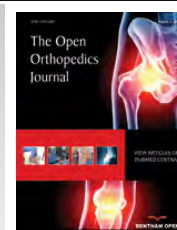




# The Open Orthopaedics Journal

Content list available at: [www.benthamopen.com/TOORTHJ/](http://www.benthamopen.com/TOORTHJ/)

DOI: 10.2174/1874325001610010330



## RESEARCH ARTICLE

# Summary of Meta-Analyses Dealing with Single-Row *versus* Double-Row Repair Techniques for Rotator Cuff Tears

U.J. Spiegl<sup>1,\*</sup>, S.A. Euler<sup>2</sup>, P.J. Millett<sup>3</sup> and P. Hepp<sup>1</sup>

<sup>1</sup>Department of Orthopaedics, Trauma Surgery and Plastic Surgery, University of Leipzig, Germany

<sup>2</sup>Department of Trauma Surgery and Sports Traumatology, Medical University Innsbruck, Austria

<sup>3</sup>The Steadman Clinic, Vail, Colorado, USA

Received: April 12, 2015

Revised: May 16, 2015

Accepted: February 1, 2016

## Abstract:

### Background:

Several meta-analyses of randomized clinical trials have been performed to analyze whether double-row (DR) rotator cuff repair (RCR) provides superior clinical outcomes and structural healing compared to single-row (SR) repair. The purpose of this study was to sum up the results of meta-analysis comparing SR and DR repair with respect on clinical outcomes and re-tear rates.

### Methods:

A literature search was undertaken to identify all meta-analyses dealing with randomized controlled trials comparing clinical and structural outcomes after SR *versus* DR RCR.

### Results:

Eight meta-analyses met the eligibility criteria: two including Level I studies only, five including both Level I and Level II studies, and one including additional Level III studies. Four meta-analyses found no differences between SR and DR RCR for patient outcomes, whereas four favored DR RCR for tears greater than 3 cm. Two meta-analyses found no structural healing differences between SR and DR RCR, whereas six found DR repair to be superior for tears greater than 3 cm tears.

### Conclusion:

No clinical differences are seen between single-row and double-row repair for small and medium rotator cuff tears after a short-term follow-up period with a higher re-tear rate following single-row repairs. There seems to be a trend to superior results with double-row repair in large to massive tear sizes.

**Keywords:** Double-row repair, large tear size, meta-analysis, rotator cuff tear, single-row repair, small tear size, structural healing.

## INTRODUCTION

Rotator cuff tears can be repaired by an open approach, mini-open, or all-arthroscopically. Numerous rotator cuff repair techniques have been reported. The most commonly used techniques are single-row (SR) and double-row (DR) repairs. However, controversy exists about superiority of either one strategy.

DR constructs offered superior results in a biomechanical point of view, including increased mechanical strength, decreased gap formation, increased footprint coverage, and water tight isolation of the healing zone avoiding synovial fluid interaction [1 - 15]. Thus, favorable biomechanical reconstruction can be achieved, improving the healing process

\* Address correspondence to this author at the Department of Orthopaedics, Trauma Surgery and Plastic Surgery, University of Leipzig, 20 04103 Leipzig, Germany; Tel: 0341/97 17105; Fax: 0341/97 17399; E-mail: [uli.spiegl@gmx.de](mailto:uli.spiegl@gmx.de)

and allowing for a more aggressive postoperative shoulder mobilization [1, 3]. In contrast, it is postulated that SR constructs lead to less interaction with the regional blood supply at the healing zone supporting the biologic healing process. Additionally, the implant costs are lower in SR reconstruction techniques [16].

On a clinical point of view, the results comparing outcomes after SR *versus* DR repair have been inconsistent. Whereas some studies report significantly superior results after DR repair with respect to subjective, objective, and radiographic outcomes [17 - 25], several studies have found no differences between both techniques [26 - 36].

There are several meta-analyses available [29, 34, 35, 37 - 41] as well as a recent systematic review [42] dealing with this entity. The purpose of this study was to sum up the results of meta-analyses comparing SR and DR repair with respect on clinical outcomes and re-tear rates.

## METHODS

A literature review was based on a systematic review of the literature using PubMed database, and Cochrane Database. The search was performed using the terms: single-row, double-row, rotator cuff, and meta-analysis [42]. The search was conducted on April 1, 2015. The search was limited to articles written in English or German language. We included all meta-analyses that compared SR and DR rotator-cuff repair techniques excluding studies with Oxman-Guyatt scores of 1 and 2, which are considered to indicate that the studies have “major flaws” [43, 44]. A total of eight studies were included for this study [34, 35, 37 - 41, 45]. They are listed in Table 1. Compared to the systematic review by Mascarenhas *et al.* [42], one study has been included and one study was excluded because of the insufficient Oxman-Guyatt score [45, 46].

**Table 1. Meta-analyses included in this review.**

Studies	Year of publication	Number of patients	Number of primary studies	Level of evidence (primary studies)
Perser <i>et al.</i> [41]	2011	303	5	I - II
Prasathaporn <i>et al.</i> [34]	2011	308	5	I - II
Sheibani-Rad <i>et al.</i> [35]	2013	349	5	I
Chen <i>et al.</i> [39]	2013	476	12	I - III
Zhang <i>et al.</i> [40]	2013	619	8	I - II
Xu <i>et al.</i> [38]	2014	651	9	I - II
Millett <i>et al.</i> [37]	2014	567	7	I
Ying <i>et al.</i> [45]	2014	807	11	I - II
All Studies	2011-2014	1075	13	I - III

The included studies were heterogeneous with respect to both the standardized and non-standardized outcome measures used [42]. A total of six clinical indices were utilized: Constant scores, American Shoulder and Elbow Surgeons (ASES) scores, University of California, Los Angeles (UCLA) scores, Western Ontario Rotator Cuff (WORC) index scores, Disabilities of the Arm, Shoulder and Hand (DASH) scores, and Single Assessment Numeric Evaluation (SANE) scores. Additionally, the studies were heterogeneous with respect to their method analyzing postoperative structural healing rates [42], ranging from complete re-tears, partial re-tears, rates of overall re-tears, and rates of tendon healing.

The study qualities and validities ranged from 12 to 17 based on the QUOROM score, with the maximum possible score being 18, and a medium of 3.5 (range 2-7) [42].

The meta-analyses are summed up including the main message.

## RESULTS

Eight meta-analyses were included in this study (Table 1). The primary studies that have been included in the meta-analyses are listed in Table 2. The summary of all meta-analyses including the authors' conclusion are described in the following section in chronological order of the year of publication.

Perser *et al.* [41] included three Level I [28, 30, 31] and two Level II [18, 48] studies with a total of 303 patients with a mean follow-up of 19.7 months. They were unable to analyze repair results according to tear size or number of anchors, owing to lack of detail in the studies. The authors pointed out that no study was adequately powered to detect a 5-point difference on the Constant, ASES, or Western Ontario Rotator Cuff Index scores or a 2-point difference on the UCLA scale and were unable to support their hypothesis that double-row rotator cuff repair would lead to better clinical

and radiographic results compared with single-row.

Prasathaporn *et al.* [34] reported a meta-analysis of 2 Level I [28, 30, 31] and 3 Level II [19, 48] studies available up until 2009 comparing single- and double-row arthroscopic treatment for rotator cuff tears. They used standardized mean differences to compare clinical (ASES, ZCLA, Constant, SST, SANE, WORC, DASH, pain, patient satisfaction, range of motion, muscle strength, return to pre-injury level of activity, complications) and structural outcomes of above mentioned 5 studies with a total of 308 patients. They reported significantly improved tendon healing and external rotation following double-row repair (relative risk, 1.41; 95% CI, 1.01 to 1.95;  $p = 0.04$ ; mean difference, 2.50; 95% CI, 1.13 to 3.87;  $p = 0.0003$ , respectively). No significant differences were found for functional scores, muscle strength, or adverse events. By means of MRI and Arthro-CT, the re-tear rate was lower in the double-row group, but not significantly. Reported results were derived by evaluating comparable data of at least three studies.

**Table 2. Primary studies included in meta-analyses.**

Primary study	Perser <i>et al.</i> [41]	Prasathaporn <i>et al.</i> [34]	Sheibani-Rad <i>et al.</i> [35]	Chen <i>et al.</i> [39]	Zhang <i>et al.</i> [40]	Xu <i>et al.</i> [38]	Millett <i>et al.</i> [37]	Ying <i>et al.</i> [45]
Sugaya <i>et al.</i> [24]	-	-	-	+	-	-	-	-
Charousset <i>et al.</i> [18]	+	+	-	+	+	+	-	+
Franceschi <i>et al.</i> [30]	+	+	+	+	+	+	+	+
Park <i>et al.</i> [48]	+	+	-	+	+	+	-	+
Grasso <i>et al.</i> [31]	+	+	+	+	+	+	+	+
Burks <i>et al.</i> [28]	+	+	+	+	+	+	+	+
Aydin <i>et al.</i> [26]	-	-	-	+	+	+	-	+
Koh <i>et al.</i> [32]	-	-	+	+	+	+	+	+
Mihata <i>et al.</i> [49]	-	-	-	+	-	-	-	-
Carbonel <i>et al.</i> [19]	-	-	-	+	-	+	+	+
Lapner <i>et al.</i> [22]	-	-	+	+	-	-	+	+
Ma <i>et al.</i> [50]	-	-	-	+	-	+	-	+
Gartsman <i>et al.</i> [51]	-	-	-	-	-	-	+	+

The authors concluded that there was no significant difference regarding improvement in clinical outcome after SR or DR repair. However, there was a significantly higher rate of tendon healing and greater external rotation after DR repair compared to SR repair.

Shabani-Rad *et al.* [35] performed a systematic meta-analysis of 5 Level I studies [22, 28, 30 - 32] available up until 2012 comparing SR and DR arthroscopic treatment for rotator cuff tears in terms of clinical outcome. They found no significant differences in clinical outcomes (ASES, UCLA, Constant) evaluating a total of 349 patients included after a minimum follow-up of 18 months (mean 21.2 months). Analysis for heterogeneity did not show any differences between the studies. Due to incomplete data available, the rate of structural re-tears was not evaluated.

The authors concluded that there were no significant differences in clinical outcomes between the SR and DR RCR in a meta-analysis of Level I studies.

Chen *et al.* [39] included 12 studies in the meta-analysis (Levels I, II, and III) with a total of 476 patients enrolled in level I studies. The mean follow-up ranged from 12 to 34 months. Each study compared the 2 groups and found no statistically significant differences in terms of age, male ratio, dominant extremity, rotator cuff tear size, fatty degeneration, and follow-up. No clinically significant difference could be demonstrated regarding the shoulder function scores. The analysis of 6 Level I randomized controlled trials with a good rating score of 13 to 17, according to the CONSORT checklist [19, 22, 28, 30 - 32] confirmed these findings. Radiographic assessment results for rotator cuff footprint integrity were documented in 5 Level I studies at the final follow-up [19, 22, 28, 30]. The odds of intact healing in a radiographic image were higher in patients treated with double-row repair than in patients treated with single-row repair. A subgroup analysis was performed with 5 articles [19, 24, 47 - 49] studying the outcome in dependence on rotator cuff tear size (tear sizes less than 3 cm and tears greater than 3 cm): A small but statistically significant benefit of double-row repair was observed in the subgroup of tears greater than 3 cm. However, these differences were not clinically significant.

The authors concluded that the repair of rotator cuffs using arthroscopic DR suture anchor techniques has a significantly higher rate of tendon healing, as determined by imaging, than does arthroscopic SR suture anchor techniques. However, this healing has not been universally shown to translate into improved overall clinical function in patients. Thus, DR repair should be used in carefully selected patients.

Zhang *et al.* [40] included 6 level I [19, 22, 30 - 32, 49] and 2 level II [18, 47] studies with a total of 619 patients in the meta-analysis. Minimum follow-up was 2 years (range: 24 – 33.5 months). Clinical outcome measurements were the ASES score, UCLA score, and constant score. Additionally structural outcomes confirming re-tears were analyzed dividing those into full-thickness re-tears, partial thickness re-tears, and cuff integrity. The authors found significantly lower ASES scores and UCLA scores after single-row repair compared with double row repair (mean difference, -0.84; 95% CI, -1.66 to -0.02; mean difference, -0.75; 95% CI, -1.30 to -0.20, respectively). No difference was seen with respect to the constant score. With respect to post-operative rotator cuff integrity, the relative risk of cuff integrity was 20% lower in the SR group (relative risk, 0.81; 95% CI, 0.72 to 0.91;  $p = 0.0004$ ). The relative risk of partial thickness tears was 93% higher in the SR group (relative risk, 1.93; 95% CI, 1.20 to 3.11;  $p = 0.007$ ). No differences were seen for full-thickness tears. A subgroup analysis was performed with 3 articles [19, 47, 49] studying the outcome in dependence on rotator cuff tear size (tear sizes less than 3 cm and tears greater than 3 cm). The authors found significant higher UCLA scores, and ASES scores in the patients with large to massive tears in the DR group (mean difference, -1.17, 95% CI, -0.33 to -2.01; mean difference, -1.95; 95% CI, -3.14 to -0.76, respectively), whereas no differences were seen in those patients with small to medium tear sizes.

The authors concluded that the DR fixation technique increases the post-operative rotator cuff integrity and improves the clinical outcomes, especially for tear sizes greater than 3 cm. For tear sizes less than 3 cm, there was no difference in clinical outcomes between the two techniques.

Xu *et al.* [38] included 5 level I [19, 28, 30 - 32] and 4 level II [18, 26, 47, 49] studies with a total of 651 patients. The mean follow-up time ranged from 12 to 34 months. Clinical outcome measurements were the ASES score, UCLA score, constant score, range of motion (ROM) of the shoulder, and muscle strength. Additionally structural outcomes confirming re-tears were analyzed. The authors found significantly higher ASES scores in the DR group (mean difference, 1.22; 95% CI, 0.39 to 2.05), a statistically significant difference in the re-tear rate, favoring DR repairs (risk ratio, 0.59; 95% CI, 0.41 to 0.86), and significantly higher internal rotation in the DR patients (mean difference, 1.64; 95% CI, 1.00 to 2.29). No further significant differences were seen. A subgroup analysis was performed with 3 articles [19, 47, 49] studying the outcome in dependence on rotator cuff tear size (tear sizes less than 3 cm and tears greater than 3 cm). The authors found significant higher UCLA scores, and ASES scores in the patients with large to massive tears in the DR group (mean difference, -1.48, 95% CI, -0.44 to -2.51; mean difference, 2.08; 95% CI, 0.84 to 3.32, respectively), whereas no differences were seen in those patients with small to medium tear sizes.

The authors concluded that some of the outcome measurements showed significantly better results after DR repair, whereas others could not find significant differences. However, larger tears ( $> 3$  cm) show statistically significant improved functional outcomes with DR repairs.

Millett *et al.* [37] included level I studies only. A total of 7 studies were included [19, 22, 28, 30 - 32, 50] with a total of 567 patients and a mean follow-up of 23.2 months. Clinical outcome measurements were the ASES score, UCLA score, and the constant score. Additionally structural outcomes confirming re-tears were analyzed. No significant differences were seen in preoperative and postoperative change in all clinical scores between the SR and DR groups. However, there was a statistically significant increased risk of imaging-proven re-tears in the SR group (relative risk, 1.76, 95% CI, 1.25 to 2.48;  $p = 0.001$ ).

The authors concluded that SR repairs resulted in a significantly higher re-tear rate compared with DR re-tears. However, there were no statistically significant differences in outcome scores between SR and DR repairs.

Ying *et al.* [45] included 7 level I [19, 22, 28, 30 - 32, 50] and 4 level II [18, 26, 47, 49] studies with a total of 807 patients in the meta-analysis. The mean follow-up time was 24.7 months (range 12 to 36 months). Clinical outcome measurements were the ASES score, UCLA score, constant score, shoulder muscle strength, range of motion, surgical time, and patient satisfaction. Additionally structural outcomes confirming re-tears were analyzed. No statistically significant and clinically relevant difference was seen in clinical outcome scores, muscle strength, tendon healing, and patient satisfaction. Operative time was significantly longer for DR repair than SR repair (standard mean difference, 17.65; 95% CI, 8.89 to 26.42;  $p < 0.05$ ). Additionally, UCLA scores at final follow-up were in favor of DR repair. However, the differences were not clinically relevant. A subgroup analysis was performed with 3 articles [19, 47, 49] studying the outcome in large rotator cuff tears (tears greater than 3 cm). A small statistically significant benefit of DR repair was observed in the subgroup of tears greater than 3 cm concerning the UCLA score and the external rotation shoulder strength index (mean difference, 1.17; 95% CI, 0.33 to 2.01;  $p = 0.006$ ; mean difference, 0.02; 95% CI, 0.00 to 0.03;  $p = 0.03$ , respectively).

The authors concluded that based on the paucity of high-quality evidence it is difficult to reach definitive recommendations. No definite conclusion could be drawn about differences in the overall outcome of DR and SR techniques for repairing small and medium (< 3cm) or large to massive (> 3cm) rotator cuff tears, even though some measures of clinical outcome showed significant differences between both techniques.

The conclusions of all 8 meta-analyses are summarized in Table 3.

**Table 3. Main conclusion of the meta-analyses.**

Primary studies	Conclusion: Statistically significant differences between SR and DR repair		
	Clinical Outcome in small to moderate tears (< 3 cm)	Clinical Outcome in large to massive tears (> 3 cm)	Structural healing
Perser <i>et al.</i>	No difference		No difference
Prasathaporn <i>et al.</i>	No difference		DR: Superior SH
Sheibani-Rad <i>et al.</i>	No difference		Not evaluated
Chen <i>et al.</i>	No difference	DR: Higher UCLA/ASES	DR: Superior SH
Zhang <i>et al.</i>	No difference	DR: Higher UCLA/ASES	DR: Superior SH
Xu <i>et al.</i>	No difference	DR: Higher UCLA/ASES	DR: Superior SH
Millett <i>et al.</i>	No difference		DR: Superior SH
Ying <i>et al.</i>	No difference	DR: Higher UCLA/ASES	DR: Superior SH

SR: Single-row; DR: Double-row; SH: Structural healing

## DISCUSSION

The majority of the studies have shown a higher re-tear rate after SR repair. However, the superior tendon healing after DR repair did not correlate with improved overall clinical shoulder function. Overall, no clinical differences were seen after a follow-up ranging from 12 to 36 months. In contrast, some measures of clinical outcomes showed superior results in patients with large or massive tears, treated by DR repair compared to a SR technique.

Mascarenhas *et al.* [42] performed a systemic review of overlapping meta-analysis in 2014 and included 8 meta-analyses [29, 34, 35, 37 - 41]. In contrast to their study, we excluded the study by DeHaan *et al.* [29] because of the low Oxman-Guyatt score of 2 and included the study by Ying *et al.* [45] which was published afterwards. Similarly, Mascarenhas *et al.* [42] concluded that DR RCR results in higher rates of structural healing. However, the authors asked for further cost-effectiveness research to examine whether the superior structural healing following DR repair are still significant when accounting for the higher implant costs and longer operating time. Additionally, the beneficial effect of tissue compression on rotator cuff tears and clinical healing must be delineated more clearly.

Similarly, the latest meta-analysis by Ying *et al.* [45], who included a total of 11 studies with 807 patients found no clinically relevant differences between SR und DR repairs. However, by performing a subgroup analysis studying the effect of tear size, a small statistically significant benefit of DR repair was observed in patients with tears greater than 3 cm.

Generally, the primary interest after rotator cuff repair is to improve shoulder function and patients' well-being. Lower healing rates are of no concerns if they do not affect the outcome negatively. Thus, SR repair would be the preferred treatment strategy, especially in small and medium tears, based on the lower costs and faster operating time. Notwithstanding, it is surprising that the healing rate does not affect the outcome considerably. There are mainly two rational reasons, which could explain the lack of clinical differences in patients with re-tears compared to those with cuff integrity. First of all, the follow-up period was assessed too short. Even though the majority of the primary re-tears occur between six and twenty-six weeks after arthroscopic rotator cuff repair [51], some evidence exist that rotator cuff tears can remain asymptomatic for several years until they become apparent. Mall *et al.* [52] analyzed 195 patients with asymptomatic rotator cuff tears. Only 23% of those patients became symptomatic after a period of 2 years. In addition, Yamaguchi *et al.* [53] studied 45 patients with asymptomatic rotator cuff tears and found that about half of the patients (51%) became symptomatic after a mean of 2.8 years. Similarly, Moosmayer *et al.* [54] observed 50 patients with asymptomatic rotator cuff tears over a period of 3 years. Eighteen of those (36%) developed symptoms during this time span. The mean follow-up of all meta-analyses ranged from 19.7 to 27.1 months. Thus, it is possible that the gradual transformation to clinically symptomatic rotator cuff tears may take a longer time. Thus a considerable number of patients with re-tears may have not developed relevant symptoms at the time when these studies ended. Additionally, there might be a lack of sufficient shoulder scores. Lubiawski *et al.* [55] analyzed 111 patients after an average of 40 months after rotator cuff repair. They found cuff integrity in 74%, complete re-tears in 16% and partial re-tears in 10%

of the patients. The authors found no significant differences in the shoulder scores (ASES, UCLA, VAS, ROM) related to the quality of healing. In contrast, there was a difference using isokinetic tests. They observed 29–43 % deficits in peak external rotation torque and a reduced ability to generate shoulder power (40–43%) comparing complete re-tears *versus* full cuff integrity. Additionally, higher loads could be withstood (34–55%) in patients with full cuff integrity compared to patients with complete re-tears. Partial re-tears did not have a negative impact on the biomechanical properties of shoulders. According to these results, there are quantifiable clinical differences in the shoulder function between healed or re-torn rotator cuffs. However, these differences do not seem to affect standard clinical shoulder scores.

There are several limitations to be noted. First of all, this study is no meta-analysis what has to be considered. Next, the conclusions that are done are based on the quality of the original articles that have been analyzed. There are limitations and biases inherent to each study in this review that may have skewed the results. Secondly, due to the potential for publication bias it cannot be ruled out there exists unpublished data, which are not published based on undesirable results.

## CONCLUSION

No clinical differences are seen between SR and DR repair for small and medium rotator cuff tears after a short-term follow-up period with a higher re-tear rate following SR repairs. There seems to be a trend to superior results with DR repair in large to massive tear sizes. However, further randomized-controlled trials with a follow-up of five years or longer using advanced shoulder tests are warranted to understand, which patient might benefit from the more cost-intensive and more technically demanding DR technique.

## LIST OF ABBREVIATIONS

<b>ASES score</b>	=	American shoulder and elbow surgeons score
<b>CI</b>	=	Confidence interval
<b>CT</b>	=	Computer tomography
<b>DASH</b>	=	Disabilities of the arm, shoulder and hand
<b>DR</b>	=	Double-row
<b>MRI</b>	=	Magnetic resonance imaging
<b>RCR</b>	=	Rotator cuff repair
<b>ROM</b>	=	Range of motion
<b>SR</b>	=	Single-row
<b>UCLA score</b>	=	University of California, Los Angeles score
<b>VAS</b>	=	Visual analogue scale
<b>WORC index score</b>	=	Western Ontario rotator cuff index scores

## CONFLICT OF INTEREST

U.J.S. and S.A.E. were sponsored by Arthrex. P.J.M. is a consultant for Arthrex and holds stock options with GameReady and VuMedi.

## ACKNOWLEDGEMENTS

The authors have not received grant support or research funding and have no proprietary interests in the materials described in the article.

## REFERENCES

- [1] Baums MH, Buchhorn GH, Spahn G, Poppendieck B, Schultz W, Klinger HM. Biomechanical characteristics of single-row repair in comparison to double-row repair with consideration of the suture configuration and suture material. *Knee Surg Sports Traumatol Arthrosc* 2008; 16(11): 1052-60. [http://dx.doi.org/10.1007/s00167-008-0590-2] [PMID: 18758750]
- [2] Klinger HM, Steckel H, Spahn G, Buchhorn GH, Baums MH. Biomechanical comparison of double-loaded suture anchors using arthroscopic Mason-Allen stitches *versus* traditional transosseous suture technique and modified Mason-Allen stitches for rotator cuff repair. *Clin Biomech (Bristol, Avon)* 2007; 22(1): 106-11. [http://dx.doi.org/10.1016/j.clinbiomech.2006.07.009] [PMID: 16996666]

- [3] Burkhart SS, Adams CR, Burkhart SS, Schoolfield JD. A biomechanical comparison of 2 techniques of footprint reconstruction for rotator cuff repair: the SwiveLock-FiberChain construct *versus* standard double-row repair. *Arthroscopy* 2009; 25(3): 274-81. [<http://dx.doi.org/10.1016/j.arthro.2008.09.024>] [PMID: 19245990]
- [4] Kim DH, Elattrache NS, Tibone JE, *et al.* Biomechanical comparison of a single-row *versus* double-row suture anchor technique for rotator cuff repair. *Am J Sports Med* 2006; 34(3): 407-14. [<http://dx.doi.org/10.1177/0363546505281238>] [PMID: 16282581]
- [5] Lorbach O, Kieb M, Raber F, Busch LC, Kohn D, Pape D. Comparable biomechanical results for a modified single-row rotator cuff reconstruction using triple-loaded suture anchors *versus* a suture-bridging double-row repair. *Arthroscopy* 2012; 28(2): 178-87. [<http://dx.doi.org/10.1016/j.arthro.2011.08.298>] [PMID: 22112611]
- [6] Ma CB, Comerford L, Wilson J, Puttlitz CM. Biomechanical evaluation of arthroscopic rotator cuff repairs: double-row compared with single-row fixation. *J Bone Joint Surg Am* 2006; 88(2): 403-10. [<http://dx.doi.org/10.2106/JBJS.D.02887>] [PMID: 16452754]
- [7] 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(12): 1861-8. [<http://dx.doi.org/10.1177/0363546505279575>] [PMID: 16210578]
- [8] Meier SW, Meier JD. The effect of double-row fixation on initial repair strength in rotator cuff repair: a biomechanical study. *Arthroscopy* 2006; 22(11): 1168-73. [<http://dx.doi.org/10.1016/j.arthro.2006.07.004>] [PMID: 17084292]
- [9] Milano G, Grasso A, Zarelli D, Deriu L, Cillo M, Fabbriani C. Comparison between single-row and double-row rotator cuff repair: a biomechanical study. *Knee Surg Sports Traumatol Arthrosc* 2008; 16(1): 75-80. [<http://dx.doi.org/10.1007/s00167-007-0382-0>] [PMID: 17684730]
- [10] Nassos JT, ElAttrache NS, Angel MJ, Tibone JE, Limpisvasti O, Lee TQ. A watertight construct in arthroscopic rotator cuff repair. *J Shoulder Elbow Surg* 2012; 21(5): 589-96. [<http://dx.doi.org/10.1016/j.jse.2011.04.008>]
- [11] Nelson CO, Sileo MJ, Grossman MG, Serra-Hsu F. Single-row modified mason-allen *versus* double-row arthroscopic rotator cuff repair: a biomechanical and surface area comparison. *Arthroscopy* 2008; 24(8): 941-8. [<http://dx.doi.org/10.1016/j.arthro.2008.03.011>] [PMID: 18657744]
- [12] Smith CD, Alexander S, Hill AM, *et al.* A biomechanical comparison of single and double-row fixation in arthroscopic rotator cuff repair. *J Bone Joint Surg Am* 2006; 88(11): 2425-31. [<http://dx.doi.org/10.2106/JBJS.E.00697>] [PMID: 17079400]
- [13] Tuoheti Y, Itoi E, Yamamoto N, *et al.* Contact area, contact pressure, and pressure patterns of the tendon-bone interface after rotator cuff repair. *Am J Sports Med* 2005; 33(12): 1869-74. [<http://dx.doi.org/10.1177/0363546505278256>] [PMID: 16157853]
- [14] van der Meijden OA, Wijdicks CA, Gaskill TR, Jansson KS, Millett PJ. Biomechanical analysis of two-tendon posterosuperior rotator cuff tear repairs: extended linked repairs and augmented repairs. *Arthroscopy* 2013; 29(1): 37-45. [<http://dx.doi.org/10.1016/j.arthro.2012.07.012>] [PMID: 23276412]
- [15] Baums MH, Schminke B, Posmyk A, Miosge N, Klinger HM, Lakemeier S. Effect of single- and double-row rotator cuff repair at the tendon-to-bone interface: preliminary results using an in vivo sheep model. *Arch Orthop Trauma Surg* 2015; 135(1): 111-8. [<http://dx.doi.org/10.1007/s00402-014-2118-1>] [PMID: 25416099]
- [16] Bisson L, Zivaljevic N, Sanders S, Pula D. A cost analysis of single-row *versus* double-row and suture bridge rotator cuff repair methods. *Knee Surg Sports Traumatol Arthrosc* 2015; 23(2): 487-93. [<http://dx.doi.org/10.1007/s00167-012-2338-2>] [PMID: 23229385]
- [17] Brady PC, Arrigoni P, Burkhart SS. Evaluation of residual rotator cuff defects after *in vivo* single- *versus* double-row rotator cuff repairs. *Arthroscopy* 2006; 22(10): 1070-5. [<http://dx.doi.org/10.1016/j.arthro.2006.05.007>] [PMID: 17027404]
- [18] 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(8): 1247-53. [<http://dx.doi.org/10.1177/0363546507301661>] [PMID: 17452513]
- [19] Carbonel I, Martinez AA, Calvo A, Ripalda J, Herrera A. Single-row *versus* double-row arthroscopic repair in the treatment of rotator cuff tears: a prospective randomized clinical study. *Int Orthop* 2012; 36(9): 1877-83. [<http://dx.doi.org/10.1007/s00264-012-1559-9>] [PMID: 22584619]
- [20] Denard PJ, Jiwani AZ, Lädermann A, Burkhart SS. Long-term outcome of arthroscopic massive rotator cuff repair: the importance of double-row fixation. *Arthroscopy* 2012; 28(7): 909-15. [<http://dx.doi.org/10.1016/j.arthro.2011.12.007>] [PMID: 22365267]
- [21] 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(4): 835-41. [<http://dx.doi.org/10.1177/0363546509359679>] [PMID: 20357403]

- [22] Lapner PL, Sabri E, Rakhra K, *et al.* A multicenter randomized controlled trial comparing single-row with double-row fixation in arthroscopic rotator cuff repair. *J Bone Joint Surg Am* 2012; 94(14): 1249-57. [<http://dx.doi.org/10.2106/JBJS.K.00999>] [PMID: 22810395]
- [23] Mahar A, Tamborlane J, Oka R, Esch J, Pedowitz RA. Single-row suture anchor repair of the rotator cuff is biomechanically equivalent to double-row repair in a bovine model. *Arthroscopy* 2007; 23(12): 1265-70. [<http://dx.doi.org/10.1016/j.arthro.2007.07.010>] [PMID: 18063168]
- [24] Sugaya H, Maeda K, Matsuki K, Moriishi J. Functional and structural outcome after arthroscopic full-thickness rotator cuff repair: single-row versus dual-row fixation. *Arthroscopy* 2005; 21(11): 1307-16. [<http://dx.doi.org/10.1016/j.arthro.2005.08.011>] [PMID: 16325080]
- [25] Tudisco C, Bisicchia S, Savarese E, *et al.* Single-row vs. double-row arthroscopic rotator cuff repair: clinical and 3 Tesla MR arthrography results. *BMC Musculoskelet Disord* 2013; 14: 43. [<http://dx.doi.org/10.1186/1471-2474-14-43>] [PMID: 23351978]
- [26] Aydin N, Kocaoglu B, Guven O. Single-row versus double-row arthroscopic rotator cuff repair in small- to medium-sized tears. *J Shoulder Elbow Surg* 2010; 19(5): 722-5.
- [27] Buess E, Waibl B, Vogel R, Seidner R. A comparative clinical evaluation of arthroscopic single-row versus double-row supraspinatus tendon repair. *Acta Orthop Belg* 2009; 75(5): 588-94. [PMID: 19999868]
- [28] Burks RT, Crim J, Brown N, Fink B, Greis PE. A prospective randomized clinical trial comparing arthroscopic single- and double-row rotator cuff repair: magnetic resonance imaging and early clinical evaluation. *Am J Sports Med* 2009; 37(4): 674-82. [<http://dx.doi.org/10.1177/0363546508328115>] [PMID: 19204365]
- [29] DeHaan AM, Axelrad TW, Kaye E, Silvestri L, Puskas B, Foster TE. Does double-row rotator cuff repair improve functional outcome of patients compared with single-row technique? A systematic review. *Am J Sports Med* 2012; 40(5): 1176-85. [<http://dx.doi.org/10.1177/0363546511428866>] [PMID: 22156169]
- [30] Franceschi F, Ruzzini L, Longo UG, *et al.* Equivalent clinical results of arthroscopic single-row and double-row suture anchor repair for rotator cuff tears: a randomized controlled trial. *Am J Sports Med* 2007; 35(8): 1254-60. [<http://dx.doi.org/10.1177/0363546507302218>] [PMID: 17554104]
- [31] Grasso A, Milano G, Salvatore M, Falcone G, Deriu L, Fabbriani C. Single-row versus double-row arthroscopic rotator cuff repair: a prospective randomized clinical study. *Arthroscopy* 2009; 25(1): 4-12. [<http://dx.doi.org/10.1016/j.arthro.2008.09.018>] [PMID: 19111212]
- [32] Koh KH, Kang KC, Lim TK, Shon MS, Yoo JC. Prospective randomized clinical trial of single- versus double-row suture anchor repair in 2- to 4-cm rotator cuff tears: clinical and magnetic resonance imaging results. *Arthroscopy* 2011; 27(4): 453-62. [<http://dx.doi.org/10.1016/j.arthro.2010.11.059>] [PMID: 21444007]
- [33] Nho SJ, Slabaugh MA, Seroyer ST, *et al.* Does the literature support double-row suture anchor fixation for arthroscopic rotator cuff repair? A systematic review comparing double-row and single-row suture anchor configuration. *Arthroscopy* 2009; 25(11): 1319-28. [<http://dx.doi.org/10.1016/j.arthro.2009.02.005>] [PMID: 19896055]
- [34] Prasathaporn N, Kuptniratsaikul S, Kongruekreatiyos K. Single-row repair versus double-row repair of full-thickness rotator cuff tears. *Arthroscopy* 2011; 27(7): 978-85. [<http://dx.doi.org/10.1016/j.arthro.2011.01.014>] [PMID: 21693349]
- [35] Sheibani-Rad S, Giveans MR, Arnoczky SP, Bedi A. Arthroscopic single-row versus double-row rotator cuff repair: a meta-analysis of the randomized clinical trials. *Arthroscopy* 2013; 29(2): 343-8. [<http://dx.doi.org/10.1016/j.arthro.2012.11.019>] [PMID: 23369480]
- [36] Wall LB, Keener JD, Brophy RH. Clinical outcomes of double-row versus single-row rotator cuff repairs. *Arthroscopy* 2009; 25(11): 1312-8. [<http://dx.doi.org/10.1016/j.arthro.2009.08.009>] [PMID: 19896054]
- [37] Millett PJ, Warth RJ, Dornan GJ, Lee JT, Spiegl UJ. Clinical and structural outcomes after arthroscopic single-row versus double-row rotator cuff repair: a systematic review and meta-analysis of level I randomized clinical trials. *J Shoulder Elbow Surg* 2014; 23(4): 586-97. [<http://dx.doi.org/10.1016/j.jse.2013.10.006>]
- [38] Xu C, Zhao J, Li D. Meta-analysis comparing single-row and double-row repair techniques in the arthroscopic treatment of rotator cuff tears. *J Shoulder Elbow Surg* 2014; 23(2): 182-8. [<http://dx.doi.org/10.1016/j.jse.2013.08.005>]
- [39] Chen M, Xu W, Dong Q, Huang Q, Xie Z, Mao Y. Outcomes of single-row versus double-row arthroscopic rotator cuff repair: a systematic review and meta-analysis of current evidence. *Arthroscopy* 2013; 29(8): 1437-49. [<http://dx.doi.org/10.1016/j.arthro.2013.03.076>] [PMID: 23711754]
- [40] Zhang Q, Ge H, Zhou J, Yuan C, Chen K, Cheng B. Single-row or double-row fixation technique for full-thickness rotator cuff tears: a meta-analysis. *PLoS One* 2013; 8(7): e68515. [<http://dx.doi.org/10.1371/journal.pone.0068515>] [PMID: 23874649]
- [41] Perser K, Godfrey D, Bisson L. Meta-analysis of clinical and radiographic outcomes after arthroscopic single-row versus double-row rotator cuff repair. *Sports Health* 2011; 3(3): 268-74.



- [http://dx.doi.org/10.1177/1941738111403106] [PMID: 23016017]
- [42] Mascarenhas R, Chalmers PN, Sayegh ET, *et al.* Is double-row rotator cuff repair clinically superior to single-row rotator cuff repair: a systematic review of overlapping meta-analyses. *Arthroscopy* 2014; 30(9): 1156-65. [http://dx.doi.org/10.1016/j.arthro.2014.03.015] [PMID: 24821226]
- [43] Oxman AD, Guyatt GH. Validation of an index of the quality of review articles. *J Clin Epidemiol* 1991; 44(11): 1271-8. [http://dx.doi.org/10.1016/0895-4356(91)90160-B] [PMID: 1834807]
- [44] Poolman RW, Abouali JA, Conter HJ, Bhandari M. Overlapping systematic reviews of anterior cruciate ligament reconstruction comparing hamstring autograft with bone-patellar tendon-bone autograft: why are they different? *J Bone Joint Surg Am* 2007; 89(7): 1542-52. [http://dx.doi.org/10.2106/JBJS.F.01292] [PMID: 17606794]
- [45] Ying ZM, Lin T, Yan SG. Arthroscopic single-row *versus* double-row technique for repairing rotator cuff tears: a systematic review and meta-analysis. *Orthop Surg* 2014; 6(4): 300-12. [http://dx.doi.org/10.1111/os.12139] [PMID: 25430714]
- [46] Brown MJ, Pula DA, Kluczynski MA, Mashtare T, Bisson LJ. Does suture technique affect re-rupture in arthroscopic rotator cuff repair? A meta-analysis. *Arthroscopy* 2015; 31(8): 1576-82. [Epub ahead of print]. [http://dx.doi.org/10.1016/j.arthro.2015.02.004] [PMID: 25828166]
- [47] Park JY, Lhee SH, Choi JH, Park HK, Yu JW, Seo JB. Comparison of the clinical outcomes of single- and double-row repairs in rotator cuff tears. *Am J Sports Med* 2008; 36(7): 1310-6. [http://dx.doi.org/10.1177/0363546508315039] [PMID: 18413680]
- [48] Mihata T, Watanabe C, Fukunishi K, *et al.* Functional and structural outcomes of single-row *versus* double-row *versus* combined double-row and suture-bridge repair for rotator cuff tears. *Am J Sports Med* 2011; 39(10): 2091-8. [http://dx.doi.org/10.1177/0363546511415660] [PMID: 21785001]
- [49] Ma HL, Chiang ER, Wu HT, *et al.* Clinical outcome and imaging of arthroscopic single-row and double-row rotator cuff repair: a prospective randomized trial. *Arthroscopy* 2012; 28(1): 16-24. [http://dx.doi.org/10.1016/j.arthro.2011.07.003] [PMID: 21982391]
- [50] Gartsman GM, Drake G, Edwards TB, *et al.* Ultrasound evaluation of arthroscopic full-thickness supraspinatus rotator cuff repair: single-row *versus* double-row suture bridge (transosseous equivalent) fixation. Results of a prospective, randomized study. *J Shoulder Elbow Surg* 2013; 22(11): 1480-7.
- [51] Iannotti JP, Deutsch A, Green A, *et al.* Time to failure after rotator cuff repair: a prospective imaging study. *J Bone Joint Surg Am* 2013; 95(11): 965-71. [http://dx.doi.org/10.2106/JBJS.L.00708] [PMID: 23780533]
- [52] Mall NA, Kim HM, Keener JD, *et al.* Symptomatic progression of asymptomatic rotator cuff tears: a prospective study of clinical and sonographic variables. *J Bone Joint Surg Am* 2010; 92(16): 2623-33. [http://dx.doi.org/10.2106/JBJS.I.00506] [PMID: 21084574]
- [53] Yamaguchi K, Tetro AM, Blam O, Evanoff BA, Teefey SA, Middleton WD. Natural history of asymptomatic rotator cuff tears: a longitudinal analysis of asymptomatic tears detected sonographically. *J Shoulder Elbow Surg* 2001; 10(3): 199-203. [http://dx.doi.org/10.1067/mse.2001.113086]
- [54] Moosmayer S, Tariq R, Stiris M, Smith HJ. The natural history of asymptomatic rotator cuff tears: a three-year follow-up of fifty cases. *J Bone Joint Surg Am* 2013; 95(14): 1249-55. [http://dx.doi.org/10.2106/JBJS.L.00185] [PMID: 23864172]
- [55] Lubiawski P, Kaczmarek P, Dzianach M, *et al.* Clinical and biomechanical performance of patients with failed rotator cuff repair. *Int Orthop* 2013; 37(12): 2395-401. [http://dx.doi.org/10.1007/s00264-013-2024-0] [PMID: 23948981]