Arthroscopic Single-Row Versus Double-Row Suture Bridge Technique for Rotator Cuff Tears in Patients Younger Than 55 Years

A Prospective Comparative Study

Michael E. Hantes,*† MD, Yohei Ono,‡ MD, Vasilios A. Raoulis,† MD, Nikolaos Doxariotis,† MD, Aaron Venouziou,† MD, Aristidis Zibis,† MD, and Marianna Vlychou,§ MD

Investigation performed at the Department of Orthopaedics and Department of Radiology, University Hospital of Larissa, University of Thessalia, Larissa, Greece

Background: When arthroscopic rotator cuff repair is performed on a young patient, long-lasting structural and functional tendon integrity is desired. A fixation technique that potentially provides superior tendon healing should be considered for the younger population to achieve long-term clinical success.

Hypothesis/Purpose: The purpose was to compare the radiological and clinical midterm results between single-row and double-row (ie, suture bridge) fixation techniques for arthroscopic rotator cuff repair in patients younger than 55 years. We hypothesized that a double-row technique would lead to improved tendon healing, resulting in superior mid- to long-term clinical outcomes.

Study Design: Cohort study; Level of evidence, 2.

Methods: A consecutive series of 66 patients younger than 55 years with a medium to large full-thickness tear of supraspinatus and infraspinatus tendons who underwent arthroscopic single-row or double-row (ie, suture bridge) repair were enrolled and prospectively observed. Thirty-four and 32 patients were assigned to single-row and double-row groups, respectively. Postoperatively, tendon integrity was assessed by MRI following Sugaya's classification at a minimum of 12 months, and clinical outcomes were assessed with the Constant score and the University of California, Los Angeles (UCLA) score at a minimum of 2 years.

Results: Mean follow-up time was 46 months (range, 28-50 months). A higher tendon healing rate was obtained in the double-row group compared with the single-row group (84% and 61%, respectively [$P < .05$]). Although no difference in outcome scores was observed between the 2 techniques, patients with healed tendon demonstrated superior clinical outcomes compared with patients who had retorn tendon (UCLA score, 34.2 and 27.6, respectively [$P < .05$]; Constant score, 94 and 76, respectively [$P < .05$]).

Conclusion: The double-row repair technique potentially provides superior tendon healing compared with the single-row technique. Double-row repair should be considered for patients younger than 55 years with medium to large rotator cuff tears.

Keywords: shoulder; rotator cuff repair; single row; double row; tendon healing; arthroscopy; young population

Surgically repaired rotator cuffs are subject to greater demands, in terms of long-lasting functional improvement, in the younger population compared with the elderly population. Since patients typically desire early return to their occupational and sport activities, surgical treatment is often chosen before patients have exhausted all of the nonoperative treatment options. When a young patient undergoes surgical repair, tendon healing is extremely important to maintain structural and functional integrity of the repaired rotator cuff over time. To our knowledge, however, no study has demonstrated long-term results regarding tendon integrity and clinical outcomes after arthroscopic rotator cuff repair in the younger population.

*Address correspondence to Michael E. Hantes, MD, Department of Orthopaedic Surgery, Faculty of Medicine, School of Health Sciences, University of Thessalia, Mezourlo, 41110 Larisa, Greece (email: hantesmi@otenet.gr).

†Department of Orthopaedic Surgery, Faculty of Medicine, School of Health Sciences, University of Thessalia, Larissa, Greece.

‡Department of Orthopedic Surgery, Nagoya University Graduate School of Medicine, Nagoya, Japan.

§Department of Radiology, Faculty of Medicine, School of Health Sciences, University of Thessalia, Larissa, Greece.

The authors declared that they have no conflicts of interest in the authorship and publication of this contribution.

The American Journal of Sports Medicine, Vol. XX, No. X
DOI: 10.1177/0363546517728718

Despite the remarkable evolution of arthroscopic rotator cuff repair over the past 2 decades, the retear rate is still unacceptably high: from 15% for smaller tears up to 90% for massive tears.[8,14,15,18,20] Tear recurrence is strongly associated with the quality of the repair and the applied technique, and therefore improvement of surgical repair constructs is essential.[18,19,27,34,37,39,40] The double-row technique, including the suture bridge (ie, transosseous equivalent) technique, has been reported in many clinical studies as an alternative to classic single-row techniques, and reports indicate that the double-row technique typically provides improved postoperative tendon integrity.[11,12,19,26,27,29,35,36,39] These results were supported by biomechanical evidence of superior features of the double-row technique, such as a larger footprint area, improved initial strength and stiffness, and decreased gap formation and strain,[21,24,25] and even superior pressurized contact area and ultimate failure loads were noted specifically in suture bridge constructs.[30,31] Restoration of both anatomic and mechanical native rotator cuff footprint theoretically increases the healing potential of the repair.[21,24,25,30,31] However, the controversy over single-row versus double-row techniques continues, given little evidence of superior clinical outcomes with double-row repair, despite improved tendon healing.[3,39]

Currently, tendon integrity and clinical outcomes after arthroscopic rotator cuff repair are subjects of disagreement, on the basis of the cumulative clinical evidence comparing single-row and double-row techniques.[27,34] However, while only short-term outcomes are available for arthroscopic rotator cuff repair, likely due to its novelty,[2,14,26,40] several studies of open rotator cuff repair correlated postoperative tendon integrity with functional outcomes at mid- to long-term follow-up.[1,15,18,22,38,41] We believe this correlation should hold for arthroscopic repair as well, if followed up longer, which is particularly relevant for younger patients who are in need of long-lasting structural and functional integrity.

The purpose of this prospective study was to compare the radiological and clinical midterm results between single-row and double-row (ie, suture bridge) fixation techniques for arthroscopic rotator cuff repair in patients younger than 55 years. We hypothesized that a double-row technique would lead to improved tendon healing, eventually resulting in superior mid- to long-term clinical outcomes.

METHODS

Study Design

This is a nonrandomized, prospective comparative study of arthroscopic single-row versus double-row repair of rotator cuff tear in patients younger than 55 years. To participate in the study, all patients signed an informed consent form approved by the institutional review board.

Patient Enrollment

All patients seen for the treatment of rotator cuff tear in our department from February 2006 to June 2010 were asked to enroll in the study. If the patient was willing to participate in the study, standard radiographs, including anteroposterior, axillary, and supraspinatus outlet views, and plain magnetic resonance imaging (MRI) of the affected shoulder were routinely performed. The inclusion criteria were (1) age less than 55 years; (2) presence of a medium to large, full-thickness tear (ie, tear size 1-5 cm in any dimension)[5] of the supraspinatus and infraspinatus on MRI; (3) failed nonoperative treatment for at least 3 months; and (4) decision for surgical repair made after thorough discussion with patient and family. Diagnosis was confirmed by the senior author (M.E.H.) on the basis of patient history, physical examination, and imaging studies (ie, standard radiography, MRI). Excluded from the study were patients with massive tears (ie, tear size >5 cm), full-thickness subscapularis tear requiring a repair (determined from physical examination and MRI), pseudoparalysis,[7] radiographic findings of proximal humeral migration and cuff tear arthropathy (Hamada grade ≥2),[17] and stage 3 to 4 fatty degeneration following the criteria established by Goutallier et al[16] and adapted for MRI by Fuchs et al.[13] We excluded massive rotator cuff tears since we believe that the medial row creates tension overload to the musculotendinous junction (in double-row repair) and possibly affects circulation and healing of the repaired area. In addition, if a tear was found to be irreparable intraoperatively, or if a tear of the subscapularis was present that required a repair, the patient was excluded from the analysis.

Sixty-six consecutive patients who met the inclusion criteria were eligible for the study. Patients were preoperatively assigned to 1 of 2 groups—single-row (SR) group and double-row with suture bridge (DR) group—depending on the patient's preference, cost of the procedure, availability of implants, and operation time. Patients were informed the following: "SR and DR have been reported to provide comparable clinical outcomes. According to some reports, DR may provide better tendon healing than SR, although DR typically requires more anchors and longer operation time." We followed the current literature in answering all of the patients' questions. The nonrandom allocation resulted in 34 patients in the SR group and 32 patients in the DR group.

Operative Techniques

The senior author performed arthroscopic surgery on all patients, who were placed under general anesthesia in a beach-chair position. A standardized diagnostic arthroscopy of the glenohumeral joint was initially performed. The long head of the biceps tendon was examined, and a decision for tenotomy or tenodesis was made based on the pathologic condition (eg, partial tear, instability) and preoperative findings on physical examination. The arthroscope was then inserted into the subacromial space, where a meticulous bursectomy followed by acromioplasty was routinely performed. At this point, a thorough assessment of the rotator cuff was performed to evaluate size, pattern, and reparability of the tear. The footprint on the greater tuberosity was debrided down to bleeding bone, followed by a suture anchor–based repair of the torn rotator cuff tendon.

For the SR group, absorbable anchors with 2 preloaded, standard, high-strength, No. 2 sutures (Duet Suture Anchors

6.0 mm in diameter, with 2 Hi-Fi sutures; Conmed-Linvatec) were inserted into the greater tuberosity, 10 to 12 mm apart, where a repair with minimal tension was easily achieved. Two or 3 anchors were used depending on the tear size. One limb of each suture from the anchors was then passed through the tendon at approximately 10 mm from the torn edge by use of a Scorpion suture passer (Arthrex). Once placed, all the sutures were tied in a simple suture fashion.

For the DR group, 2 anchors (6-mm-diameter Duet Suture Anchors) were inserted at the medial margin of the greater tuberosity 10 to 12 mm apart. Both limbs of each suture from the 2 medial anchors were then passed through the tendon at 12 to 15 mm medial to the torn edge by use of a Scorpion suture passer. Once placed, all the sutures were tied in a mattress fashion. The suture limbs were then brought laterally down to the lateral aspect of the greater tuberosity to create a suture bridge construct with the use of 2 Bio-PushLock anchors (Arthrex).

Postoperative Rehabilitation

Both patient groups followed the same postoperative rehabilitation protocol, including a standardized physical therapy program. A shoulder sling with an abduction pillow was used to immobilize the affected shoulder postoperatively for 6 weeks, while patients were allowed to perform wrist and elbow exercises and shoulder pendulums for axilla hygiene, immediately after the operation. Patients began passive range of motion exercises at 3 weeks under the supervision of an experienced physical therapist. After this period, the sling was discontinued followed by active-assisted range of motion exercises. Active range of motion exercises began at 10 weeks, followed by rotator cuff strengthening exercises beginning 12 weeks postoperatively.

Tendon Integrity Assessment and Postoperative MRI

Postoperatively, integrity of the repaired tendon was assessed by MRI performed at a minimum of 12 months after the surgery, in the same setting as used preoperatively.

All patients underwent preoperative and postoperative MRI with the same protocol in a 3-T MRI scanner (GE Healthcare). The imaging protocol for the postoperative shoulder differs from the protocol used for the native shoulder in order to reduce susceptibility artifacts induced from the metalwork. A surface shoulder coil was used for maximum signal-to-noise ratio, and the imaging planes included axial, coronal oblique, and sagittal oblique perspectives. Short-tau inversion recovery (STIR) sequences in oblique sagittal and coronal planes are considered the most efficient in reducing metal artifacts and producing diagnostic images. The total scanning time is approximately 25 minutes.

The healing was assessed and classified into 5 types according to Sugaya et al[35]: type I, sufficient thickness with homogeneously low intensity; type II, sufficient thickness with partial high intensity; type III, insufficient thickness without discontinuity; type IV, presence of a minor discontinuity; and type V, presence of a major discontinuity. All MRI results were assessed both preoperatively and postoperatively by the same experienced musculoskeletal radiologist (M.V.), who had more than 15 years of experience in MRI and was blinded to the treatment method, following the protocols above.

Clinical Outcome Assessment

Clinical outcomes were assessed in all patients preoperatively and postoperatively. The Constant score[6] and the University of California, Los Angeles (UCLA) score,[32] which have been used widely to assess results after surgical treatment of rotator cuff repair, were used for clinical assessments by 2 independent authors who were not aware of the technique performed (ie, single-row or double-row). The scores obtained from the examiners were averaged to calculate the final score. The Constant and UCLA scores at final follow-up (minimum of 2 years) were used to analyze clinical outcome correlation with performed techniques as well as postoperative tendon integrity.

Statistical Analyses

Statistical analyses were conducted with chi-square test to compare tendon integrity as well as Student t test to compare the differences in clinical scores (ie, UCLA, Constant) between groups. All analyses were performed with SPSS 16.0 software (SPSS Inc). The level of significance was set at $P < .05$.

According to the literature, a retear rate of 30% to 40% for single-row repair and 8% to 16% for double-row repair could be anticipated.[10,20] Power analysis demonstrated that a total sample size of 52 patients (26 patients in each group) would provide a statistical power of 0.8 to detect a significant difference between groups ($P \leq .05$) for the retear rate.

RESULTS

Follow-up time was 46 months (range, 28-50 months). No patient was lost to follow-up. All tears were fully repaired with the technique assigned. No patient was excluded due to arthroscopic findings (eg, subscapularis tear requiring a repair, massive rotator cuff tear); therefore, 66 patients were eligible for the analysis. Comparison of the patient demographics revealed well-matched groups for age, sex, tear size, fatty degeneration, and clinical scores (Table 1).

Postoperatively, MRI was performed in all patients around 6 months before the final clinical follow-up at a mean of 39 months (range, 27-44 months) after the index operation. Tendon healing was evaluated on the postoperative MRI and classified according to the system of Sugaya et al[35]: types I, II, and III were considered healed, while types IV and V (tendon discontinuity) were considered retorn. Tendon healing was obtained in 48 of 66 shoulders (73%). Healing rates were 61% in the SR group (21/34 shoulders) and 84% in the DR group (27/32 shoulders), with statistically significant differences (Table 2).

At the final follow-up, no significant clinical differences were found between the 2 groups of patients (Table 3).

TABLE 1
Patient Demographics and Preoperative Scores[a]

	Single-Row Group (n = 34)	Double-Row Group (n = 32)	*P* Value
Age (range), y	49.4 (32-54)	51.2 (33-55)	.628
Sex, male:female, n	22:12	23:9	.564
Tear size, medium:large, n	20:14	17:15	.312
Fatty degeneration, stage 0:1:2, n	22:10:2	20:10:1	.129
Constant score (range)	56 (42-67)	54 (40-64)	.168
University of California, Los Angeles score (range)	17 (13-20)	16 (13-20)	.244

[a]Values are given as means, unless otherwise indicated.

TABLE 2
Summary of Postoperative Tendon Integrity According to Sugaya Classification

	Single-Row Group (n = 34)	Double-Row Group (n = 32)	*P* Value
Healed			.031
n (%)	21 (61)	27 (84)	
Type I:II:III, n	2:10:9	7:12:8	
Retorn			.027
n (%)	13 (39)	5 (16)	
Type IV:V, n	9:4	3:2	

However, when the study population was analyzed in terms of tendon integrity (ie, healed or retorn), the patients with healed repair demonstrated significantly better clinical outcomes in both UCLA and Constant scores (Table 4).

The minimal clinically important difference (MCID) of the Constant score in patients with rotator cuff tear has been reported to be 10.4,[23] and therefore the difference in the Constant score between the 2 groups was both clinically and statistically significant. However, to our knowledge, the MCID for the UCLA score has not been reported, and therefore no evidence is available to conclude whether the difference in the UCLA score (ie, 6.6) was also clinically significant.

TABLE 3
Summary of the Postoperative Clinical Outcome Scores[a]

	Single-Row Group (n = 34)	Double-Row Group (n = 32)	*P* Value
University of California, Los Angeles score	30.1	32.2	.134
Constant score	86.3	90.3	.254

[a]Values are given as means, unless otherwise indicated.

TABLE 4
Correlations Between Patients With Healed or Retorn Tendon and Outcome Scores

	Healed Tendon (n = 48)	Retorn Tendon (n = 18)	*P* Value
University of California, Los Angeles score	34.2	27.6	.032
Constant score	94	76	<.024

DISCUSSION

In the current study, postoperative MRI revealed significantly greater tendon healing after double-row repair compared with single-row repair. Furthermore, the patients with healed tendon demonstrated clinical scores superior to the scores of patients with retorn tendon or recurrent tear.

The finding of no difference in postoperative clinical outcomes between single-row and double-row procedures is consistent with results of previous studies.[4,11,12,28,35] Our finding of superior tendon healing after double-row repair compared with single-row repair has also been reported by other authors.[4,11,12,26,35] However, a majority of these reports were from the general population with rotator cuff tears, which typically consisted of patients aged around 65 years, and the mean follow-up period was relatively short.[4,11,26,28,35] The strong and important features of the current study included younger patient age (<55 years) and longer follow-up period (mean, 46 months; range, 28-50 months). Our aim was to understand the postoperative course of this specific, younger age group in a midterm follow-up with a particular focus on the association of clinical outcomes with tendon integrity.

In the literature, long-term results after rotator cuff repair vary among studies, likely due to various procedures and tear characteristics.[1,22,33,38,41] Interestingly, a study by Vastamäki et al,[38] which entailed the longest mean follow-up (20 years) and the youngest mean patient age (52 years) at surgery, emphasized significant deterioration of tendon integrity (ie, 94% retear verified by magnetic resonance arthrogram) and of clinical outcomes over time. Sperling at al[33] reported an unsatisfactory long-term functional result in a study of rotator cuff repair in patients younger than 50 years, although no imaging examination was performed. In the current study, MRI was performed approximately 3 years postoperatively, and these findings will play an extremely important role as a reference in a planned future study when another MRI will be assessed for long-term tendon integrity.

According to some studies, postoperative rehabilitation protocols may affect tendon integrity after rotator cuff repair. A recent randomized controlled trial with level 1 evidence reported that, in selected patients who required accelerated postoperative rehabilitation, double-row repair lowered the risk of retear while maintaining a low rate of stiffness.[11] This is particularly relevant for young, active patients who require early return to work and given that young age is a risk factor for postoperative stiffness after rotator cuff repair.[37] However, all patients in our study followed the same postoperative rehabilitation protocol, and we cannot conclude whether an accelerated rehabilitation protocol would affect tendon integrity in these patients.

The current results regarding tendon integrity and clinical outcomes at midterm follow-up appear to be acceptable for arthroscopic single-row and double-row techniques. The fact that healed tendon was associated with improved function indicates the importance of further long-term assessment of this patient population. This will include 2 focuses: (1) how patients with initially poor tendon integrity will fare, and (2) how the integrity of initially healed tendons will change and affect functional outcomes in the 10 to 15 years after surgery. The importance of this continuous investigation is inarguable in light of the increased longevity of the population and, accordingly, the increased numbers of active middle-aged and elderly people. We believe that initial tendon integrity after arthroscopic rotator cuff repair will have a huge effect on long-term functional outcomes, particularly in the younger population. Therefore, the double-row (or suture bridge) fixation technique, which is currently known to provide a potentially superior healing environment, should be recommended to this specific population.

This study has some unavoidable limitations. First, the follow-up time of 46 months is not sufficient to determine long-term (ie, >10 years) outcomes; therefore, we can only assume the superior long-term functional outcomes of the double-row technique. However, given the greater tendon healing after double-row repair than single-row repair, we believe it is reasonable to predict improved and long-lasting tendon integrity provided by the double-row technique. While only midterm outcomes are currently available, we continue to study long-term outcomes, which will be published once data are collected.

Second, although this was a prospective study to compare 2 surgical techniques, the enrollment of the patients was not randomized, and therefore potential biases cannot be ignored. For example, patient expectations regarding either procedure might have influenced clinical outcomes, as indicated in the recent literature for rotator cuff tear treatment.[9] However, patients were enrolled and assigned to the 2 groups before arthroscopy was performed. Therefore, the bias relating to arthroscopic appearance and characteristics of the tear should have been minimized. Third, we can make no direct comparisons with older patients who have rotator cuff tears, and our conclusions are limited to patients younger than 55 years. However, our purpose was to differentiate this younger population from the general population with rotator cuff tear and thus to evaluate superior techniques specifically for younger population. Therefore, we believe the current results are of use. A fourth possible limitation could be that MRI evaluation was performed by only one assessor. Fifth, we limited the tear size to medium and large tears, and no small or massive tears were included; thus, the results are not generally applicable to all rotator cuff tears. We made this decision because the retear rates of small tears after single-row and suture bridge repair do not appear to differ[10,19]; further, an attempt at full repair under great tension on a massive tear is not desireable, no matter whether the technique is single-row or double-row repair. By limiting tear size to medium and large tears, we could focus on the choice of fixation technique for the "fully repairable" tear, which we believed to be clinically most relevant.

CONCLUSION

The current study provides new evidence regarding the choice of arthroscopic repair technique for rotator cuff tear in a young population. Our findings suggest that a double-row repair technique improves tendon healing, which translates to improved clinical outcomes at midterm follow-up. We propose that the double-row technique be considered for patients younger than 55 years who have medium to large rotator cuff tears.

REFERENCES

1. Bartl C, Kouloumentas P, Holzapfel K, et al. Long-term outcome and structural integrity following open repair of massive rotator cuff tears. *Int J Shoulder Surg*. 2012;6(1):1-8.
2. 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(6):1229-1240.
3. 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):1877-1883.
4. 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):1247-1253.
5. Cofield RH. Subscapular muscle transposition for repair of chronic rotator cuff tears. *Surg Gynecol Obstet*. 1982;154(5):667-672.
6. Constant CR, Murley AH. A clinical method of functional assessment of the shoulder. *Clin Orthop Relat Res*. 1987;214:160-164.
7. Denard PJ, Ladermann A, Jiwani AZ, Burkhart SS. Functional outcome after arthroscopic repair of massive rotator cuff tears in individuals with pseudoparalysis. *Arthroscopy*. 2012;28(9):1214-1219.
8. Dines JS, Bedi A, ElAttrache NS, Dines DM. Single-row versus double-row rotator cuff repair: techniques and outcomes. *J Am Acad Orthop Surg*. 2010;18(2):83-93.
9. Dunn WR, Kuhn JE, Sanders R, et al. 2013 Neer Award: predictors of failure of nonoperative treatment of chronic, symptomatic, full-thickness rotator cuff tears. *J Shoulder Elbow Surg*. 2016;25(8):1303-1311.
10. 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):835-841.
11. Franceschi F, Papalia R, Franceschetti E, et al. Double-row repair lowers the retear risk after accelerated rehabilitation. *Am J Sports Med*. 2016;44(4):948-956.

12. 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):1254-1260.
13. Fuchs B, Weishaupt D, Zanetti M, Hodler J, Gerber C. Fatty degeneration of the muscles of the rotator cuff: assessment by computed tomography versus magnetic resonance imaging. *J Shoulder Elbow Surg*. 1999;8(6):599-605.
14. Galatz LM, Ball CM, Teefey SA, 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(2):219-224.
15. Gazielly DF, Gleyze P, Montagnon C. Functional and anatomical results after rotator cuff repair. *Clin Orthop Relat Res*. 1994;304:43-53.
16. 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.
17. Hamada K, Fukuda H, Mikasa M, Kobayashi Y. Roentgenographic findings in massive rotator cuff tears: a long-term observation. *Clin Orthop Relat Res*. 1990;254:92-96.
18. Harryman DT II, Mack LA, Wang KY, Jackins SE, Richardson ML, Matsen FA III. Repairs of the rotator cuff: correlation of functional results with integrity of the cuff. *J Bone Joint Surg Am*. 1991; 73(7):982-989.
19. Hein J, Reilly JM, Chae J, Maerz T, Anderson K. Retear rates after arthroscopic single-row, double-row, and suture bridge rotator cuff repair at a minimum of 1 year of imaging follow-up: a systematic review. *Arthroscopy*. 2015;31(11):2274-2281.
20. Jost B, Pfirrmann CW, Gerber C, Switzerland Z. Clinical outcome after structural failure of rotator cuff repairs. *J Bone Joint Surg Am*. 2000;82(3):304-314.
21. 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):407-414.
22. Kluger R, Bock P, Mittlbock M, Krampla W, Engel A. Long-term survivorship of rotator cuff repairs using ultrasound and magnetic resonance imaging analysis. *Am J Sports Med*. 2011;39(10):2071-2081.
23. Kukkonen J, Kauko T, Vahlberg T, Joukainen A, Aarimaa V. Investigating minimal clinically important difference for Constant score in patients undergoing rotator cuff surgery. *J Shoulder Elbow Surg*. 2013;22(12):1650-1655.
24. 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):1861-1868.
25. Meier SW, Meier JD. Rotator cuff repair: the effect of double-row fixation on three-dimensional repair site. *J Shoulder Elbow Surg*. 2006;15(6):691-696.
26. 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):2091-2098.
27. 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): 586-597.
28. Nicholas SJ, Lee SJ, Mullaney MJ, et al. Functional outcomes after double-row versus single-row rotator cuff repair: a prospective randomized trial. *Orthop J Sports Med*. 2016;4(10):2325967116667398.
29. Park MC, Elattrache NS, Ahmad CS, Tibone JE. ''Transosseous-equivalent'' rotator cuff repair technique. *Arthroscopy*. 2006;22(12): 1360 e1361-1365.
30. Park MC, ElAttrache NS, Tibone JE, Ahmad CS, Jun BJ, Lee TQ. Part I: footprint contact characteristics for a transosseous-equivalent rotator cuff repair technique compared with a double-row repair technique. *J Shoulder Elbow Surg*. 2007;16(4):461-468.
31. Park MC, Tibone JE, ElAttrache NS, Ahmad CS, Jun BJ, Lee TQ. Part II: biomechanical assessment for a footprint-restoring transosseous-equivalent rotator cuff repair technique compared with a double-row repair technique. *J Shoulder Elbow Surg*. 2007;16(4):469-476.
32. Roach KE, Budiman-Mak E, Songsiridej N, Lertratanakul Y. Development of a shoulder pain and disability index. *Arthritis Care Res*. 1991;4(4):143-149.
33. Sperling JW, Cofield RH, Schleck C. Rotator cuff repair in patients fifty years of age and younger. *J Bone Joint Surg Am*. 2004; 86(10):2212-2215.
34. Spiegl UJ, Euler SA, Millett PJ, Hepp P. Summary of meta-analyses dealing with single-row versus double-row repair techniques for rotator cuff tears. *Open Orthop J*. 2016;10:330-338.
35. 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):1307-1316.
36. 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(5): 953-960.
37. Tashjian RZ, Hollins AM, Kim HM, et al. Factors affecting healing rates after arthroscopic double-row rotator cuff repair. *Am J Sports Med*. 2010;38(12):2435-2442.
38. Vastamaki M, Lohman M, Borgmastars N. Rotator cuff integrity correlates with clinical and functional results at a minimum 16 years after open repair. *Clin Orthop Relat Res*. 2013;471(2):554-561.
39. 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):182-188.
40. 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(3): 733-741.
41. 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(11):2423-2431.