Original Article

Arthroscopic Anchorless Transosseous Rotator Cuff Repair Produces Equivalent Clinical Outcomes and Imaging Results as a Standard Suture Bridge Technique with Anchors

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Purpose: To compare the clinical and imaging outcome of arthroscopic transosseous (TO)-equivalent rotator cuff repair (RCR) with anchors with arthroscopic anchorless TO RCR at a minimum of 2 years postoperatively. **Methods:** The study population included patients who underwent RCR using either an anchorless TO technique with a TO suture passing device (group A) and those who were matched for tear size and underwent RCR using suture anchors for repair (group B). The inclusion criterion was an easily reducible rotator cuff tear with a sagittal extension of 2 to 4 cm. After a minimum of 2 years, clinical outcome scores and magnetic resonance imaging were obtained. Tendon quality and footprint integration were evaluated using the Sugaya classification. **Results:** Seventy patients were included. A total of 45 were in group A and 25 were in group B. Group A had 2 bone tunnels and 4 sutures using an X-box configuration, and group B had a suture bridge construct of 4 anchors. Group A and B had identical anteroposterior tear size and were comparable for age. The Constant score improved from 50 ± 17.4 to 88 ± 8.6 in group A versus 48 ± 14.5 to 87 ± 7.2 in B. The Subjective Shoulder Value rose from 47 ± 19.1 to 95 ± 7.4 in group A vs from 47 ± 19.4 to 95 ± 7.6 in B. Neither the preoperative ($P \geq .502$) nor postoperative scores ($P \geq .29$) showed a significant difference. Magnetic resonance imaging showed 2 small retears in group A and one in B, resulting in an identical 4% retear rate. The mean Sugaya type was 2.02 versus 2.24 ($P = .206$) for groups A versus B. **Conclusions:** Anchorless TO RCR is a valid alternative to suture anchor techniques. Clinical outcome data showed comparable results for both techniques after a follow-up of 2 years. The healing results as observed on magnetic resonance imaging were also equivalent for both groups. **Level of Evidence:** Level III, retrospective comparative study.

Historically, the gold standard of rotator cuff repair (RCR) has been open repair with transosseous (TO) sutures compressing the cuff to the bony footprint. This technique has proved to demonstrate convincing biomechanical properties[1,2] and to produce reliable healing results. In search of arthroscopic options, anchor fixation progressively emerged as the new gold standard,[3] evolving from single-row (SR) to double-row (DR) and transosseous-equivalent (TOE, i.e., suture-bridge) repair.[4,5] The TOE technique was intended to mimic the classical open TO technique and has shown to produce broader footprint contact than SR and DR. In one study, TOE and DR techniques provided superior clinical and healing results than SR.[6]

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Fig 1. The ARTHROTUNNELER (AT) device.

However, TOE anchor fixation seems to produce a greater number of type 2 failures, also termed "medial failures," as opposed to type 1 or lateral failures at the footprint.[7] Medial failures typically can present significant obstacles in the revision setting.[8]

Some other obstacles of anchor use have also remained, including knot impingement with prolonged postoperative pain, suture cut-through tendon,[9] anchor pull-out, cyst formation around anchors,[10] problems for additional anchor placement in revisions and high financial costs described by several authors.[11] Although rare, bone anchors also can be a source of infection.[12]

TO fixation, however, was not abandoned, and authors proposed completely arthroscopic techniques as early as 2002.[13] A variety of techniques for arthroscopic TO RCR has been proposed in the literature, such as an anterior cruciate ligament tibial drill guide, a customized drill guide,[14] or a variety of bone needles.[15,16] Subsequently, arthroscopic devices such as the ARTHROTUNNELER (Tornier/Wright, Memphis TN) were designed to allow the creation of intersecting bone tunnels[17] (Fig 1). The purpose of the study was to compare the clinical and imaging outcome of arthroscopic TOE RCR with anchors with arthroscopic anchorless TO RCR at a minimum of 2 years postoperatively. We hypothesized, first, that anchorless repair of medium-to-large tears of the supra- and infraspinatus would lead to similar clinical outcomes as defined by the Constant score (CS), the Simple Shoulder Value (SSV), the Simple Shoulder Test, and a visual analog scale for pain, if compared with anchored repairs. Second, we hypothesized that the magnetic resonance imaging (MRI) results of TO RCR would be at least equal or superior to that of an anchor-based arthroscopic technique.

Methods

Study Design, Indications, Patient Selection, and Inclusion Criteria

Board approval was obtained at the University of Vienna with the number EK 1369/2018. This was a comparative study of 2 cohorts of patients with traumatic or degenerative tears of the supra/infraspinatus (SSP/ISP) tendon unit who chose arthroscopic repair because of persisting pain and functional impairment. They all had MRI findings of a full-thickness rotator cuff tear with good tendon quality and no or minimal signs of muscle atrophy (Goutallier grade 0-1).

The main inclusion criterion for the study was the anterior-to-posterior diameter of the tear after debridement measured intraoperatively with a hook probe. This diameter has previously been termed "exposed footprint" (EFP)[18] and is defined as a linear measurement of the extent of the tear. The tears were crescent-shaped, U-shaped, or (anteriorly or posteriorly) L-shaped. They were easily reducible to the footprint without extensive releases. We included patients with concomitant small partial tears of the subscapularis (SSC) type Lafosse I[19] that were repaired in situ with one anchor to prevent tear progression. Patients with biceps pathology needing tenotomy or tenodesis were included as well. Shoulders with a massive (i.e., EFP ≥4.5 cm) SSP/ISP tear, with more complex tear configurations, retracted SSC tears, retears, poor tendon quality, cartilage damage, and stiffness were excluded from this study.

All patients with a full-thickness tear of SSP/ISP with an EFP of 2 to 4 cm and operated on using a TO X-box repair technique were prospectively included since January 14, 2014. The X-box configuration uses 2 bone tunnels and 4 suture strands, 2 of which run straight and the 2 others cross over from one tunnel to the other (Fig 2 A and B). All patients were operated by one single surgeon (E.B.). Until November 15, 2015, the number of TO cases reached 50 (cohort A). The results compared with 25 matched patients undergoing anchor-based TOE suture bridge technique by same surgeon using same indications from February 2012 to November 2013 (cohort B) (Appendix Fig 1, available at www.arthroscopyjournal.org).

Data Collection

After a minimum of 2 years, 2 independent orthopaedic surgeons (H.B. and P.B.) collected patient-recorded outcomes and strength measurements, which were performed with the Isobex device (Cursor AG, Bern, Switzerland). An MRI was obtained at the 2-year follow-up and evaluated as described in the section to follow.

MRI Evaluation

An MRI (MAGNETOM Aera 1.5-T Scanner; Siemens Healthineers, Cary, NC) was performed to evaluate the structural integrity of the repaired cuff in all cases with the use of a dedicated shoulder coil (16-channel coil). The protocol included a three-plane localizing sequence (T1 turbo spin echo [TSE] axial blade resolution 448 × 448, proton density TSE fat-suppressed coronal blade resolution 320 × 320, proton density TSE fat-suppressed sagittal blade resolution: 384 × 384). The

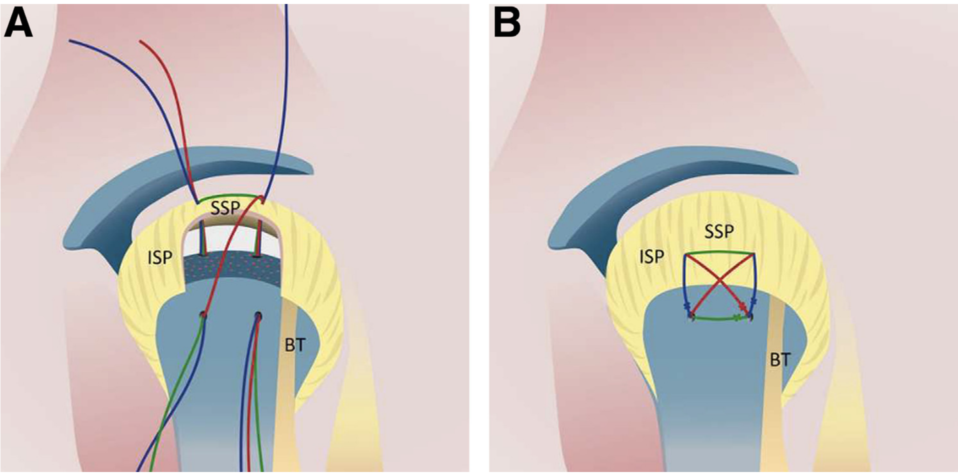

Fig 2. Transosseous repair (group A): Diagram showing right shoulder, lateral view. (A) Suture passing for TO RC repair with 2 bone tunnels and 4 color-coded sutures. Blue, straight sutures; green, box-suture; red, x-suture. (B) Final aspect of X-box repair configuration. (BT, biceps tendon; ISP, infraspinatus; SSP, supraspinatus.)

sequences were anonymized and analyzed separately by an independent radiologist (M.S.) and an independent orthopaedic surgeon (B.W.) not involved in the treatment. Both graded the images and classified independently according to Sugaya's grading system (Table 1) and then compared their results. If the grading differed, they discussed their findings until reaching consensus. The same procedure was repeated a second time 2 months later. Only the result of the second course—likely more accurate and with a greater interrater reliability—was retained to calculate the results. The interrater reliability was 0.58 in the first and rose to 0.64 in the second course. Intraobserver reliability was 0.71 and 0.70, respectively.

Surgical Technique

Patients were operated on in the beach-chair position using a custom-made soft-tissue traction system that maintains the arm in loose forward flexion of 30-40° and allows for free rotation and extension. Apart from the posterior standard portal, 3 other portals were established routinely: an anterosuperior, a lateral, and a posterolateral portal. Additional percutaneous portals were established as needed for suture management. The glenohumeral phase of the intervention included biceps tenodesis or tenotomy and repair of small subscapularis tears if indicated. Next, footprint preparation with an aggressive shaver to expose bleeding bone (anteroposterior diameter 2-4 cm) was accomplished, followed by bone marrow stimulation with a microfracture device. After performing an extended bursectomy and sparse acromioplasty, tear configuration and mobility were tested with a suture retriever.

Table 1. Sugaya Classification of the Repaired Cuff (2005)

Type I: sufficient thickness compared with normal cuff with homogenously low intensity
Type II: sufficient thickness ($\geq$3mm) with partial high intensity areas
Type III: thinned cuff with less than half of normal thickness without discontinuity ($\leq$2.5mm)
Type IV: minor discontinuity in only 1 or 2 slices on both oblique coronal and sagittal images
Type V: major discontinuity observed in more than 2 slices on both oblique coronal and sagittal images

Anchorless TO Repair with the ARTHROTUNNELER (AT) Device

In the prospective cohort A, tears were repaired using 2 bone tunnels and 4 high-strength sutures with the operative technique that has been previously described (Fig 2 A and B).[20] Two medial tunnels 1.5 cm apart from each other and adjacent to the articular surface were created with a 2.9-cm trocar with the humerus in 2 different positions of abduction. The tip was inserted into the medial hole until the arch of the aiming device was in contact with the footprint. A lateral intersecting tunnel was drilled and a nitinol loop was passed to retrieve a FiberWire shuttling loop (Arthrex, Naples, FL) through the tunnel. A Clever hook (DePuy Mitek, Raynham, MA) was used to pass the anterior loop through the anterior cuff tissue first, and then, the posterior loop through the posterior cuff. With the help of the posterior loop, 3 color-coded high-strength sutures (FiberWire or ORTHOCORD [DePuy Synthes, Warsaw, IN]) were then shuttled through the posterior tunnel. A fourth high-strength suture was added before performing the shuttling maneuver anteriorly. The sutures were tightened over the cuff in an X-box configuration and all the knots placed onto the greater tuberosity.

Anchor-Based Repair (SpeedBridge; Arthrex)

In the retrospective comparative cohort B, the SSP/ISP tear was repaired with a typical 4-anchor construct (2 medial and 2 lateral SwiveLock anchors) and 4 limbs of suture tape (Fig 3 A and B). As a modification of the

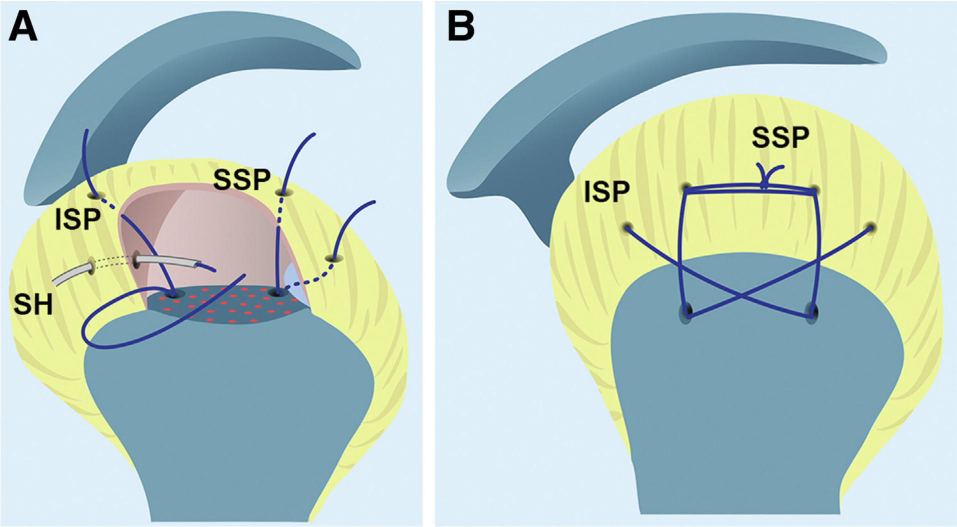

Fig 3. Anchor-based repair (group B): Diagram showing right shoulder, lateral view. (A) Passage of the FiberTapes of the 2 medial anchors. One limb of each tape is pierced separately by means of a suture hook. Posteriorly the deep ISP layer is included. (B) Completed suture bridge repair with 2 lateral anchors and medial bridge using the eyelet retention sutures. (ISP, infraspinatus; SH, suture hook; SSP, supraspinatus.)

standard technique, one limb of the suture tape was pierced separately through the posterior and the anterior cuff by means of a suture hook and a polydioxanone shuttle. Furthermore, we connected the medial anchors with a double pulley suture (box suture) using the eyelet retention FiberWire sutures.

Statistical Analysis

Data collection and processing were carried out with SAS's graphical statistic program JMP, version 16.0.0 (SAS Institute, Cary NC.). Statistical evaluation of the data was accomplished according to the distribution character of the data (normally distributed or non-normally distributed). In normally distributed data, univariate analysis of variance was the standard outcome evaluation tool. In non-normally distributed data, the nonparametric Wilcoxon/Kruskal—Wallis test was used to evaluate the significance levels, respectively. Significance level was set to $P = .05$. A post-hoc power analysis revealed for the CS a required sample size of 15 in each group to obtain a power of 0.8 with an alpha level of 0.05. For the SSV, a sample size of 96 and for the Sugaya score of 14 would be needed.

Table 2. Demographic and Intraoperative Patient Data for the Two Cohorts

	Group A*	Group B†	*P* Value
Sample size	45	25	
Follow-up time, mo	29 ± 5.2 (24-54)	34 ± 6.8 (24-47)	.0002
Age, y	56 ± 9 (36-76)	61 ± 8 (46-72)	.035
Sex, male	49%	84%	.003
Side, right	67%	64%	.82
EFP, cm	2.9 ± 0.5 (2-4)	2.9 ± 0.4 (2-4)	.73
SSC repair (in %)	13	36	.03
LHBT tenodesis/ tenotomy (in %)	56	84	.02

NOTE. Data presented as mean ± standard deviation + range () or %.

Significance levels were calculated via the Wilcoxon/Kruskal—Wallis test.

EFP, exposed footprint; LHBT, long head of biceps tendon; SSC, subscapularis.

*Transosseous anchorless (TO).

†Transosseous equivalent (TOE) with anchors.

Results

As shown in Table 2, the 2 cohorts A and B had the same mean tear size of 2.9 cm, as expressed by the EFP ($P = .73$). Age did not show a significant difference ($P = .035$). There were more men in cohort B with 84% as compared with 49% in cohort A ($P =. 003$). Follow-up time was significantly longer for cohort B, as this was the control group operated during an earlier period (34 vs 29 months; $P = .0002$). Regarding the concomitant procedures for the biceps and the SSC, these were applied more frequently in cohort B ($P = .03$ and $P = .02$, respectively).

The clinical results for both cohorts were almost identical with highly significant improvements for all scores ($P < .01$), as shown in Table 3 and Figure 4. Neither the pre- nor the postoperative scores showed a difference between the 2 techniques ($P \geq .502$ and $P \geq .29$, respectively). The postoperative results showed a final subjective shoulder value of 95% for both groups and an improvement of the CS of 38 and 39 points, respectively.

As to MRI results shown in Table 4 and Figure 5, structural tendon integrity was not statistically different ($P = .206$), and the retear rate was equal. We found 2 small retears classified as Sugaya type IV in cohort A and one in B resulting, which resulted in an identical retear rate of 4% for both cohorts. Type I and II

Table 3. Clinical Results

	Group A[*] (n = 45)		Group B[†] (n = 25)	
	Pre	Post	Pre	Post
Constant score	50 ± 17.4	88 ± 8.6	48 ± 14.5	87 ± 7.2
95% CI	44-55	85-91	41-55	84-90
SSV	47 ± 19.1	95 ± 7.4	47 ± 19.4	95 ± 7.6
95% CI	41-52	93-97	39-55	92-98
SST	4.1 ± 2.5	11.5 ± .87	4.4 ± 3.2	11.6 ± .76
95% CI	3.4-4.9	11.2-11.8	3.0-5.7	11.3-11.9
VAS	6.8 ± 2.0	0.4 ± 1.1	6.4 ± 2.1	0.6 ± .9
95% CI	6.2-7.4	.09-.72	5.5-7.3	.18-.94

NOTE. Data are presented as mean ± standard deviation and 95% CI.

No significant difference in preoperative scores ($P \geq .502$).

All scores improved significantly from pre- to postoperative ($P < .01$).

No significant difference in postoperative scores ($P \geq .29$).

CI, confidence interval; SST, Simple Shoulder Test; SSV, Subjective Shoulder Value; VAS, visual analog scale.

[*] Transosseous anchorless (TO)

[†] Transosseous equivalent (TOE) with anchors'

combined added up to 80% in cohort A and 64% in B, whereas type III was less frequent in cohort A (16% vs 32%) ($P = .145$). See examples in Figures 6-8.

Discussion

Comparison of the results of arthroscopic anchorless TO RCR with the results of a control group operated with an anchor-based repair construct showed no difference in improvement of clinical scores. The postoperative results can be rated excellent for both cohorts, with a final subjective shoulder value of 95% and an improvement of the CS of 38 versus 39 points from pre- to postoperative for the anchorless TO and the anchored TOE technique, respectively. Hence, our study shows that anchorless TO RCR leads to reliably good results with significant improvements in all clinical scores, low retear rates, and high patient satisfaction. We applied a standardized technique with an X-box suture configuration in all included cases.

The structural healing rate was equal. However, the healing results on MRI after minimum of 2 years showed a greater percentage of type I and II healing (normal or near normal, Fig 6 and 7) in the anchorless TO group, whereas in the anchored TOE repairs intact but thinned cuffs graded Sugaya type III (Fig 8) were observed more frequently. The tendency toward slightly better tendon healing at the humeral footprint might be the result of enhanced blood flow from the bone tunnels.

The hypothesis that both techniques would produce equivalent clinical results was confirmed. However, the assumption of better structural healing in the anchorless group failed to reach statistical significance.

Randelli et al.,[21] in a randomized double blinded clinical trial (level I) comparing 31 arthroscopic anchorless TO vs 35 anchored SR repairs showed similar results for both techniques regarding MRI assessed tendon healing (87% vs 88% Sugaya type I-III 1 year after surgery) and shoulder function assessed by the CS and the QuickDASH. Srikumaran et al.[22] compared 2 matched cohorts of 50 patients each using clinical scores and imaging with ultrasound. They found that TO and TOE techniques resulted in no difference for range of motion, American Shoulder and Elbow Surgeons scores, retear rates, and operating time. In their study, retear rates on ultrasound were 14% in both groups. Seidl et al.[23] compared implant cost, operating time and patient based clinical scores of 2 cohorts of 21 patients each without imaging. While costs were lower in the anchorless TO group, operating time and the clinical scores showed no difference.

Our study is in line with the previous comparative studies on anchorless vs anchored arthroscopic RCR. However, in our study an important improvement of the CS was found, while Randelli et al.[21] reported a surprisingly modest improvement of 6 and 7 points, respectively. The minimal clinically important difference for the CS in patients with RCR was calculated to be 10.4 points by Kukkonen et al.[24] They also reported a greater retear rate of 13 versus 12% on MRI. The latter is also true for the comparative study of Srikumaran et al. [22] with retear rates of 14% for both groups on ultrasound.

Three studies from 2013 to 2016 describe case series of 31 to 384 cases of arthroscopic anchorless TO repair.[14,25,26] They all obtained good results in American Shoulder and Elbow Surgeons or UCLA scores. Kuroda et al.,[14] in the largest series of 384 patients,

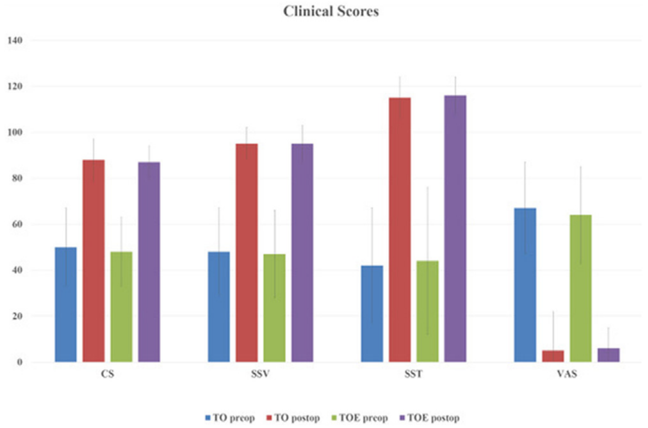

Fig 4. Clinical scores. (CS, Constant score; SST, simple shoulder test; SSV, subjective shoulder value; TO, transosseous; TOE, transosseous equivalent; VAS, visual analog scale.)

Table 4. Radiologic Results

Sugaya Type	I	II	III	IV	V
Group A TO (n = 45)	22% (10)	58% (26)	16% (7)	4% (2)	0% (0)
Group B TOE (n = 25)	16% (4)	48% (12)	32% (8)	4% (1)	0% (0)

NOTE. No significant difference regarding postoperative tendon integrity (Pz = .206).

TO, transosseous; TOE, transosseous equivalent.

A/TO combined I + II = 80% combined III + IV = 20%

B/TOE combined I + II = 64% combined III + IV = 36% (*P* = .145).

observed only 6% of retears on MRI, which is similar to our results. They used a customized drill guide and K-wires inserted in an angle of 55° from the lateral cortex of the greater tuberosity to the medial rotator cuff footprint and exiting percutaneously behind the acromioclavicular joint to pull the sutures through the cuff. Of note, they observed only 1 bone tunnel related issue intraoperatively and no axillary nerve damage in postoperative electromyography. Liu et al.,[27] in a study on patients with TO repairs of medium-sized rotator cuff tears, found a surprisingly high retear rate of 33% on MRI in a case series of 27 patients. The authors included the Sugaya type III cases in the anatomic failure group, which is unusual, as most authors consider only cuffs with a discontinuity a failure. In our own experience, patients with a type III cuff generally do clinically well and remain stable with a good shoulder function over time. Even including type III cuffs would result in a failure rate of only 21% in our own TO series.

Cadaver laboratory studies showed mixed results of biomechanical testing. Salata et al.[28] in 2013 compared 4 techniques in regard to ultimate failure load and cyclic elongation on 28 specimens randomized in the 4 repair groups: TOE with 4 anchors, TO simple with 2 bone tunnels, AT simple, and AT X-box. The TOE-anchored construct performed best, with a maximum failure load of 558 N as compared with 291 to 388 N for the 3 anchorless techniques. The AT X-box (with 388 N) performed second best of the 4 constructs. In the same year, Kummer et al.[29] published a study on 6 pairs of cadaver shoulders comparing cuff edge displacement at 10,000 cycles and ultimate failure load for identical repair constructs as we have applied in our study. They found no statistical difference and concluded that an arthroscopic TO repair using an X-box configuration is similar in strength and stability to a TOE suture bridge-repair.

Kilcoyne et al.[30] found that in 10 pairs of shoulders mean failure load was greater in the anchored TOE technique but also observed a greater incidence of type 2 failures at the musculotendinous junction as compared with the anchorless AT group (7/10 vs 4/10). They conclude that the potential benefit of greater stability might come at the cost of an unfavorable failure mode. Finally, Bronsnick et al.[31] were unable to demonstrate an influence of different tunnel angles and bone quality on the strength of the bone—suture interface by mechanical testing of 10 cadaver humeri.

Urita et al.[32] published a basic science anatomic study in 2017: They compared the sequential blood flow as measured by contrast-enhanced ultrasound in 21 shoulders after arthroscopic cuff repair in a randomized study. The TO repair group showed greater blood flow inside the cuff and in the area of the bone tunnels than the TOE group. They concluded that bone tunnels might contribute to biological healing at the footprint by increasing blood flow at 1 to 3 months' postoperatively.

RCR has become increasingly frequent in the last 2 decades and so have concerns about its economic impact. Studies about its societal and economic value seem, however, to confirm its positive balance especially in patients younger than 61 years.[33] Several studies have focused on implant costs and operating times of anchorless and anchor-based repairs.[11,23] In our own environment, we found a difference of implant costs of 400 Euros in favor of the TO approach (770 vs 1170 Euros).

Thickness of the rotator cuff on imaging is an important feature when applying the widely used Sugaya classification. As to normal thickness of the SSP tendon, there is no consensus in the literature, with different indications in MRI, ultrasound, and cadaver studies with a variance of 4 to 8 mm.[34-36] As a compromise, the reviewers in our study chose to accept

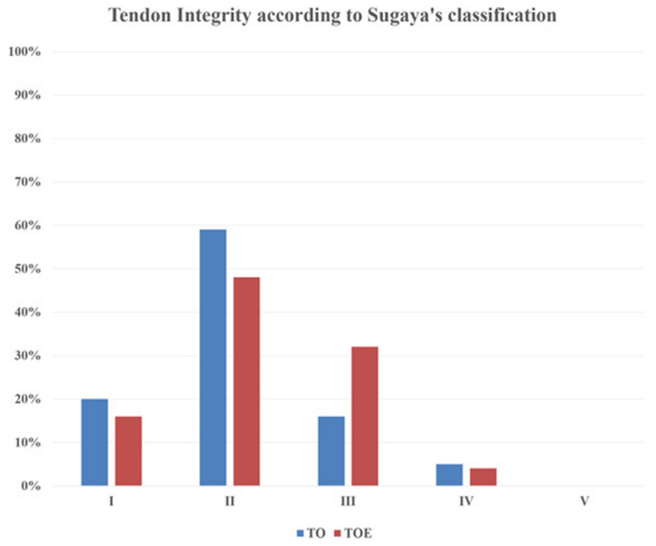

Fig 5. Tendon integrity according to Sugaya's classification. (TO, transosseous; TOE, transosseous equivalent.)

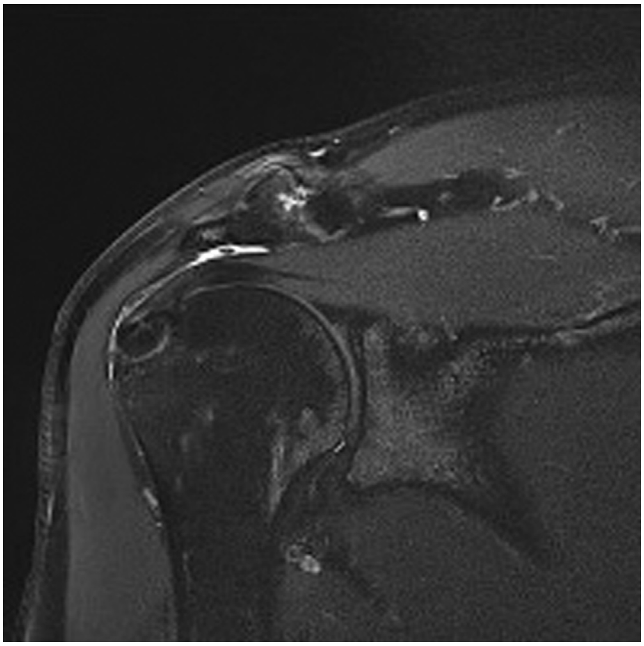

Fig 6. Example of coronal magnetic resonance imaging (right shoulder) 2 years after TO RC repair. The SSP tendon was graded Sugaya type I. The bone tunnel is clearly appreciated. (RC, rotator cuff; SSP, supraspinatus; TO, transosseous.)

2.5 mm as the threshold to define half of the thickness of a normal cuff. That means an intact cuff with ≥3 mm thickness would be rated type II, and if thickness was ≤2.5 mm, it was rated as a Sugaya type III. A location in the middle between the apex of the humeral head and the cartilage limit adjacent to the footprint was chosen to perform the before mentioned measurement.

When comparing the 2 cohorts, we are aware of a lower percentage of additional procedures addressing the biceps and the subscapularis in the anchorless TO repair cohort. This might induce a bias towards potentially better clinical results because of a tendency of less complex tear patterns in this cohort. The greater percentage of male patients in the anchored TOE group might in part counterbalance this bias, as the literature reports generally better results for male patients than for women.[37]

Limitations

There are limitations to this study. The results are a comparison from a prospective cohort versus a retrospective cohort, which could open it to selection bias. Second, this study is also limited by its sample size. While a post-hoc power analysis revealed sufficient power regarding the CS and Sugaya score results, a considerable greater sample size, which is not feasible in a single-center setting, would have been needed to detect significant differences regarding the SSV.

Conclusions

Anchorless TO RCR is a valid alternative to suture anchor techniques. Clinical outcome data showed comparable results for both techniques after a follow-up of 2 years. The healing results as observed on MRI were also equivalent for both groups.

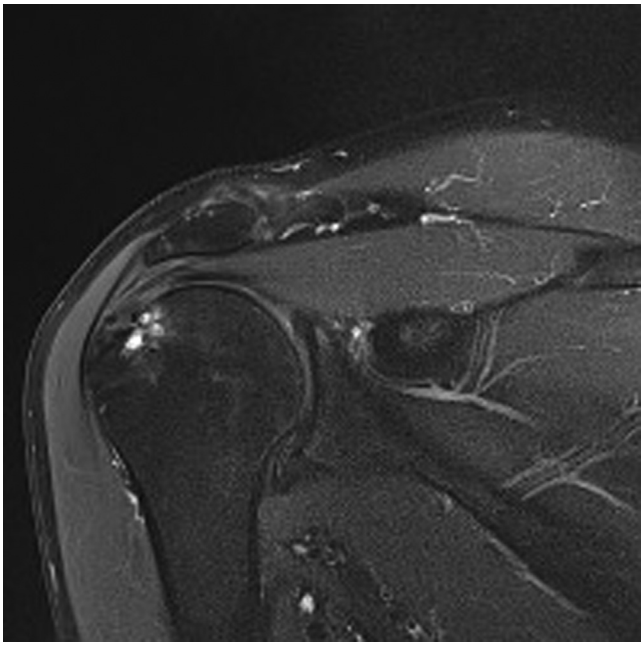

Fig 7. Example of coronal magnetic resonance imaging (right shoulder) of SSP tendon rated as Sugaya type II. (SSP, supraspinatus.)

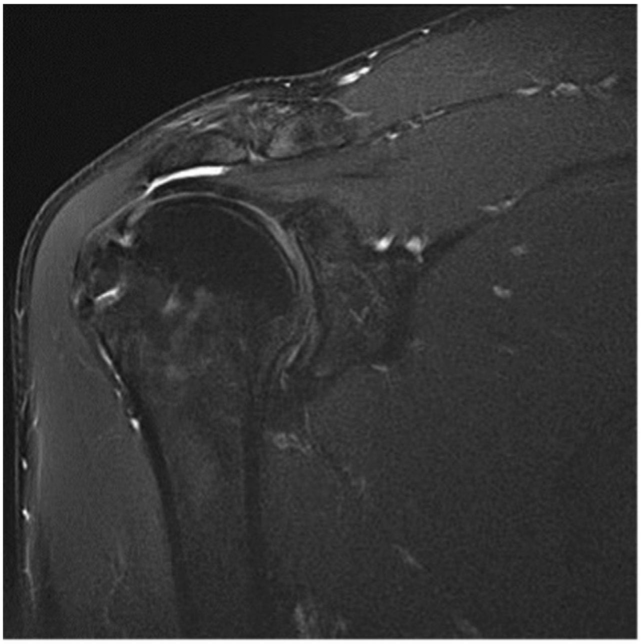

Fig 8. Example of coronal magnetic resonance imaging (right shoulder) of SSP tendon rated as Sugaya type III. (SSP, supraspinatus.)

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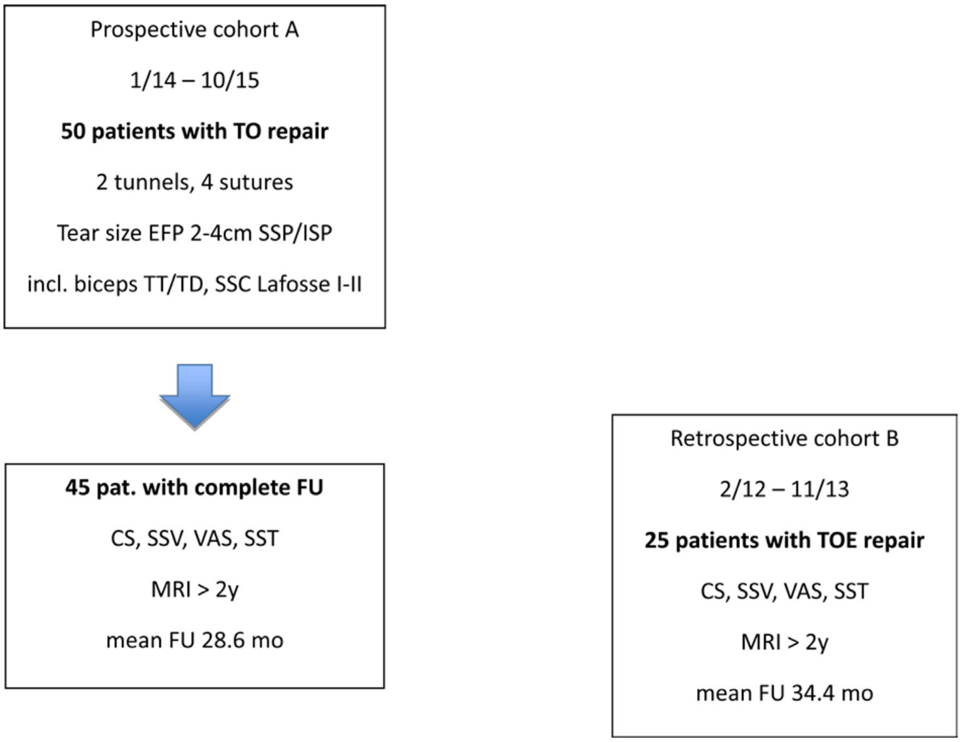

Appendix Fig 1. Flow chart of patient selection. (CS, Constant score; EFP, exposed footprint; FU, follow-up; ISP, infraspinatus; MRI, magnetic resonance imaging; pat., patients; SSC, subscapularis; SST, Simple Shoulder Test; SSV, Subjective Shoulder Value; TD, tenodesis; TO, transosseous; TOE, transosseous equivalent; TT, tenotomy; VAS, visual analog scale.