P = .41$, $I^2 = 0\%$; Fig. 2, B). A pooled analysis of the UCLA score[45,67] between patients treated with and without BMS also demonstrated no statistical difference (2 studies [181 patients]; mean difference, 0.38; 95% CI, −1.08 to 1.84; $P = .61$, $I^2 = 0\%$; Fig. 2, D). In addition, there was no statistical difference between the 2 groups in the DASH score[45,62] (2 studies [197 patients]; mean difference, −2.57; 95% CI, −7.50 to 2.35; $P = .31$, $I^2 = 0\%$; Fig. 2, C).
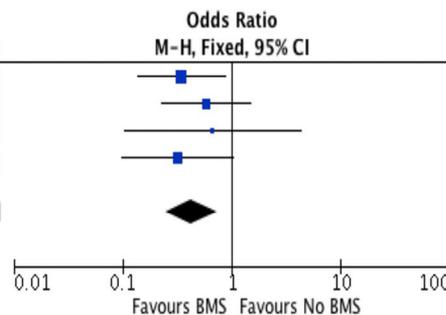
Discussion

The main finding from this study was that BMS performed in the setting of primary arthroscopic RCR significantly reduces the rate of retear at a minimum of 1 year after surgery. Consistent with our hypothesis, there were no statistically significant differences in patient-reported functional outcomes as measured by the Constant-Murley, DASH, and UCLA scores among patients treated with and without BMS after RCR. This is also consistent with the literature regarding PRP, where lower retear rates have been observed in the context of small to medium tears[17,20,72,81] and no detectable differences in shoulder-specific functional outcomes.[17,20,32,91,92]

Recurrent tearing after RCT remains a frequent surgical issue. Our findings demonstrated that patients receiving BMS had significantly lower retear rates (18.4%) than patients treated with conventional repair only (31.8%). Concurring with our clinical findings, several animal-based models have also shown increased rotator cuff healing rates when applying BMS.[8,49] Furthermore, a previous study conducted by Yoon et al[90] that included 75 patients demonstrated significantly lower retear
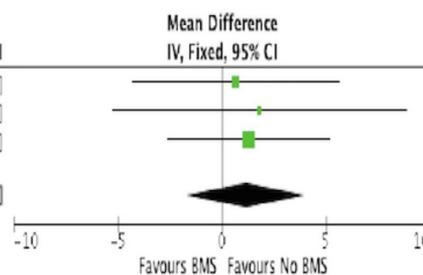
A Re-tear Rates

B Constant Score

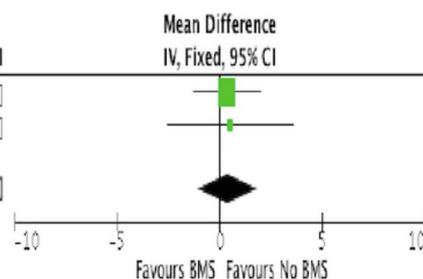**C DASH Score**

D UCLA Score

Figure 2 Forest plots illustrate the results of the pooled analysis for (**A**) bone marrow stimulation (*BMS*) vs. no BMS for retear rates, (**B**) Constant score, (**C**) Disabilities of the Arm, Shoulder and Hand (*DASH*) score, and (**D**) University of California Los Angeles (*UCLA*) Shoulder Rating Scale score. The ■ indicate the mean difference and are proportional to the weights used in the meta-analysis, and the —— indicate the 95% confidence interval (*CI*). The ◆ indicates the weighted mean difference, and the lateral tips of the diamond indicate the associated 95% confidence interval (*CI*). *IV*, inverse variance; *M-H*, Mantel-Haenszel.

rates in patients undergoing BMS with combined patch augmentation (19%) compared with patients receiving conventional repair only (46.3%). Dierckman et al[27] reported a low retear rate of 9% among 52 patients undergoing BMS with RCR, but their study was retrospective and lacked a control group.

Although BMS reduces retear rates by enhancing tendon-to-bone healing, this failed to improve functional outcomes.[45,62,67] The overall effect of failure of rotator cuff healing on functional outcomes remains poorly quantified and understood. Previous studies reported a poor correlation between retearing and clinical outcomes.[3,21] However, most

recent clinical studies have reported that clinical outcome at a minimum of 2 years of follow-up is significantly improved in patients with intact rotator cuff tendons.[5,38,51,74,78] A more recent meta-analysis[88] including 29 studies further concluded that patients with recurrent tearing exhibited significantly lower functional outcomes irrespective of the surgical technique used. Although our review did not find superior functional outcomes with BMS, it is possible that longer-term outcomes would be improved with long-term follow-up due to the improved structural integrity associated with BMS application.

The rationale behind the enhanced tendon-to-bone healing associated with BMS application is possibly due to increased excretion of healing elements, including the influx of fibroblasts[80] and the migration of MSCs,[45,49] from the proximal humerus to the bone-tendon interface of the repaired rotator cuff tendon. Complementary flow cytometry analysis conducted by Jo et al[45] confirmed that the cells recruited at the RCR site after BMS were consistent with the MSC phenotype because CD73, CD90, and CD105 were positively expressed, but CD45 was negatively expressed.

Growth factors that are present in the BM can mitigate inflammation, enhance tissue remodeling, and may induce an angiogenic effect, which has the potential to improve physiological healing.[65] PRP is a new biological therapy that contains an array of growth factors that are essential for the enthesis healing process, including transforming growth factor-β, vascular endothelial growth factor, basic fibroblast growth factor, insulin growth factor 1 and 2, connective tissue growth factor, platelet-derived growth factor, and epidermal growth factor.[4,14,31,71] However, the conflicting clinical evidence and high associated costs,[73,81] coupled with the uncertainty regarding the dose, location, and timing of administration, make PRP difficult to implement and impractical. Several studies have concluded that PRP application is safe and effective[17,69,70]; however, most recent studies have consistently shown that PRP injections do not significantly improve shoulder-specific outcomes[17,20,32,91,92] or overall retear rates[30,82,92] but may be beneficial in reducing retears of small- to medium-sized tears after arthroscopic RCR.[17,20,72,81] However, using PRP has been shown to be cost-ineffective.[73,81]

Alternatively, the in situ delivery of MSCs induced by BMS offers a feasible surgical solution to augmenting rotator cuff healing. Drilling BM vents is a quick and simple surgical technique to potentially increase healing success without the risk of additional complications. Importantly, this technique also potentially limits operative costs and does not compromise postoperative recovery. With the foreseen availability of a variety of biological augmentation modalities that may be associated with high costs and increased risk of complications, we believe that the results of this review provide convincing evidence that BMS is an important strategy for enhancing RCR healing postoperatively.

To our knowledge, this is the first systematic review and meta-analysis that has investigated BMS in the context of RCR.

The strength of this study is that all of the included studies, which comprised Level I to III evidence, reported retear rates using cross-sectional imaging.

However, this meta-analysis also has several limitations. First, given that only 4 studies were available for inclusion in this review, our sample size was relatively small, and bias within 1 study could influence the overall observed effect.

Second, the 2 retrospective Level III studies[45,79] comprised a large proportion of the analyzed patients.

Third, we recognize the heterogeneity in surgical fixation techniques, postoperative radiologic imaging, concomitant procedures performed, and BMS technique. However, such differences do allow for improved generalizability of our findings.

Finally, the influence of patient factors, including comorbidities, on postoperative outcomes could not be controlled for in this study, because these data could not be extracted consistently from the included studies.

Conclusion

BMS is a safe, simple, and inexpensive surgical technique that reduces the retear rate after primary arthroscopic RCR but does not significantly improve functional outcomes compared with conventional repair. This study provides evidence for the use of BMS with primary RCR as a potential cost-effective, biological approach towards improving rotator cuff healing.

Disclaimer

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References

1. Abtahi AM, Granger EK, Tashjian RZ. Factors affecting healing after arthroscopic rotator cuff repair. World J Orthop 2015;6:211-20. http://dx.doi.org/10.5312%2Fwjo.v6.i2.211

2. Amstutz H, Sew Hoy AL, Clarke IC. UCLA anatomic total shoulder arthroplasty. Clin Orthop Relat Res 1981;(155):7-20.

3. Anderson K, Boothby M, Aschenbrener D, van Holsbeeck M. Outcome and structural integrity after arthroscopic rotator cuff repair using 2 rows of fixation: minimum 2-year follow-up. Am J Sports Med 2006;34:1899-905. http://dx.doi.org/10.1177/0363546506290187

4. Anitua E, Andia I, Ardanza B, Nurden P, Nurden AT. Autologous platelets as a source of proteins for healing and tissue regeneration. Thromb Haemost 2004;91:4-15. http://dx.doi.org/10.1177/0363546506290187

5. Barth J, Fotiadis E, Barthelemy R, Genna S, Saffarini M. Ultrasonic evaluation of the repair integrity can predict functional outcomes after arthroscopic double-row rotator cuff repair. Knee Surg Sports Traumatol Arthrosc 2015;23:376-85. http://dx.doi.org/10.1007/s00167-015-3505-z

6. Beaton DE, Katz JN, Fossel AH, Wright JG, Tarasuk V, Bombardier C. Measuring the whole or the parts? J Hand Ther 2001;14:128-42.

7. Bennett WF. Arthroscopic repair of anterosuperior (supraspinatus/subscapularis) rotator cuff tears: a prospective cohort with 2- to 4-year follow-up. Classification of biceps subluxation/instability. Arthroscopy 2003;19:21-33. http://dx.doi.org/10.1053/jars.2003.50023

8. Bilsel K, Yildiz F, Kapicioglu M, Uzer G, Elmadag M, Pulatkan A, et al. Efficacy of bone marrow-stimulating technique in rotator cuff repair. J Shoulder Elbow Surg 2017;26:1360-6. http://dx.doi.org/10.1016/j.jse.2017.02.014

9. Bishop J, Klepps S, Lo IK, Bird J, Gladstone JN, Flatow EL. Cuff integrity after arthroscopic versus open rotator cuff repair: a prospective study. J Shoulder Elbow Surg 2006;15:290-9. http://dx.doi.org/10.1016/j.jse.2005.09.017

10. Bjornsson HC, Norlin R, Johansson K, Adolfsson LE. The influence of age, delay of repair, and tendon involvement in acute rotator cuff tears: structural and clinical outcomes after repair of 42 shoulders. Acta Orthop 2011;82:187-92. http://dx.doi.org/10.3109/17453674.2011.566144

11. Boileau P, Brassart N, Watkinson DJ, Carles M, Hatzidakis AM, Krishnan SG. Arthroscopic repair of full-thickness tears of the supraspinatus: does the tendon really heal? J Bone Joint Surg Am 2005;87:1229-40. http://dx.doi.org/10.2106/JBJS.D.02035

12. Bonfield TL, Nolan MT, Lennon DP, Caplan AI. Defining human mesenchymal stem cell efficacy in vivo. J Inflamm (Lond) 2010;7:1-12. http://dx.doi.org/10.1186%2F1476-9255-7-51

13. Boonstraa AM, Schiphorst Preuper HR, Renemanb MF, Posthumusa JB, Stewart RE. Reliability and validity of the visual analogue scale for disability in patients with chronic musculoskeletal pain. Int J Rehabil Res 2008;31:165-9. http://dx.doi.org/10.1097/MRR.0b013e3282fc0f93

14. Boswell SG, Cole BJ, Sundman EA, Karas V, Fortier LA. Platelet-rich plasma: a milieu of bioactive factors. Arthroscopy 2012;28:429-39. http://dx.doi.org/10.1016/j.arthro.2011.10.018

15. Boutron I, Moher D, Tugwell P, Giradeau B, Poiraudeau S, Nizard R, et al. A checklist to evaluate a report of a nonpharmacological trial (CLEAR NPT) was developed using consensus. J Clin Epidemiol 2005;58:1233-40. http://dx.doi.org/10.1016/j.jclinepi.2005.05.004

16. Breckenridge JD, McAuley JH. Shoulder Pain and Disability Index (SPADI). J Physiother 2011;57:197. http://dx.doi.org/10.1016/S1836-9553(11)70045-5

17. Cai YZ, Zhang C, Lin XJ. Efficacy of platelet-rich plasma in arthroscopic repair of full-thickness rotator cuff tears: a meta-analysis. J Shoulder Elbow Surg 2015;24:1852-9. http://dx.doi.org/10.1016/j.jse.2015.07.035

18. Caplan AI. Why are MSCs therapeutic? New data: new insight. J Pathol 2009;217:318-24. http://dx.doi.org/10.1002/path.2469

19. Caplan AI. Adult mesenchymal stem cells for tissue engineering versus regenerative medicine. J Cell Physiol 2007;213:341-7. http://dx.doi.org/10.1002/jcp.21200

20. Chahal J, Van Thiel GS, Mall N, Heard W, Bach BR, Cole BJ, et al. The role of platelet-rich plasma in arthroscopic rotator cuff repair: a systematic review with quantitative synthesis. Arthroscopy 2012;28:1718-27. http://dx.doi.org/10.1016/j.arthro.2012.03.007

21. Charousset C, Grimberg J, Duranthon LD, Bellaiche L, Petrover D. Can a double-row anchorage technique improve tendon healing in arthroscopic rotator cuff repair?: A prospective, nonrandomized, comparative study of double-row and single-row anchorage techniques with computed tomographic arthrography tendon healing assessment. Am J Sports Med 2007;35:1247-53. http://dx.doi.org/10.1177/0363546507301661

22. Chuckpaiwong B, Berkson EM, Theodore GH. Microfracture for osteochondral lesions of the ankle: outcome analysis and outcome predictors of 105 cases. Arthroscopy 2008;24:106-12. http://dx.doi.org/10.1016/j.arthro.2007.07.022

23. Chung SW, Oh JH, Gong HS, Kim JY, Kim SH. Factors affecting rotator cuff healing after arthroscopic repair: osteoporosis as one of the independent risk factors. Am J Sports Med 2011;39:2099-107. http://dx.doi.org/10.1177/0363546511415659

24. Cole BJ, McCarty LP III, Kang RW, Alford W, Lewis PB, Hayden JK. Arthroscopic rotator cuff repair: prospective functional outcome and repair integrity at minimum 2-year follow-up. J Shoulder Elbow Surg 2007;16:579-85. http://dx.doi.org/10.1016/j.jse.2006.12.011

25. Constant CR, Murley AH. A clinical method of functional assessment of the shoulder. Clin Orthop Relat Res 1987;(214):160-4.

26. Davis AM, Beaton DE, Hudak P, Amadio P, Bombardier C, Cole D, et al. Measuring disability of the upper extremity: a rationale supporting the use of a regional outcome measure. J Hand Ther 1999;12:269-74.

27. Dierckman BD, Ni JJ, Karzel RP, Getelman MH. Excellent healing rates and patient satisfaction after arthroscopic repair of medium to large rotator cuff tears with a single-row technique augmented with bone marrow vents. Knee Surg Sports Traumatol Arthrosc 2017;26:136-45. http://dx.doi.org/10.1007/s00167-017-4595-6

28. Dimarino AM, Caplan AL, Bonfield TL. Mesenchymal stem cells in tissue repair. Front Immunol 2013;4:1-9. http://dx.doi.org/10.3389/fimmu.2013.00201

29. Duquin TR, Buyea C, Bisson LJ. Which method of rotator cuff repair leads to the highest rate of structural healing? A systematic review. Am J Sports Med 2010;38:835-41. http://dx.doi.org/10.1177/0363546509359679

30. Ebert JR, Wang A, Smith A, Nairn R, Breidahl W, Zheng MH, et al. A midterm evaluation of postoperative platelet-rich plasma injections on arthroscopic supraspinatus repair: a randomized controlled trial. Am J Sports Med 2017;45:2965-74. http://dx.doi.org/10.1177/0363546517719048

31. Everts P, Knape J, Wibrich G, Schonberger JP, Hoffman J, Overdevest E, et al. Platelet-rich plasma and platelet gel: a review. J Extra Corpor Technol 2006;38:174-87.

32. Flury M, Rickenbacher D, Schwyzer HK, Jung C, Schneider MM, Stahnke K, et al. Does pure platelet-rich plasma affect postoperative clinical outcomes after arthroscopic rotator cuff repair? A randomized controlled trial. Am J Sports Med 2016;44:2136-46. http://dx.doi.org/10.1177/0363546516645518

33. Galatz L, Ball CM, Teefey S, Middleton WD, Yamaguchi K. The outcome and repair integrity of completely arthroscopically repaired large and massive rotator cuff tears. J Bone Joint Surg Am 2004;86:219-24.

34. Godfrey J, Hamman R, Lowenstein S, Briggs K, Kocher M. Reliability, validity, and responsiveness of the simple shoulder test: psychometric properties by age and injury type. J Shoulder Elbow Surg 2007;16:260-7. http://dx.doi.org/10.1016/j.jse.2006.07.003

35. Goutallier D, Postel JM, Bernageau J, Lavau L, Voisin MC. Fatty muscle degeneration in cuff ruptures pre- and postoperative evaluation by CT scan. Clin Orthop Relat Res 1994;(304):78-83.

36. Gowd AK, Cabarcas BC, Frank RM, Cole BJ. Biologic augmentation of rotator cuff repair: the role of platelet-rich plasma and bone marrow aspirate concentrate. Oper Tech Sports Med 2018;26:48-57. http://dx.doi.org/10.1053/j.otsm.2017.10.008

37. Guimaraes-Camboa N, Cattaneo P, Sun Y, Moore-Morris T, Gu Y, Dalton ND, et al. Pericytes of multiple organs do not behave as mesenchymal stem cells in vivo. Cell Stem Cell 2017;20:345-59. http://dx.doi.org/10.1016/j.stem.2016.12.006

38. Hantes ME, Ono Y, Raoulis VA, Doxariotis N, Venouziou A, Zibis A, et al. Arthroscopic single-row versus double-row suture bridge technique for rotator cuff tears in patients younger than 55 years: a prospective comparative study. Am J Sports Med 2017;46:116-21. http://dx.doi.org/10.1177/0363546517728718

39. Hawker GA, Mian S, Kendzerska T, French M. Measures of adult pain: Visual Analog Scale for Pain (VAS Pain), Numeric Rating Scale for Pain (NRS Pain), McGill Pain Questionnaire (MPQ), Short-Form McGill Pain Questionnaire (SF-MPQ), Chronic Pain Grade Scale (CPGS), Short Form-36 Bodily Pain Scale (SF-36 BPS), and measure of Intermittent and Constant Osteoarthritis Pain (ICOAP). Arthritis Care Res (Hoboken) 2011;63:240-52. http://dx.doi.org/10.1002/acr.20543

40. Henry P, Wasserstein D, Park S, Dwyer T, Chahal J, Slobogean G, et al. Arthroscopic repair for chronic massive rotator cuff tears: a systematic

review. Arthroscopy 2015;31:2472-80. http://dx.doi.org/10.1016/j.arthro.2015.06.038

41. Hernigou P, Lachaniette CH, Delambre J, Zilber S, Duffiet P, Chevallier N, et al. Biologic augmentation of rotator cuff repair with mesenchymal stem cells during arthroscopy improves healing and prevents further tears: a case-controlled study. Int Orthop 2014;38:1811-8. http://dx.doi.org/10.1007/s00264-014-2391-1

42. Higgins JP, Thompson SG. Quantifying heterogeneity in a meta-analysis. Stat Med 2002;21:1539-58. http://dx.doi.org/10.1002/sim.1186

43. Hozo SP, Djulbegovic B, Hozo I. Estimating the mean and variance from the median, range, and the size of a sample. BMC Med Res Methodol 2005;5:13. http://dx.doi.org/10.1186/1471-2288-5-13

44. Huijsmans PE, Pritchard MP, Berghs BM, van Rooyen KS, Wallace AL, de Beer JF. Arthroscopic rotator cuff repair with double-row fixation. J Bone Joint Surg Am 2007;89:1248-57. http://dx.doi.org/10.2106/JBJS.E.00743

45. Jo CH, Shin JS, Park IW, Kim H, Lee SY. Multiple channeling improves the structural integrity of rotator cuff repair. Am J Sports Med 2013;41:2650-7. http://dx.doi.org/10.1177/0363546513499138

46. Jo CH, Yoon KS, Lee JH, Kang SB, Lee JH, Han HS, et al. The effect of multiple channeling on the structural integrity of repaired rotator cuff. Knee Surg Sports Traumatol Arthrosc 2011;19:2098-107. http://dx.doi.org/10.1007/s00167-011-1520-2

47. Jones CK, Savoie FH. Arthroscopic repair of large and massive rotator cuff tears. Arthroscopy 2003;19:564-71. http://dx.doi.org/10.1016/S0749-8063(03)00169-5

48. Kean TJ, Lin P, Caplan AL, Dennis JE. MSCs: delivery routes and engraftment, cell-targeting strategies, and immune modulation. Stem Cells Int 2013;1-13. http://dx.doi.org/10.1155/2013/732742

49. Kida Y, Morihara T, Matsuda K, Kajikawa Y, Tachiiri H, Iwata Y, et al. Bone marrow-derived cells from the footprint infiltrate into the repaired rotator cuff. J Shoulder Elbow Surg 2013;22:197-205. http://dx.doi.org/10.1016/j.jse.2012.02.007

50. Kim DH, Elattrache NS, Tibone JE, Jun BJ, DeLaMora SN, Kvitne RS, et al. Biomechanical comparison of a single-row versus double-row suture anchor technique for rotator cuff repair. Am J Sports Med 2006;34:407-14. http://dx.doi.org/10.1177/0363546505281238

51. Kim SJ, Choi YR, Jung M, Lee W, Chun YM. Arthroscopic repair of anterosuperior massive rotator cuff tears: does repair integrity affect outcomes? Am J Sports Med 2017;45:1762-8. http://dx.doi.org/10.1177/0363546517694028

52. Kim SJ, Kim EK, Kim SJ, Song DH. Effects of bone marrow aspirate concentrate and platelet-rich plasma on patients with partial tear of the rotator cuff tendon. J Orthop Surg Res 2018;13:1-7. http://dx.doi.org/10.1186/s13018-017-0693-x

53. Kim YS, Sung CH, Chung SH, Kwak SJ, Koh YG. Does an injection of adipose-derived mesenchymal stem cells loaded in fibrin glue influence rotator cuff repair outcomes? A clinical and magnetic resonance imaging study. Am J Sports Med 2017;45:2010-8. http://dx.doi.org/10.1177/0363546517702863

54. Lee YS, Jeong JY, Park CD, Kang SG, Yoo JC. Evaluation of the risk factors for a rotator cuff retear after repair surgery. Am J Sports Med 2017;45:1755-61. http://dx.doi.org/10.1177/0363546517695234

55. Leggin BG, Michener LA, Shaffer MA, Brenneman SK, Iannotti JP, Williams GR Jr. The Penn shoulder score: reliability and validity. J Orthop Sports Phys Ther 2006;36:138-51. http://dx.doi.org/10.2519/jospt.2006.36.3.138

56. Longo UG, Rizzello G, Berton A, Maltese L, Fumo C, Khan WS, et al. Biological strategies to enhance rotator cuff healing. Curr Stem Cell Res Ther 2013;8:464-70. http://dx.doi.org/10.2174/1574888X113086660065

57. MacDermid JC, Solomon P, Prkachin K. The Shoulder Pain and Disability Index demonstrates factor, construct and longitudinal validity. BMC Musculoskelet Disord 2006;7:12. http://dx.doi.org/10.1186/1471-2474-7-12

58. MacLean S, Khan WS, Malik AA, Snow M, Anand S. Tendon regeneration and repair with stem cells. Stem Cells Int 2012;2012:316281. http://dx.doi.org/10.1155/2012/316281

59. Marx RG, Koulouvaris P, Chu SK, Levy BA. Indications for surgery in clinical outcome studies of rotator cuff repair. Clin Orthop Relat Res 2009;467:450-6. http://dx.doi.org/10.1007%2Fs11999-008-0585-9

60. Mazzocca AD, Millett PJ, Guanche CA, Santangelo SA, Arciero RA. Arthroscopic single-row versus double-row suture anchor rotator cuff repair. Am J Sports Med 2005;33:1861-8. http://dx.doi.org/10.1177/0363546505279575

61. Michener LA, McClure PW, Sennett BJ. American Shoulder and Elbow Surgeons Standardized Shoulder Assessment Form, patient self-report section: reliability, validity, and responsiveness. J Shoulder Elbow Surg 2002;11:587-94. http://dx.doi.org/10.1067/mse.2002.127096

62. Milano GS, Saccomanno MF, Careri S, Taccardo G, De Vitis R, Fabbriciani C. Efficacy of marrow-stimulating technique in arthroscopic rotator cuff repair: a prospective randomized study. Arthroscopy 2013;29:802-10. http://dx.doi.org/10.1016/j.arthro.2013.01.019

63. Min BH, Truong MD, Song HK, Cho JH, Park DY, Kweon HJ, et al. Development and efficacy testing of a "Hollow Awl" that leads to patent bone marrow channels and greater mesenchymal stem cell mobilization during bone marrow stimulation cartilage repair surgery. Arthroscopy 2017;33:2045-51. http://dx.doi.org/10.1016/j.arthro.2017.06.022

64. Mithoefer K, McAdams T, Williams RJ, Kreuz PC, Mandelbaum BR. Clinical efficacy of the microfracture technique for articular cartilage repair in the knee: an evidence-based systematic analysis. Am J Sports Med 2009;37:2053-63. http://dx.doi.org/10.1177/0363546508328414

65. Molloy T, Wang Y, Murrell G. The roles of growth factors in tendon and ligament healing. Sports Med 2003;33:381-94. http://dx.doi.org/10.2165/00007256-200333050-00004

66. Mora MV, Iban MR, Heredia JD, Laakso RB, Cuellar R, Arranz MG. Stem cell therapy in the management of shoulder rotator cuff disorders. World J Stem Cells 2015;7:691-9. http://dx.doi.org/10.4252%2Fwjsc.v7.i4.691

67. Osti L, Del Buono A, Maffulli N. Microfractures at the rotator cuff footprint: a randomised controlled study. Int Orthop 2013;37:2165-71. http://dx.doi.org/10.1007/s00264-013-1952-z

68. Osti L, Papalia R, Paganelli M, Denaro E, Maffulli N. Arthroscopic vs mini-open rotator cuff repair. A quality of life impairment study. Int Orthop 2010;34:389-94. http://dx.doi.org/10.1007/s00264-009-0796-z

69. Pandey V, Bandi A, Madi S, Agarwal L, Acharya KK, Maddukuri S, et al. Does application of moderately concentrated platelet-rich plasma improve clinical and structural outcome after arthroscopic repair of medium-sized to large rotator cuff tear? A randomized controlled trial. J Shoulder Elbow Surg 2016;25:1312-22. http://dx.doi.org/10.1016/j.jse.2016.01.036

70. Randelli P, Margheritini F, Cabitza P, Dogliotti G, Corsi MM. Release of growth factors after arthroscopic acromioplasty. Knee Surg Sports Traumatol Arthrosc 2009;17:98-101. http://dx.doi.org/10.1007/s00167-008-0653-4

71. Rodeo SA. Biologic augmentation of rotator cuff tendon repair. J Shoulder Elbow Surg 2007;16:191-7. http://dx.doi.org/10.1016/j.jse.2007.03.012

72. Saltzman BM, Jain A, Campbell KA, Mascarenhas R, Romeo AA, Verma NN, et al. Does the use of platelet-rich plasma at the time of surgery improve clinical outcomes in arthroscopic rotator cuff repair when compared with control cohorts? A systematic review of meta-analyses. Arthroscopy 2016;32:906-18. http://dx.doi.org/10.1016/j.arthro.2015.10.007

73. Samuelson EM, Odum SM, Fleischli JE. The cost-effectiveness of using platelet-rich plasma during rotator cuff repair: a Markov model analysis. Arthroscopy 2016;32:1237-44. http://dx.doi.org/10.1016/j.arthro.2015.12.018

74. Slabaugh MA, Nho SJ, Grumet RC, Wilson JB, Seroyer ST, Frank RM, et al. Does the literature confirm superior clinical results in radiographically healed rotator cuffs after rotator cuff repair? Arthroscopy 2010;26:393-403. http://dx.doi.org/10.1016/j.arthro.2009.07.023

75. Slim K, Nini E, Forestier D, Kwiatkowshi F, Panis Y, Chipponi J. Methodological Index for Non-Randomized Studies (MINORS): development and validation of a new instrument. ANZ J Surg 2003;73:712-6. http://dx.doi.org/10.1046/j.1445-2197.2003.02748.x

76. Snyder SB. Rotator cuff healing and the bone marrow "Crimson Duvet" from clinical observations to science. Tech Shoulder Elbow Surg 2009;10:130-7. http://dx.doi.org/10.1097/BTE.0b013e3181c2a940

77. Steadman JR, Miller BS, Karas SG, Schlegel TF, Briggs KF, Hawkins RJ. The microfracture technique in the treatment of full-thickness chondral lesions of the knee in National Football League players. J Knee Surg 2003;16:83-6.

78. Sugaya H, Maeda K, Matsuki K, Moriishi J. Repair integrity and functional outcome after arthroscopic double-row rotator cuff repair. A prospective outcome study. J Bone Joint Surg Am 2007;89:953-60. http://dx.doi.org/10.2106/JBJS.F.00512

79. Taniguchi N, Suenaga N, Oizumi N, Miyoshi N, Yamaguchi H, Inoue K, et al. Bone marrow stimulation at the footprint of arthroscopic surface-holding repair advances cuff repair integrity. J Shoulder Elbow Surg 2015;24:860-6. http://dx.doi.org/10.1016/j.jse.2014.09.031

80. Uhthoff H, Trudel G, Himori K. Relevance of pathology and basic research to the surgeon treating rotator cuff disease. J Orthop Res 2003;8:449-56. http://dx.doi.org/10.1007/s10776-002-0624-5

81. Vavken P, Sadoghi P, Palmer M, Rosso C, Mueller AM, Szoelloesy G, et al. Platelet-rich plasma reduces retear rates after arthroscopic repair of small- and medium-sized rotator cuff tears but is not cost-effective. Am J Sports Med 2015;43:3071-6. http://dx.doi.org/10.1177/0363546515572777

82. Wang A, McCann P, Colliver J, Koh E, Ackland T, Joss B, et al. Do postoperative platelet-rich plasma injections accelerate early tendon healing and functional recovery after arthroscopic supraspinatus repair? A randomized controlled trial. Am J Sports Med 2015;43:1430-7. http://dx.doi.org/10.1177/0363546515572602

83. Warner JJ, Tétreault P, Lehtinen J, Zurakowski D. Arthroscopic versus mini-open rotator cuff repair: a cohort comparison study. Arthroscopy 2005;21:328-32. http://dx.doi.org/10.1016/j.arthro.2004.11.006

84. Warth RJ, Dornan GJ, James EW, Horan MP, Millett PJ. Clinical and structural outcomes after arthroscopic repair of full-thickness rotator cuff tears with and without platelet-rich product supplementation: a meta-analysis and meta-regression. Arthroscopy 2015;31:306-20. http://dx.doi.org/10.1016/j.arthro.2014.09.007

85. Wexler SA, Donaldson C, Denning-Kendall P, Rice C, Bradley B, Hows JM. Adult bone marrow is a rich source of human mesenchymal "stem" cells but umbilical cord and mobilized adult blood are not. Br J Haematol 2003;121:368-74. http://dx.doi.org/10.1046/j.1365-2141.2003.04284.x

86. Wolf EM, Pennington WT, Agrawal V. Arthroscopic rotator cuff repair: 4- to 10-year results. Arthroscopy 2004;20:5-12. http://dx.doi.org/10.1016/j.arthro.2003.11.001

87. Yamaguchi K, Ditsios K, Middleton WD, Hildebolt CF, Galatz LM, Teefey SA. The demographic and morphological features of rotator cuff disease a comparison of asymptomatic and symptomatic shoulders. J Bone Joint Surg Am 2006;88:1699-704. http://dx.doi.org/10.2106/JBJS.E.00835

88. Yang J Jr, Robbins M, Reilly J, Maerz T, Anderson K. The clinical effect of a rotator cuff retear: a meta-analysis of arthroscopic single-row and double-row repairs. Am J Sports Med 2017;45:733-41. http://dx.doi.org/10.1177/0363546516652900

89. Yoo JC, Ahn JH, Koh KH, Lim KS. Rotator cuff integrity after arthroscopic repair for large tears with less-than-optimal footprint coverage. Arthroscopy 2009;25:1093-100. http://dx.doi.org/10.1016/j.arthro.2009.07.010

90. Yoon JP, Chung SW, Kim JY, Lee BJ, Kim HS, Kim JE, et al. Outcomes of combined bone marrow stimulation and patch augmentation for massive rotator cuff tears. Am J Sports Med 2016;44:963-71. http://dx.doi.org/10.1177/0363546515625044

91. Zhang Q, Ge H, Zhou J, Cheng B. Are platelet-rich products necessary during the arthroscopic repair of full-thickness rotator cuff tears: a meta-analysis. PLoS One 2013;8:e69731. http://dx.doi.org/10.1371/journal.pone.0069731

92. Zhao JG, Zhao L, Jiang YX, Wang ZL, Wang J, Zhang P. Platelet-rich plasma in arthroscopic rotator cuff repair: a meta-analysis of randomized controlled trials. Arthroscopy 2015;31:125-35. http://dx.doi.org/10.1016/j.arthro.2014.08.008

93. Zingg PO, Jost B, Sukthankar A, Buhler M, Pfirrmann CW, Gerber C. Clinical and structural outcomes of nonoperative management of massive rotator cuff tears. J Bone Joint Surg Am 2007;89:1928-34. http://dx.doi.org/10.2106/JBJS.F.01073

94. Zumstein MA, Jost B, Hempel J, Hodler J, Gerber C. The clinical and structural long-term results of open repair of massive tears of the rotator cuff. J Bone Joint Surg Am 2008;90:2423-31. http://dx.doi.org/10.2106/JBJS.G.00677