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Arthroscopic rotator cuff repair in active patients younger than 45 Years: a prospective analysis with a mean 5-year follow-up

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Background: To report clinical and activity-specific outcomes after arthroscopic rotator cuff repair (ARCR) for full-thickness supraspinatus tears in active individuals aged less than or equal to 45 years. The pre hoc hypothesis was that patients in this age group would demonstrate significant improvements in clinical outcomes following ARCR along with a significant improvement of athletic abilities.
Methods: Patients were included in this study if they were (1) active individuals aged between 18 and 45 years at the time of surgery, (2) had a full-thickness rotator cuff tear of the supraspinatus tendon with or without anterior or posterior extension, and (3) underwent ARCR. Preoperative and postoperative patient-reported outcomes scores including the American Shoulder and Elbow Surgeons (ASES) score; Disabilities of Arm, Shoulder and Hand; Single Assessment Numeric Evaluation; and Short Form-12 Physical Component Summary were prospectively collected and postoperative patient satisfaction (scale of 1-10) was recorded at a minimum of 2 years postoperatively. Attainment of the minimal clinically important difference and patient acceptable symptom state for the ASES was calculated. Athletic activity–specific outcomes and return to activity were investigated prospectively via a custom-made comprehensive questionnaire.
Results: Between November 2005 and June 2020, of 1149 RCRs performed by the senior author, 54 patients (mean age 40.9 years, 13 female; follow-up 69.7 ± 35.2 months in a range of 24.6-179.6 months) were included into the outcomes analysis. Of those, 4 patients (7.4%) had progressed to revision RCR. At a follow-up of 5.8 years, outcome scores had significantly improved compared to preoperative baselines (ASES 55.6 ± 13.8 to 90.1 + 15.8; $P < .001$; Disabilities of Arm, Shoulder and Hand 38.9 ± 18.4 to 11.9 ± 17.1; $P < .001$, Single Assessment Numeric Evaluation 60.7 ± 22.7 to 79.3 ± 27.6; $P = .001$, Short Form-12 Physical Component Summary 41.6 ± 8.3 to 51.9 ± 9.0; $P \leq .001$). Ninety three point six percent of the patients reached the minimal clinically important difference and 72.6% reached the patient acceptable symptom state. Median satisfaction was 9.5/10. Eighty six percent of the patients returned to sports, while 67% of the patients returned to a similar level compared to preoperatively. All sport-specific metrics such as shoulder strength and endurance ($P < .001$), intensity ($P < .001$), and impairments from pain affecting speed ($P = .002$), endurance ($P = .002$), and competition ($P < .001$) significantly improved postoperatively.
Conclusion: ARCR of full-thickness rotator cuff tear in active individuals aged 45 years or less results in a clinically relevant improvement of outcomes, function, and quality of life at a minimum of 2 years and mean 5.8-year follow-up with a low rate of revision. While 86% of patients were able to return to activity and sport-specific outcome metrics significantly and substantially improved compared to preoperatively, a return to preinjury levels was not reliably achieved in all patients, with particular limitations observed in overhead active individuals. The data support the hypothesis that patients in this age group demonstrate significant improvements in clinical outcomes following ARCR along with significant improvements in athletic abilities.

Research performed at the Steadman Philippon Research Institute, Vail, CO.
This study was approved by Vail Health Hospital Institutional Review Board Protocol 2019-77.

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Rotator cuff tears (RCTs) are a major cause of disability in senior patients but are typically uncommon in younger patients. The incidence of RCTs in patients with shoulder disability between the ages of 20 and 50 years has been reported to be as low as 5.1%,[37] and asymptomatic tears are present in an additional 4.0% of patients aged less than 40 years.[31]

However, in an attempt to increasingly personalize the treatment of RCTs according to age and functional demand, the patient population aged less than 40 years has gained increasing recognition more recently.[3,6,20,30] Given the critical need for long-lasting structural and functional integrity for shoulder function,[24] as well as the substantial potential for both short-term and long-term disability,[3,19] appropriate diagnosis and treatment of RCTs is paramount particularly in younger patients. Thus, an array of various factors including injury etiology, symptom chronicity, healing potential, preoperative activity level, and long-term expectations should be considered carefully for the optimal treatment in this patient population.[10,13]

Despite the potential for superior biologic healing potential in younger patients,[38] the current literature reports satisfaction rates as low as 68%[15] after rotator cuff repair (RCR) in younger patients, which are lower than those of older patients.[5,9] Next to underlying genetic factors potentially involved in the pathogenesis of RCTs in these patients which also may affect structural healing and clinical outcomes,[33] inferior outcomes and satisfaction may potentially be attributable to the higher athletic demands and expectations in younger patients.[11]

Given that RCTs in this population oftentimes originate from a traumatic event, there is limited evidence in regard to the outcomes following isolated arthroscopic RCR (ARCR) in this population unbiased by concomitant injuries or procedures;[26,30] data that are critical to evaluate the outcomes specifically attributable to ARCR in this population. Furthermore, there is a paucity of evidence regarding the ability to successfully return to activity (RTA) following ARCR for isolated RCTs and the association between sport-specific outcomes and overall satisfaction in young active individuals. As the return to preinjury activity levels and occupational capacity is significantly associated with the subjective satisfaction with the outcome in sports medicine procedures,[25] a concise understanding of those outcome parameters may expand the understanding in this age group beyond validated patient-reported outcome (PRO) scores, which are often abstract at the individual level,[2] and may allow for adequate preoperative management of expectations in the young active individual undergoing ARCR.

As such, the purpose of this study was to report clinical and sport-specific outcomes after ARCR for full-thickness supraspinatus (SSP) tears in patients aged less than or equal to 45 years. The pre hoc hypothesis was that patients in this age group would demonstrate significant improvements in clinical outcomes following ARCR along with significant improvements in athletic abilities.

Methods

Study population

This was an Institutional Review Board–approved level IV retrospective study (Approval Number: 2019-77) using prospectively collected data from a single-surgeon series (P.J.M.). Patients were included in this study if they were (1) aged between 18 and 45 years at the time of surgery,[20] (2) had a full-thickness tear of the SSP tendon with or without extension into the subscapularis or infraspinatus tendon, (3) underwent ARCR, and (4) reported PRO scores at a minimum of 2 years. Patients who underwent concomitant long head of the biceps tenodesis and concomitant subacromial decompression (SAD) were included. Patients were excluded if they suffered from RCTs not involving the SSP tendon, if they sustained concomitant injuries or underwent additional concomitant reconstructive procedures at the time of surgery, if they had advanced osteoarthritis of the shoulder joint, or if they did not report any preoperative physical activity.

Surgical technique

All patients underwent an ARCR with the optimal repair configuration according to the individual tear pattern as previously described.[22] The preferred method for ARCR was a double-row transosseous-equivalent self-reinforcing construct with suture tapes and anchors.[21,23] In case of small full-thickness tears classified as Snyder type C grade I, a single-row repair was performed.[22] All procedures were performed in the beach-chair position under general anesthesia with an interscalene nerve block. Following diagnostic arthroscopy, glenohumeral débridement, lysis of adhesions (if necessary), SAD, and synovectomy (if necessary) were performed. Concomitant biceps tenotomy with subpectoral biceps tenodesis was performed if the biceps tendon demonstrated degeneration, synovitis, disruption, or a biceps reflection pulley lesion and/or if there was significant pain in the biceps on palpation in the groove or on Speed's test. Subsequently, the rotator cuff insertional footprint was débrided to a bleeding surface. Medial anchors were placed at articular cartilage margin. For the knotless technique with suture tapes, the limbs of the suture tape were passed through the torn rotator cuff tendon using a Lasso (Arthrex, Inc., Naples, FL, USA), and the lateral bridging portion was performed. One limb of suture tape from each medial anchor was retrieved from the lateral portal. The suture tapes were then loaded into the eyelet of another knotless suture anchor. A bone socket was created with a punch. The eyelet of the anchor was then seated into the socket. The limbs of the suture tape were then individually tensioned before advancing the body of the anchor. Once the anatomy of the footprint was restored, the anchor was inserted laterally to secure the tapes. These steps were repeated for the posterolateral anchor, thereby creating the final bridging, interconnected construct.[23] If the biceps tendon had been previously tenotomized, the shoulder was then re-prepped, and a small incision was made in the axilla and a subpectoral biceps tenodesis was performed according to a previously described technique.[28]

Postoperative rehabilitation

Postoperative rehabilitation consisted of protection in a sling for 4 weeks with immediate passive range of motion. At week 4, patients weaned from the sling and began active and active-assisted range of motion. For patients who underwent biceps tenodesis, early active and passive elbow motion was permitted but resisted elbow flexion was avoided for the first 6 weeks.[36] At 6 weeks, patients were cleared to use their operative extremity with a lifting restriction of 10 lbs. Initial resistance training starts at 6-8 weeks.

More advanced resistance training started at 12 weeks. Return to activities such as golfing, hiking, biking, and skiing were allowed at 14-16 weeks postoperatively. Return to overhead sports or contact sports were allowed as early as 16 weeks, provided that patients met return to play criteria of function pain-free active range of motion, maximized strength and optimal scapulothoracic kinematics.

Clinical outcome

Patient demographics, mechanism of injury, and surgical data were collected prospectively and reviewed retrospectively. Preoperatively and at a minimum of 2 years postoperatively, patients completed evaluations including the American Shoulder and Elbow Surgeons (ASES) score; Disabilities of Arm, Shoulder, and Hand (Quick-DASH); Single Assessment Numeric Evaluation (SANE); Short Form 12 Physical Component Summary (SF-12 PCS); and postoperative patient satisfaction on an ascending scale of 1-10 (10 = very satisfied). The percentage of patients who achieved an improvement in the magnitude of the minimal clinically important difference (MCID) and reached or surpassed the patient acceptable symptom state (PASS) in the ASES score were calculated using the thresholds previously established in the setting of RCR (MCID: 11.1, PASS: 86.7 point).[7] To assess the potential impact of modifiable biological factors, clinical outcomes were compared between patients, who underwent acute repair of a traumatic RCT, according to previous definitions of those parameters.[27]

Athletic activity–specific outcomes

To evaluate a patient's ability to return to their sport of choice, they were asked to specify their primary sport preoperatively, which was then categorized as an "overhead" or "nonoverhead" activity in line with previous definitions.[1,35] Additionally, the patient's preoperative level of sports (recreational, high school, collegiate, professional) was recorded. Postoperatively, patients were asked to rate their ability to participate in sports with respect to their shoulder using the following response options: (1) at or above preinjury level, (2) slightly below preinjury level, (3) moderately below preinjury level, (4) significantly below preinjury level, (5) unable to participate in their usual sport, and (6) unable to participate in any sports. Return to sports was defined as selecting options (1) through (4), while a successful return to a level similar to the preinjury level was considered selecting options (1) or (2).

To assess qualitative RTA parameters, patients were asked to rate the intensity they were able to compete with or participate with in their usual sport compared to their preinjury level both preoperatively and postoperatively using the following options: (1) "Same or better than preinjury level," (2) "75%-99% of preinjury level," (3) "50%-74% of preinjury level," (4) "25%-49% of preinjury level," (5) "less than 25% of preinjury level," and (6) "unable to participate in any sports". To evaluate the current strength and endurance of the shoulder when participating in sports, patients were asked to rate their level of weakness or fatigue using the following options: (1) "no weakness or fatigue," (2) "mild weakness or fatigue," (3) "moderate weakness or fatigue," (4) "severe weakness or fatigue," (5) "weakness or fatigue preventing competition," and (6) "unable to compete due to weakness or fatigue". Patients were also asked to rate the impact of pain on their endurance and speed in sports on a scale of (0) "none," (1) "mild," (2) "moderate," or (3) "severe". Furthermore, they were asked to rate the impact of pain on their ability to compete using the following options: (1) "no pain with competition," (2) "pain only after competition," (3) "mild pain with competition," (4) "moderate pain with competition," (5) "severe pain with competition," and (6) "pain preventing competition". Finally, to assess the impact of shoulder-related pain more globally, patients were also asked to rate the impact of pain on their activities of daily living and work on a scale of (0) "none," (1) "mild," (2) "moderate," or (3) "severe". To assess the association of subjective satisfaction, clinical outcomes and subjective satisfaction were compared between patients successfully returning to preinjury level of sports vs. those who did not. Also, the propensity of patients returning to athletic activity and activity-specific parameters were compared between overhead athletes and non-overhead athletes via bivariate analysis.

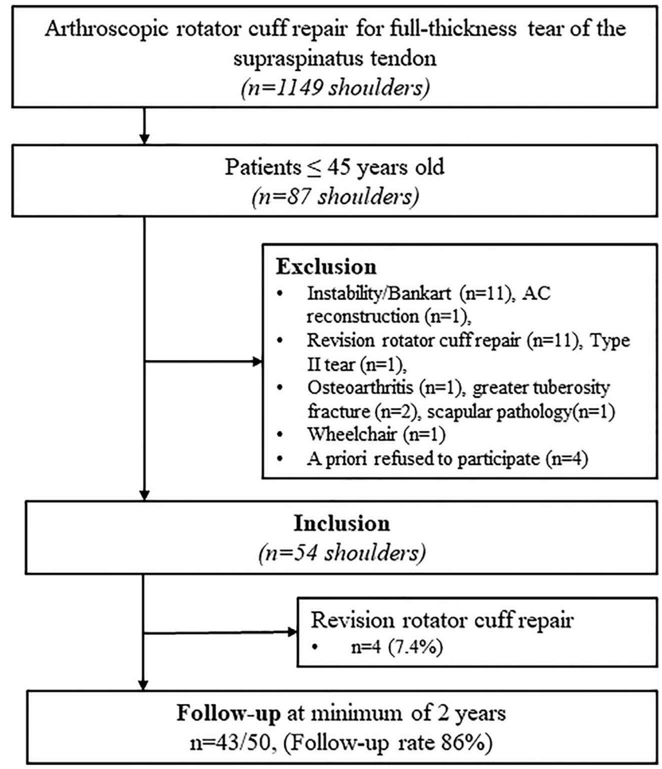

Figure 1 Flow chart visualizing the patient population for this study after accounting for inclusion criteria, exclusion criteria, clinical failures, and those lost to follow-up.

Statistical analysis

A power analysis was performed to determine the capability of the sample size to detect a clinically meaningful preoperative to postoperative difference of 11.1 points ASES score.[7] Assuming a standard deviation of 15 points, at an effect size of 0.74, a sample size of 16 patients would provide 80% power at an alpha-level of 0.05 determined in an a priori power analysis, performed with G* (Heinrich Heine Universität, Düsseldorf, Germany).[12]

Descriptive statistics were used to summarize categorical and continuous variables, with categorical variables reported as counts and percentages and continuous variables reported as mean ± standard deviation. The Shapiro-Wilk test was used to evaluate the distribution of continuous variables. To compare baseline and follow-up PROs, according to the respective distribution, a 2-tailed paired Student's *t*-test or a Wilcoxon signed rank test were employed. For intergroup comparisons, parametric tests (unpaired *t*-test) or nonparametric tests (Mann-Whitney U test) were used to compare continuous variables between groups, depending on the respective distribution of the data. Ordinal variables were compared using the Wilcoxon signed rank test for preoperative to

Table I
Population demographics and surgical information.

Factor	Number (%)
Patient demographics	
Male/Female	13 (24.1)/41 (75.9)
Right/left shoulders	21 (38.9)/33 (61.1)
Injury at dominant arm	31 (57.4)
Workman's compensation cases	6 (11.1)
Tear characteristics	
Traumatic/atraumatic	16 (29.6%)
Tendons involved	
Isolated SSP tear	25 (46.3%)
SSP and ISP tear	14 (25.9%)
SSP and SSC tear	10 (18.5%)
SSP and SSC and ISP tear	5 (9.3%)
Tear shape	
Crescent tear type	35 (64.8%)
L-shaped	5 (9.3%)
Reverse L-shaped	2 (3.7%)
Complex	12 (22.2%)
Surgical characteristics	
Double row	50 (92.6%)
Single row	4 (7.4%)
Margin convergence	9 (16.7%)
Concomitant biceps tenodesis	47 (87.0%)
Concomitant distal clavicle excision	2 (3.7%)
Concomitant subacromial decompression	54 (100%)
Concomitant SLAP repair	2 (3.7%)

SSP, supraspinatus; *ISP*, infraspinatus; *SSC*, subscapularis; *SLAP*, superior labrum anterior to posterior.

postoperative comparisons and the binary Fisher's exact test or Chi-square tests in intergroup comparisons, as appropriate. A confidence interval of 95% was calculated and the level of significance was set at $P < .05$. The statistical analysis was performed using SPSS software version 26.0 (IBM Corp., Armonk, NY, USA).

Results

Between November 2005 and June 2020, the senior surgeon (P.J.M.) performed a total of 1149 ARCR. Of those, 87 were performed in patients aged less than or equal to 45 years (Fig. 1). Of those, 33 patients were excluded due to concomitant procedures (n = 28), a priori refusal to participate (n = 4) and due to a paraplegic condition requiring wheelchair use (n = 1), thereby leaving a final study population of 54 patients. Follow-up could be obtained in 43 patients (24.1% female) with an average age of 40.9 years (range 29.9-45.4 years) at the time of index surgery. The mean follow-up was 69.7 ± 35.2 months (range, 24.6-179.6 months). Further patient demographics are listed in Table I.

Patient-reported outcomes

Mean outcome scores significantly improved postoperatively in the ASES from 55.6 ± 13.8 to 90.1 ± 15.8 ($P < .001$), in the Quick-DASH from 38.9 ± 18.4 to 11.9 ± 17.1 ($P < .001$), in the SANE from 60.7 ± 22.7 to 79.3 ± 27.6 ($P = .001$), and in the SF-12 PCS from 41.6 ± 8.3 to 51.9 ± 9.0 ($P < .001$) (Table II). Of the patients who did not proceed to revision surgery, 93.6 reached the MCID for the ASES and 72.5 reached the PASS for the ASES. Postoperatively, the median satisfaction was 9.5. There was no significance between patients who underwent repair of acute traumatic tears compared to chronic tears.

Return to activity

Within the study population, 19 (35.2%) of the patients participated in overhead athletic activity and of those, 3 patients could be classified as throwing athletes. Within the overall patient population, n = 3 participated in sports on a professional level, n = 4 at a college level, n = 2 at a high school level, and the rest of the patients at a recreational level. Preoperative sports participation is presented in Table III.

Table II
Comparative outcomes depending on etiology.

	Acute traumatic tears	Chronic tears	*P* value
ASES	88.9 ± 15.4	90.1 ± 15.5	.665
SF-12 PCS	50.9 ± 8.3	51.5 ± 9.1	.645
SANE	69.9 ± 36.5	79.6 ± 25.0	.455
Quick-DASH	14.7 ± 19.9	12.1 ± 16.4	.589
Satisfaction	8.5 (1-10)	10 (1-10)	R = .483

ASES, American Shoulder and Elbow Surgeons score; *SF-12 PCS*, short form 12 physical component summary; *SANE*, single assessment numeric evaluation; *DASH*, disabilities of the arm, shoulder, and hand.
Postoperative outcome scores of acute traumatic tears compared to chronic tears. Continuous data presented as mean ± standard deviation and ordinal data as median (range). Definitions of acute/chronic and traumatic/atraumatic were adapted from Pogorzelski et al.[27]

Of the patients who responded to the question regarding postoperative athletic activity participation, 86% of the patients were able to RTA. Sixty seven percent of the patients indicated return to activity above, equal to, or only slightly below preinjury level at final follow-up. Detailed information regarding the level of activity patients returned to is depicted in Fig. 2.

Compared to preoperatively, the level of activity in which patients were able to participate significantly improved ($P = .002$). Also, the intensity in which the patients could compete in their usual activity compared to preinjury level ($P < .001$) as well as the strength or endurance of the shoulder when participating in their usual activity compared to their preinjury level ($P < .001$) significantly improved postoperatively. Detailed information is provided in Table IV.

Postoperatively, the impact of patient-reported pain on endurance ($P = .002$), speed ($P < .002$), and ability to compete in sports ($P < .001$) improved significantly. More generally, the impact of patient-reported pain regarding activities of daily life ($P < .001$) and work ($P = .001$) improved significantly following surgery. Detailed information is provided in Supplementary Table S1.

There were no significant differences in the postoperative PROs between overhead and nonoverhead athletes in the ASES (90.3 ± 15.8 vs. 88.8 ± 15.0, $P = .769$), Quick-DASH (12.4 ± 16.5 vs. 13.8 ± 19.3, $P = .810$), SANE (78.1 ± 26.7 vs. 74.2 ± 33.2, $P = .691$), SF-PCS (51.4 ± 9.7 vs. 51.3 ± 6.9, $P = .980$), and median satisfaction (9 vs. 10, $P = .316$). Patients involved in overhead athletic activity less frequently reported a successful RTA (55%) compared to patients involved in nonoverhead activity (71%); however, this did not reach statistical significance ($P = .398$). There was a tendency toward lower satisfaction in patients who did not successfully RTA on a similar level compared to preoperatively and those who did (median satisfaction: 9 vs. 10, $P = .216$). Within the population of overhead athletes, the throwing athletes all returned to the preinjury level of activity (n = 3, 100%) and had a median satisfaction of 10/10.

Progression to revision

A total of 4 patients (7.4%) ultimately required revision RCR and were classified as failures. Of those, 2 patients had recurrent trauma with falls on their shoulders, while 1 patient had an atraumatic recurrence. For the final patient, there was no information on the mechanism of reinjury.

Discussion

The most important finding of this study is that young patients aged equal to or less than 45 years can expect clinically relevant

Table III
Preoperative sporting activity.

Discipline	Number of patients
Skiing	9
Football*	1
Basketball*	1
Baseball*	1
Volleyball*	1
Cycling	9
Horseback Riding	1
Tennis*	3
Hockey	1
Fishing*	2
Weightlifting*	9
Walking	1
Snowboarding	4
Golf	2
Motocross	2
Surfing	1
Balance Board	1
Drag Racing	1
Fitness	2
Wrestling	1
Rock climbing*	1

Athletic activity participation of the patient population.
*Overhead activity.

improvement in clinical outcomes following ARCR with a low rate of revision, with >93% attaining the MCID of the ASES score in our patient population. Furthermore, while the majority of the patients were able to RTA and all sports-specific outcome metrics significantly and substantially improved postoperatively, only two-thirds of the patients were still active on a level similar to the preinjury level at a mean follow-up of 5.8 years in this patient population.

Regarding clinical outcomes, the results underscore the positive effect of contemporary ARCR results and support the findings of previous studies reporting a high return to preinjury levels of function in young populations.[3,18,20] Comparable to the present study, Lin et al[20] reported postoperative ASES score of 84.6 in patients with a mean age of 37.5 years, Parnes et al reported mean ASES scores of 89.88 ± 14.26, and subjective shoulder value scores of 89.45 ± 14.04 in patients aged less than 40 years undergoing ARCR among other concomitant pathologies,[26] whereas Krishnan et al[18] reported a mean ASES score of 92 in a patient population with a mean age of 37 years. At mid-term, Scanaliato et al reported ASES scores of 88.68 and SANE scores of 87.32 a military population aged less than 40 years undergoing ARCR among a mixed set of concomitant pathologies.[30] In contrast to those previous studies, the decision was made in the present study to exclude reconstructive concomitant procedures beyond biceps tenodesis, which may potentially lead to an under-representation of traumatically injured patients but allows for clearly delineating the outcome to be expected following isolated ARCR not confounded by concomitant procedures beyond a long head of the biceps tenodesis and SAD in a relatively large population. Notably, the high rates of clinically relevant improvement of 93.6% in the present study are similar to previous studies in comparably young and active patient populations, which reported MCID attainment rates of up to 91.6%.[30] Regarding the patients' postoperative subjective satisfaction, the results reported in the present study are comparable to the data presented by Burns et al[6] and Lin et al.[20] In their studies, the authors reported satisfaction rates as high as 96.2%[6] and 97%,[20] respectively, differentiating between "satisfied" and "unsatisfied" patients. This is comparable to a median satisfaction of 9.5 reported in the present study. The satisfaction rates of those studies reporting the outcome after ARCR are notably higher than those reported in historic cohorts following open RCR, with satisfaction rates ranging around 68%.[15]

The revision rate reported in the present study is comparable to previous studies in younger patients, reporting rates of 0%-7.5% at short-term to mid-term follow-up.[3,6,18,20,30] Comparable to previous studies,[30] traumatic retears seem to be the most frequent mode of failure in this younger patient population.

When benchmarking the outcome data of this study against the results reported following ARCR in older patients, which are more typically affected by RCT, the outcomes are slightly inferior.[4] For example, Baumgarten et al reported on the outcomes following ARCR in 273 patients with a mean age of 58.9 years at a mean 3.7-year follow-up. In their study, they reported ASES scores of 95 and SANE scores of 95, which was slightly superior to our cohort, with ASES scores of 90.1 and SANE scores of 79.3.[4] In accordance, when comparing the findings of our present study with previously reported long-term results of ARCR in older patients, with the same arthroscopic technique and implants,[16] outcomes were slightly inferior. In that study, it was reported to have an ASES of 95.2 ± 8.2, SANE of 89.9 ± 17.0, QuickDASH of 9.8 ± 12.2, SF-12 PCS of 52.1 ± 8.5, a median satisfaction of 10, and a revision rate of 4.4% at 5 years in this older patient population. However, accounting for the fact that there was traumatic retears in 50% of all patients that were revised in the present case series, the revision rates seem to be equivalent compared to older patients.[16] However, as younger patients tend to have substantially different athletic demands compared to older patients,[11] comparing outcome parameters between inherently different patient populations may be of limited meaningfulness, but highlights that special attention needs to be dedicated to this young and active patient population.

Regarding RTA, the results reported are among the first to demonstrate the potential of ARCR to significantly and substantially improve activity-specific outcome metrics and enable active individuals aged less than 45 years to RTA. The RTA rate of 86% reported in this study is comparable to previously published studies in comparable patient populations. More specifically, RTA rates as high as 88.1% were reported in a military patient population aged less than 40 years[30] and RTA rate as high as 93% in a patient cohort of 32 adolescent athletes in a mixed cohort following ARCR of partial-thickness and full-thickness RCT.[3] These findings are generally in line with previous systematic review reporting satisfactory rates of RTA to preinjury level of activity in young patients.[19] The present study expands the body of evidence by demonstrating that prospectively collected sport-specific qualitative metrics such as shoulder specific strength, endurance and intensity as well as shoulder pain–specific impairments in speed, endurance, and the ability to compete significantly and substantially improve following ARCR, highlighting the positive effect of the procedure in this young patient population. This is consistent with the nonsport-specific data presented by Lin et al in which 76%-79% of patients describe experiencing pain relief postoperatively and 34%-62% of patients report no pain whatsoever.[20] However, the present study highlights that only two-thirds of patients were still active at a similar level compared to preoperatively at a mean follow-up of 5.8 years. This confirms the findings of previous study, which demonstrated that 57% of adolescent athletes undergoing RCR were forced to change positions[3] and 11.9% of military athletes of similar age were medically separated from the military.[30] The tendency toward inferior outcomes in overhead athletes following ARCR, with only 55% of this subgroup still active on a preinjury level of activity, has been previously noted. More specifically, Tibone et al[34] reported a rate of RTA to preinjury level as low as 32% in professional or collegiate level throwers following open RCR, and Reynolds et al[29] reported that only 55% of the elite pitchers, who underwent débridement of partial-thickness RCT, were able to return to the same or higher level of competition. Similarly, in adolescent athletes, 64% of the patients were forced to change

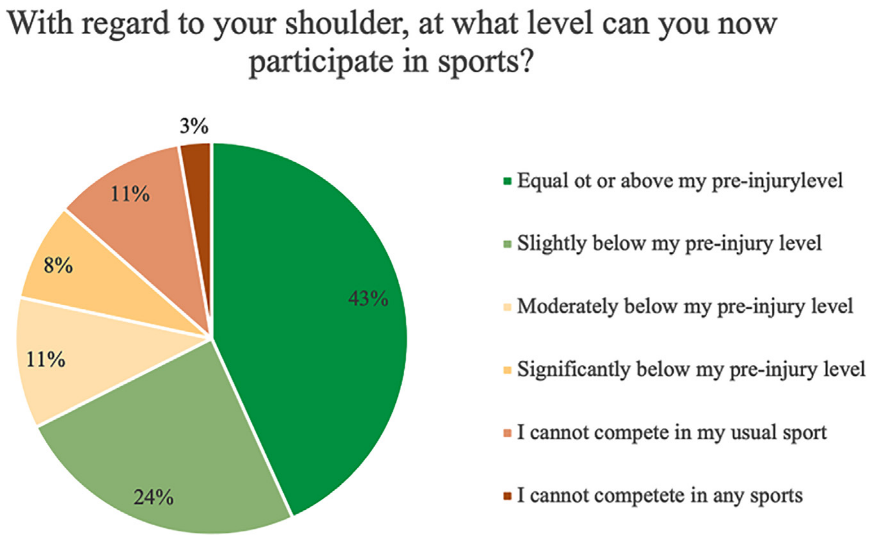

Figure 2 Graphical representation of the postoperative ability of patients to participate in sport.

Table IV
Comparison of preoperative and postoperative sport-specific outcome metrics.

Parameter	Preoperatively	Postoperatively	*P* value
Strength and endurance of shoulder when participating in usual sport			<.001*
No weakness or fatigue	0 (0%)	**16 (43.2%)**	
Mild weakness or fatigue	2 (6.9%)	10 (27%)	
Moderate weakness or fatigue	**9 (31%)**	5 (13.5%)	
Severe weakness or fatigue	7 (24.1%)	4 (10.8%)	
Weakness or fatigue prevents competition	5 (17.2%)	1 (2.7%)	
Weakness or fatigue prevents competition	6 (20.7%)	1 (2.7%)	
Intensity in usual sport compared to preinjury level			<.001*
Same of better than preinjury intensity	1 (3.4%)	**14 (37.8%)**	
75%-99% of preinjury intensity	2 (6.9%)	11 (29.7%)	
50%-74% of preinjury intensity	**10 (34.5%)**	6 (16.2%)	
25%-49% of preinjury intensity	5 (17.2%)	2 (5.4%)	
<25% of preinjury intensity	4 (13.8%)	0 (0%)	
Can no longer compete at any intensity	7 (24.1%)	4 (10.8%)	
Level of participation in athletic activity			.002*
Equal or above preinjury level	1 (3.4%)	**16 (43.2%)**	
Slightly below preinjury level	6 (20.7%)	9 (24.3%)	
Moderately below preinjury level	5 (17.2%)	4 (10.8%)	
Significantly below preinjury level	**7 (24.1%)**	3 (8.1%)	
Cannot compete in usual sport	4 (13.8%)	4 (10.8%)	
Cannot compete in any sports	6 (20.7%)	1 (2.7%)	

Comparison of level of sport-specific outcome parameters before and after arthroscopic rotator cuff repair. Formatted as number of patients (percentage of total patients). Bold format indicates most commonly selected option within respective subgroup.
*Denotes statistical significance.

positions following ARCR.[3] While in the present study, all throwing athletes returned to their preoperative level of activity; the sample size was relatively limited.

Benchmarking the activity-specific results of the present study to the general population of patients undergoing RCR, similar results can be expected. In a systematic review including a meta-analysis analyzing 874 shoulders with a mean age of 42.6 years, Klouche et al[17] reported an overall RTA rate of 84.7%, however a RTA rate of only 65.9% to an equivalent level of play following RCR. In their study, Klouche et al furthermore noted that the ability to RTA may depend on the preoperative level of activity, with only 49.9% of professional and competitive athletes being able to RTA to the same level of play.[17] These findings were confirmed in another systematic review by Altintas et al.[1] Furthermore, similar to the present study, Altintas et al reported an inferior ability for overhead athletes to RTA compared to nonoverhead athletes, reporting a pooled RTA rate to preinjury levels of activity of only 38%.[1]

Notably, these findings of the present study highlight the advancements in implants and repair techniques, when comparing the findings of the present study following state-of-the-art transosseous equivalent ARCR compared to open RCRs in historic younger patient populations. In a previous study by Hawkins et al[15] reporting outcomes following open RCR of full-thickness RCT in patients aged 40 years or less with a comparable follow-up, the majority of patients reported improvement in function, but only half of the patients were able to RTA. Sperling et al[32] reported results after open RCR of full-thickness RCT in patients aged 50 years or less and found that RCR was not associated with significant long-term improvement in range of motion. Furthermore, in their study, a large proportion of patients were dissatisfied with the results at long-term follow-up.[32]

In summary, the findings highlight the overall positive effect of ARCR on the clinical outcomes and athletic activity–specific function in young and active patients. While a high rate of RTA may be expected following ARCR, the findings generated in our study may be used to preoperatively manage patients' expectations given that a return to preinjury levels, especially in overhead athletes, cannot be guaranteed and potential modifications to athletic activity may be required.

Limitations

This study has several limitations. First, the study is subject to the general limitations of a RTA analysis. As such, not only the surgery itself but also other factors such as timing of season, natural drop off in sports participation with age, subsequent confounding injuries, or factors unrelated to the shoulder can preclude sports participation. Second, while the patient population is one of the largest monocentric experiences presented for this specific age group, the total population size is relatively low—potentially due to the low incidence of the pathology in this age group. This may limit the statistical power of the subgroup analyses. Third, the lack of postoperative imaging prevents further analysis of outcomes based on repair integrity. However, as asymptomatic retears in young patients are extremely rare,[8] we believe the lack of imaging follow-up does not detract from the overall study findings. Fourth, the external validity of the study findings may be limited, as the data presented reflect a monocentric single-surgeon experience in a tertiary referral center. Thus, the results may not be generalizable. Finally, a noncomparative study design was elected. This decision was made, as the primary goal of this study was to provide a comprehensive report on outcomes to be expected in a cohort of active individuals aged 45 years and less. Given that the younger patients are more likely to return to more demanding athletic and professional activities compared to the senior patient population typically affected by RCTs,[14] the results of a comparison of inherently different patient populations were considered of limited meaningfulness.

Conclusion

ARCR of full-thickness RCT in athletes aged 45 years or less results in a clinically relevant improvement of outcomes, function and quality of life at a minimum of 2 years, and mean 5.8-year follow-up with a low rate of revision. While 86% of patients were able to RTA and sport-specific outcome metrics significantly and substantially improved compared to preoperatively, a return to preinjury levels was not reliably achieved in all patients, with particular limitations observed in overhead athletes. The data support the hypothesis that patients in this age group demonstrate significant improvements in clinical outcomes following ARCR along with significant improvements in athletic abilities.

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Supplementary Data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jseint.2024.03.002.

References

1. Altintas B, Anderson N, Dornan GJ, Boykin RE, Logan C, Millett PJ. Return to sport after arthroscopic rotator cuff repair: is there a difference between the recreational and the competitive athlete? Am J Sports Med 2020;48:252-61. https://doi.org/10.1177/0363546519825624.
2. Ardern CL, Webster KE, Taylor NF, Feller JA. Return to sport following anterior cruciate ligament reconstruction surgery: a systematic review and meta-analysis of the state of play. Br J Sports Med 2011;45:596-606. https://doi.org/10.1136/bjsm.2010.076364.
3. Azzam MG, Dugas JR, Andrews JR, Goldstein SR, Emblom BA, Cain EL Jr. Rotator cuff repair in adolescent athletes. Am J Sports Med 2018;46:1084-90. https://doi.org/10.1177/0363546517752919.
4. Baumgarten KM, Chang PS, Dannenbring TM, Foley EK. Does arthroscopic rotator cuff repair improve patients' activity levels? J Shoulder Elbow Surg 2018;27:2167-74. https://doi.org/10.1016/j.jse.2018.04.010.
5. Bhatia S, Greenspoon JA, Horan MP, Warth RJ, Millett PJ. Two-year outcomes after arthroscopic rotator cuff repair in recreational athletes older than 70 years. Am J Sports Med 2015;43:1737-42. https://doi.org/10.1177/0363546515577623.
6. Burns JP, Snyder SJ. Arthroscopic rotator cuff repair in patients younger than fifty years of age. J Shoulder Elbow Surg 2008;17:90-6. https://doi.org/10.1016/j.jse.2007.05.006.
7. Cvetanovich GL, Gowd AK, Liu JN, Nwachukwu BU, Cabarcas BC, Cole BJ, et al. Establishing clinically significant outcome after arthroscopic rotator cuff repair. J Shoulder Elbow Surg 2019;28:939-48. https://doi.org/10.1016/j.jse.2018.10.013.
8. Diebold G, Lam P, Walton J, Murrell GAC. Relationship between age and rotator cuff retear: a study of 1,600 consecutive rotator cuff repairs. J Bone Joint Surg Am 2017;99:1198-205. https://doi.org/10.2106/jbjs.16.00770.
9. Dwyer T, Razmjou H, Holtby R. Full-thickness rotator cuff tears in patients younger than 55 years: clinical outcome of arthroscopic repair in comparison with older patients. Knee Surg Sports Traumatol Arthrosc 2015;23:508-13. https://doi.org/10.1007/s00167-014-3094-2.
10. Eisner EA, Roocroft JH, Moor MA, Edmonds EW. Partial rotator cuff tears in adolescents: factors affecting outcomes. J Pediatr Orthop 2013;33:2-7. https://doi.org/10.1097/BPO.0b013e318279c2e0.
11. Engeroff T, Ingmann T, Banzer W. Physical activity throughout the adult life span and domain-specific cognitive function in old age: a systematic review of cross-sectional and longitudinal data. Sports Med 2018;48:1405-36. https://doi.org/10.1007/s40279-018-0920-6.
12. Faul F, Erdfelder E, Lang AG, Buchner A. G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behav Res Methods 2007;39:175-91. https://doi.org/10.3758/bf03193146.
13. Frangiamore S, Dornan GJ, Horan MP, Mannava S, Fritz EM, Hussain ZB, et al. Predictive modeling to determine functional outcomes after arthroscopic rotator cuff repair. Am J Sports Med 2020;48:1559-67. https://doi.org/10.1177/0363546520914632.

14. Garcia GH, Mahony GT, Fabricant PD, Wu HH, Dines DM, Warren RF, et al. Sports- and work-related outcomes after shoulder hemiarthroplasty. Am J Sports Med 2016;44:490-6. https://doi.org/10.1177/0363546515613077.
15. Hawkins RJ, Morin WD, Bonutti PM. Surgical treatment of full-thickness rotator cuff tears in patients 40 years of age or younger. J Shoulder Elbow Surg 1999;8:259-65.
16. Johannsen AM, Arner JW, Elrick BP, Nolte PC, Rakowski DR, Horan MP, et al. Minimum 10-year outcomes of primary arthroscopic transosseous-equivalent double-row rotator cuff repair. Am J Sports Med 2021;49:2035-41. https://doi.org/10.1177/03635465211015419.
17. Klouche S, Lefevre N, Herman S, Gerometta A, Bohu Y. Return to sport after rotator cuff tear repair: a systematic review and meta-analysis. Am J Sports Med 2016;44:1877-87. https://doi.org/10.1177/0363546515598995.
18. Krishnan SG, Harkins DC, Schiffern SC, Pennington SD, Burkhead WZ. Arthroscopic repair of full-thickness tears of the rotator cuff in patients younger than 40 years. Arthroscopy 2008;24:324-8. https://doi.org/10.1016/j.arthro.2007.09.005.
19. Lazarides AL, Alentorn-Geli E, Choi JH, Stuart JJ, Lo IK, Garrigues GE, et al. Rotator cuff tears in young patients: a different disease than rotator cuff tears in elderly patients. J Shoulder Elbow Surg 2015;24:1834-43. https://doi.org/10.1016/j.jse.2015.05.031.
20. Lin EC, Mall NA, Dhawan A, Sherman SL, McGill KC, Provencher MT, et al. Arthroscopic primary rotator cuff repairs in patients aged younger than 45 years. Arthroscopy 2013;29:811-7. https://doi.org/10.1016/j.arthro.2013.01.015.
21. Millett PJ, Hussain ZB, Fritz EM, Warth RJ, Katthagen JC, Pogorzelski J. Rotator cuff tears at the musculotendinous junction: classification and surgical options for repair and reconstruction. Arthrosc Tech 2017;6:e1075-85. https://doi.org/10.1016/j.eats.2017.03.023.
22. Millett PJ, Warth RJ. Posterosuperior rotator cuff tears: classification, pattern recognition, and treatment. J Am Acad Orthop Surg 2014;22:521-34. https://doi.org/10.5435/jaaos-22-08-521.
23. Mook WR, Greenspoon JA, Millett PJ. Arthroscopic double-row transosseous equivalent rotator cuff repair with a knotless self-reinforcing technique. Open Orthop J 2016;10:286-95. https://doi.org/10.2174/1874325001610010286.
24. Muench LN, Berthold DP, Otto A, Dyrna F, Bell R, Obopilwe E, et al. Increased glenohumeral joint loads due to a supraspinatus tear can be reversed with rotator cuff repair: a biomechanical investigation. Arthroscopy 2021;38:1422-32. https://doi.org/10.1016/j.arthro.2021.10.036.
25. Nwachukwu BU, Voleti PB, Berkanish P, Chang B, Cohn MR, Williams RJ 3rd, et al. Return to play and patient satisfaction after ACL reconstruction: study with minimum 2-year follow-up. J Bone Joint Surg Am 2017;99:720-5. https://doi.org/10.2106/jbjs.16.00958.
26. Parnes N, Bartoszewski NR, Defranco MJ. Arthroscopic repair of full-thickness rotator cuff tears in active patients younger than 40 Years: 2- to 5-year clinical outcomes. Orthopedics 2018;41:e52-7. https://doi.org/10.3928/01477447-20171114-02.
27. Pogorzelski J, Erber B, Themessl A, Rupp MC, Feucht MJ, Imhoff AB, et al. Definition of the terms "acute" and "traumatic" in rotator cuff injuries: a systematic review and call for standardization in nomenclature. Arch Orthop Trauma Surg 2021;141:75-91. https://doi.org/10.1007/s00402-020-03656-4.
28. Pogorzelski J, Horan MP, Hussain ZB, Vap A, Fritz EM, Millett PJ. Subpectoral biceps tenodesis for treatment of isolated type II SLAP lesions in a young and active population. Arthroscopy 2017;34:371-6. https://doi.org/10.1016/j.arthro.2017.07.021.
29. Reynolds SB, Dugas JR, Cain EL, McMichael CS, Andrews JR. Debridement of small partial-thickness rotator cuff tears in elite overhead throwers. Clin Orthop Relat Res 2008;466:614-21. https://doi.org/10.1007/s11999-007-0107-1.
30. Scanaliato JP, Eckhoff MD, Dunn JC, Czajkowski H, Fink WA, Parnes N. Long-term results of arthroscopic repair of full-thickness traumatic rotator cuff tears in active duty military patients under the age of 40 years. Am J Sports Med 2022;50:2753-60. https://doi.org/10.1177/03635465221107371.
31. Sher JS, Uribe JW, Posada A, Murphy BJ, Zlatkin MB. Abnormal findings on magnetic resonance images of asymptomatic shoulders. J Bone Joint Surg Am 1995;77:10-5.
32. Sperling JW, Cofield RH, Schleck C. Rotator cuff repair in patients fifty years of age and younger. J Bone Joint Surg Am 2004;86:2212-5. https://doi.org/10.2106/00004623-200410000-00012.
33. Tashjian RZ, Kim SK, Roche MD, Jones KB, Teerlink CC. Genetic variants associated with rotator cuff tearing utilizing multiple population-based genetic resources. J Shoulder Elbow Surg 2021;30:520-31. https://doi.org/10.1016/j.jse.2020.06.036.
34. Tibone JE, Elrod B, Jobe FW, Kerlan RK, Carter VS, Shields CL Jr, et al. Surgical treatment of tears of the rotator cuff in athletes. J Bone Joint Surg Am 1986;68:887-91.
35. Tooth C, Gofflot A, Schwartz C, Croisier JL, Beaudart C, Bruyère O, et al. Risk factors of overuse shoulder injuries in overhead athletes: a systematic review. Sports Health 2020;12:478-87. https://doi.org/10.1177/1941738120931764.
36. Van der Meijden OA, Westgard P, Chandler Z, Gaskill TR, Kokmeyer D, Millett PJ. Rehabilitation after arthroscopic rotator cuff repair: current concepts review and evidence-based guidelines. Int J Sports Phys Ther 2012;7:197-218.
37. Yamamoto A, Takagishi K, Osawa T, Yanagawa T, Nakajima D, Shitara H, et al. Prevalence and risk factors of a rotator cuff tear in the general population. J Shoulder Elbow Surg 2010;19:116-20. https://doi.org/10.1016/j.jse.2009.04.006.
38. Zhao J, Luo M, Pan J, Liang G, Feng W, Zeng L, et al. Risk factors affecting rotator cuff retear after arthroscopic repair: a meta-analysis and systematic review. J Shoulder Elbow Surg 2021;30:2660-70. https://doi.org/10.1016/j.jse.2021.05.010.