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ORIGINAL ARTICLE

Advanced Rotator Cuff Tear Score (ARoCuS): a multi-scaled tool for the classification and description of rotator cuff tears

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Abstract

Background To introduce a (semi-)quantitative surgical score for the classification of rotator cuff tears.

Material and Methods A total of 146 consecutive patients underwent rotator cuff repair and were assessed using the previously defined Advanced Rotator Cuff Tear Score (ARoCuS) criteria: muscle tendon, size, tissue quality, pattern as well as mobilization of the tear. The data set was split into a training (125 patients) and a testing set (21 patients). The training data set fitted a nonlinear predictive model of the tear score based on the ARoCuS criteria, while the testing data served as control. Based on the scoring results, rotator cuff tears were assigned to one of four categories (ΔV I–IV) and received a stage-adapted treatment. For statistical analysis, mean values ± standard deviation, interclass correlation coefficients (ICC) and kappa values were calculated.

Results Overall, 32 patients were classified as ΔV I, 68 as ΔV II and 37 as ΔV III. Nine patients showed ΔV IV tears. Patients of all ΔV groups improved significantly their Constant scores ($p < 0.001$) and profited from significant pain reduction after surgery ($p < 0.001$). To date, ten patients have undergone revision surgery with five of them primarily classified as ΔV IV. Kappa values for the interobserver reliability ranged between 0.69 and 0.95. ICC scores for the ΔV category were 0.95 for interobserver reliability.

Conclusions The ARoCuS facilitates intra-operative decision-making and enables surgeons and researches to document rotator cuff tears in a standardized and reproducible manner.

Keywords Rotator cuff tear · Classification · Scoring tool · Intraoperative scoring · ARoCuS · Advanced Rotator Cuff Tear Score

Introduction

Multiple classifications for the description of rotator cuff tears have already been published. The variety of diverse classifications, however, states a dissatisfaction with the single, individual scoring or classification system and a dissent on which system has to be used in order to gain consensus on the optimal treatment [1]. Possible factors contributing to this situation could be inaccuracy, incompleteness, little interobserver agreement or complexity.

Obviously, some classifications are kept overly simple; regarding only the torn tendon and the size of the tear to be important [2, 3]. Other classifications in turn are very detailed and might be too specific [4, 5]. Therefore, those classifications do not necessarily result in a more differentiated treatment strategy [2, 6, 7] and impede comparability as there is no consensus on which classification to use. Thus, there is a need for a novel classification system which has to meet the following criteria:

1. Practicality and comprehensibility.
2. Standardized documentation of all rotator cuff tear's relevant characteristics.
3. Reproducibility and comparability of scoring results.
4. Predictability of clinical outcome and prognosis based on scoring results.

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Materials and methods

The study was approved by our institutional review board. The study was conducted according to the principles of the Declaration of Helsinki (World Medical Association). Data of 146 consecutive patients that were treated at our hospital in the time between 2011 and 2016 were evaluated prospectively. Inclusion criteria were the clinical and radiological (MRI-based) diagnosis of a rotator cuff tear and the subsequent surgical treatment. Patients that had been operated previously on the affected shoulder were excluded from the study. Finally, the study population consisted of 146 patients. For measurement of the clinical outcome, a Visual Analog Scale (VAS) for pain and the normalized Constant score were used [8].

The intraoperative examination of the tear was done arthroscopically, but the repair itself was made using a "Mini Open" technique [9, 10]. All operations were performed by one senior surgeon (W.T.). For the re-fixation of the torn tendons an Ethibond® Excel suture (Ethicon-Johnson & Johnson Company, Cincinnati, OH, USA) size 2 or a HEALIX TI™ anchor (DePuy Mitek, Inc., Raynham, MA, USA) was used.

All rotator cuff tears were evaluated by two senior surgeons with 37 and 16 years' experience in musculoskeletal surgery using a documentation sheet evaluating the Advanced Rotator Cuff Tear Score (ARoCuS) criteria. These criteria (muscle tendon, size, tissue quality, pattern and mobilization of the torn tendon) were documented in a firm order. Thus, it resulted a 4–5 digit (parts) coding of the ARoCuS with specific (sub-)items (Table 1).

Coding of the tear's characteristics

Muscle tendon (*M*)

The first digit in the ARoCuS is the description of the torn tendon. Each torn tendon of the rotator cuff muscles is described by a specific rank: supraspinatus muscle 1 pt., subscapular muscle 2 pts., infraspinatus muscle 3 pts. and teres minor muscle 4 pts (Fig. 1). If more than one tendon was torn, the ranks of all affected tendons were documented.

Size (*S*)

The second digit represents the greatest length of a tear. For the assessment of the tears' size, a maximum of three points was noted in cases of large tears. The following definition was made: Small tears < 1 cm (1 pt.), Medium tears 1–3 cm (2 pts.), Large tears > 3 cm (3 pts.). The tear's size was measured arthroscopically using a caliper.

Tissue quality (*T*)

The third digit in the coding describes the tissue quality of the torn tendon. The condition of the tear's edge is an indicator for the overall quality of the tissue. Clear, fresh edges are associated with not atrophic muscles and rated 0.5 pts. If there was some fraying at the tear's edge 1 pt., and in cases of severely frayed edges, 1.5 pts were documented.

Pattern (*P*)

The fourth digit of the ARoCuS coding describes the shape and pattern of a tear (Fig. 2). Articular-sided partial thickness tears were awarded 1 pt., while bursal-sided partial thickness tears were documented with 2 pts. Crescent-shaped tears were rated 3 pts., while *L*- or *T*-shaped tears were documented 4 pts. Finally, massive/complex tears were rated 5 pts.

Mobilization (MOB)

The fifth digit of the coding is applied only if the fourth digit ("pattern") was 4 pts. (L/T shaped) or 5 pts. (massive tear). In those cases, the torn tendons can impress as atrophic und retracted tissue, which can hardly be mobilized. If the retracted torn tendon and the associated muscle could be mobilized without additional force, 0.5 pts were documented. Retracted tendons with a reduced capacity of mobilization were rated 1

Table 1 The criteria (parts and items) for the ARoCuS classification are presented in this table

M-muscle tissue	*S*-size	*T*-tissue quality	*P*-pattern	mob-Mobilization
(1) Supraspinatus muscle	(1) Small (< 1 cm)	(1) Sharp, clear edge	(1) (Partial-) thickness (articular)	
(2) Subscapular muscle	(2) Medium (1–3 cm)	(2) Some fraying	(2) (Partial-) thickness (bursal)	
(3) Infraspinatus muscle	(3) Large (> 3 cm)	(3) Severe fraying	(3) Crescent shaped	
(4) Teres minor muscle			(4) *L*/*T* shaped	(1) Mobilization
			(5) Massive	(2) Reduced mobilization
				(3) Immobilization

For each criteria ranks for the tear's severity are given. Please note that the ranks shown in this table are not equal to the factors used to calculate ΔV as ranks are multiplied by specific coefficients

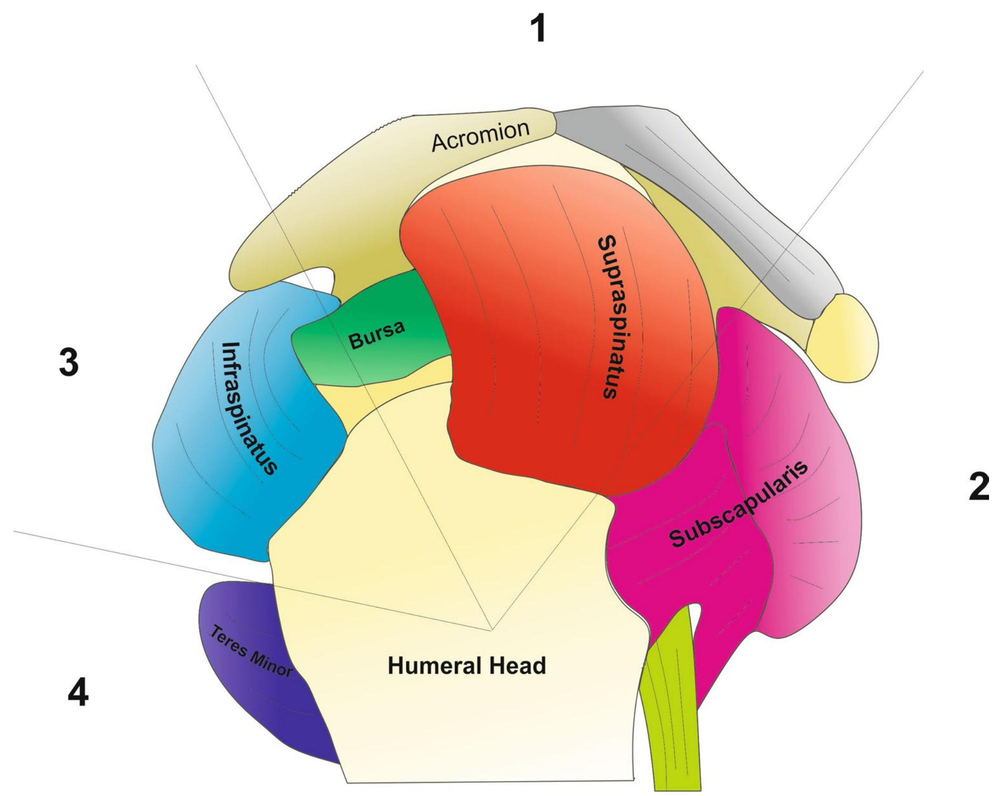


Fig. 1 Lateral view onto the right-side rotator cuff muscles. Each muscle is attributed with a specific rank for calculating the ARoCuS value. The shown submuscular bursa is not to mistake as the Bursa Subacromialis

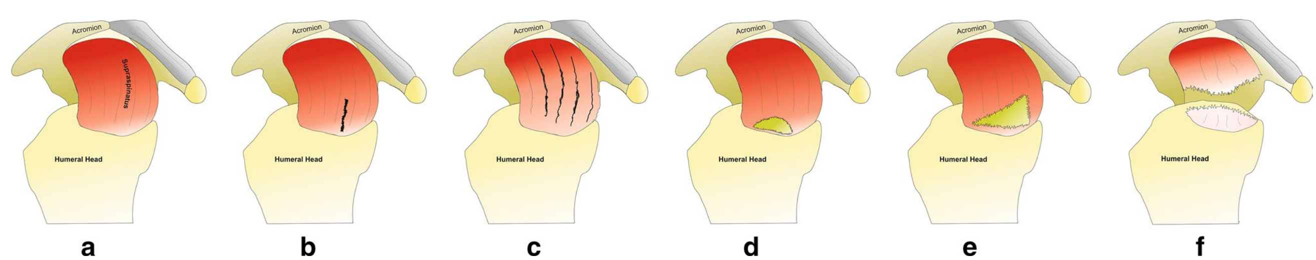


Fig. 2 In this figure, the principal five tear patterns are shown for a supraspinatus muscle tear. **a** Normal, healthy tendon without any signs of damage. **b** Partial thickness tear of the tendon. The tear can have its origin on the articular or the bursal side (Bursa Subacromialis) of the tendon. **c** Longish slit along the fiber lines with a complete perforation of the tendon or muscle. **d** Crescent-shaped tear without signs of retraction. **e** *L*-/*T*-shaped tear and **f** massive tear of the tendon

pt. If the mobilization of the retracted tendon was hardly possible or impossible 1.5 pts. were documented.

Given the ranks of each criteria, a rotator cuff tear was described as the following example demonstrates: M1 S1 T2 P1 [the supraspinatus muscle showed a small-sized lesion with some fraying of the tear's edge. The lesion itself was articular sided and of partial thickness (Table 2)].

Calculation of the tear's dimensions

Given the description of the tear and the corresponding ranks, the dimensions of the tear were calculated using a nonlinear predictive model of the form:

$$\Delta V = \left(w_1 \cdot M \cdot S + w_2 \cdot M \cdot T\right) \cdot P \cdot \mathrm{MOB} + w_3$$

Table 2 Proposed treatments according to the four clinical categories ΔV (ARoCuS grade)

Rotator cuff tear-coded description	Detailed description of the tear	Category according to ΔV
M2 S2 T1 P2	Supraspinatus muscle, which has a medium-sized, sharp-edged articular-sided partial thickness tear	II
M1,2 S3 T3 P5 mob1	Supraspinatus and subscapular muscles, which have a large, somewhat frayed, massive but mobilized tear	III

Different ΔV categories were highlighted by specific colors: ΔV I: blue, ΔV II: orange, ΔV III: gray, ΔV IV: pink

where M, S, T, P, MOB are the five assessed ARoCuS criteria and w_1, w_2, w_3 the parameter of the nonlinear model. The nonlinear weights were fitted using a nonlinear regression. The *scipy.optimize.curve_fit* [11] implementation was used to find the set of weights by a nonlinear least squares method. The model that best predicted the tear scores of the first 125 patients that were used as a training set was given as:

$$\Delta V = (0.56 \cdot M \cdot S + 1.02 \cdot M \cdot T)\text{PMOB} - 3.00$$

The residual root-mean-squared error (RMS) for the training set was assessed as:

$$\text{RMS} = \frac{\sum \left(\Delta V_{\text{predicted}} - \Delta V_{\text{true}}\right)^2}{n}$$

This is the sum of the squared distance between the measured and the predicted rotator cuff tear's dimension where $n = 125$ is the number of patients in the test set. The RMS of the model fit was 38.15. To measure the model's performance the other 25 patients were hold back as a test sample and not included in the model fit. Their scores were predicted with best fitting nonlinear predictive model as given above. The RMS of the test set was 25.86.

Classification of the tear

Given the tear's dimension a category ΔV was assigned to each patient per the values given in Table 3.

Statistics

All statistical analyses were performed using SPSS 24.0 (IBM, Chicago, IL). Level of significance for all tests was $p \leq 0.05$. Means ± standard deviations (SD) were calculated for subject characteristics. Medians and range were calculated for the total ARoCuS value. For interobserver reliability of the total ARoCuS value and for continuous variables interclass coefficients (ICC) were calculated. Interobserver reliability of the individual categorical features was determined using kappa statistics. Furthermore, two-sided *t* tests were used to test for significant differences between each different ΔV category, VAS values and normalized Constant score values.

Results

Subject and clinical characteristics

In the time between June 2011 and March 2016, 146 (60 males and 86 females) consecutive patients underwent rotator cuff repair in our clinic. The median age of all patients was 48 years (range 27–70). There were 77 right and 69 left shoulders in the analyzed cohort. The median time for duration of symptoms was 18 months (range 0.2–36). There was no correlation between the category of ΔV and age (Pearson's $p = 0.704$), and pain ($p = 0.194$) but for the initial Constant score ($p \leq 0.001$). Sixty-one patients recorded a trauma previous the onset of symptoms. A painful arc between 60° and 120° was positive in 51% of all patients. Impingement sign according to Hawkins [12] was positive in 86%, while impingement sign according to Neer [13] was positive in 64% of all cases. A positive lift-off test was achieved in 36% of all patients. The O'Briens test [14] for the clinical

Table 3 For purposes of simplification, evaluation and analysis, the score allows to code the rotator cuff tear and its specific properties

ΔV category (ARoCuS grade) according to the tear's extent		Indicated treatment
I	< 4	Side-to-side suture and/or placement of one anchor and subacromial decompression
II	4 < 16	Placement of one pair of anchors and subacromial decompression
III	16–30	Placement of multiple anchors and subacromial decompression
IV	> 30	Primary tendon repair is not indicated or impossible to perform (other treatment algorithms have to be used for the management of the rotator cuff tear)

examination of the long head of the biceps tendon was positive in 65% of all cases.

Intraoperative findings

Concomitant pathologic changes of the SLAP complex were apparent in 84 patients. A SLAP I lesion was found in 59, a SLAP II in 14 patients. A SLAP III lesion was found in 7 and a SLAP IV lesion in 4 patients.

Pathologic changes on the long head of the biceps tendon (LHBT) were found in 88 patients. Of those, 47 showed changes of the synovia, 35 a partial tear of the LHBT, 2 a complete tear of the LHBT and 17 a dislocation out of the bicipital groove. A combination of those pathologies was found in 13 patients. The glenohumeral ligament was partially torn in 10 and completely torn in five cases.

The articular side of the acromion showed a spur formation in 60 and a fraying in 33 cases. The intraoperative scoring according to the ARoCuS criteria of 146 patients with apparent rotator cuff tears are summarized in Table 4. Crescent-shaped tears were the most common pattern found (32%). The tendon of the supraspinatus muscle was affected most often. Furthermore, most cases showed medium-sized rotator cuff tears (49%), the edges of the torn tendons showed some fraying in the majority of all cases (60%). There is no "typical" tear as the combination of those criteria showed a broad spectrum among the tears thus resulting in three large subgroups (ΔV I–III; total of 94% of all patients) and one smaller subgroup ΔV IV (Tables 4, 5).

ARoCuS value and ΔV categories (ARoCuS grade)

ΔV I classified rotator cuff tears presented most often with small- or medium-sized slit or partial thickness tears that showed some fraying and were localized at the supraspinatus tendon. All 32 rotator cuff tears that were classified ΔV I were treated with side-to-side sutures and placement of one anchor. ΔV II classified rotator cuff tears had a broader spectrum of tear patterns, tissue qualities and torn muscle tendons (Tables 4, 5). However, medium-sized tears were predominant in this category (74%). All 68 tears of this category were treated by placing one pair of anchors. In the ΔV III category, a similar heterogeneous but aggravated spectrum of rotator cuff tears was found. In these 37 cases, tears were treated by placing multiple anchors in double-row technique [15].

In the category of the most severe rotator cuff tears, ΔV IV, large tears with severe fraying and retracted tendons were found. Retracted tendons could partly be mobilized or were even completely immobilized. In this category, superior capsular reconstruction, human dermal allografts, tendon transfers or inverse arthroplasty were considered as treatment procedures [5, 16, 17].

For categorical variables, the following interobserver kappa coefficients κ (95% confidence interval (CI)) were calculated: muscle tendons: 0.85 (0.79–0.90), muscle tendon rank: 0.96 (0.93–1.0), size: 0.88 (0.83–0.95), tissue quality: 0.79 (0.75–0.89), pattern: 0.87 (0.82–0.95) and mobilization: 0.75 (0.69–0.84). Continuous variables were compared for interobserver agreement by calculating the interclass correlation coefficient (ICC, 95% CI). ΔV categories thus showed an ICC of 0.95 (0.92–0.97). The ICC between treatment performed and treatment suggested by rater two was 0.94 (0.88–0.98).

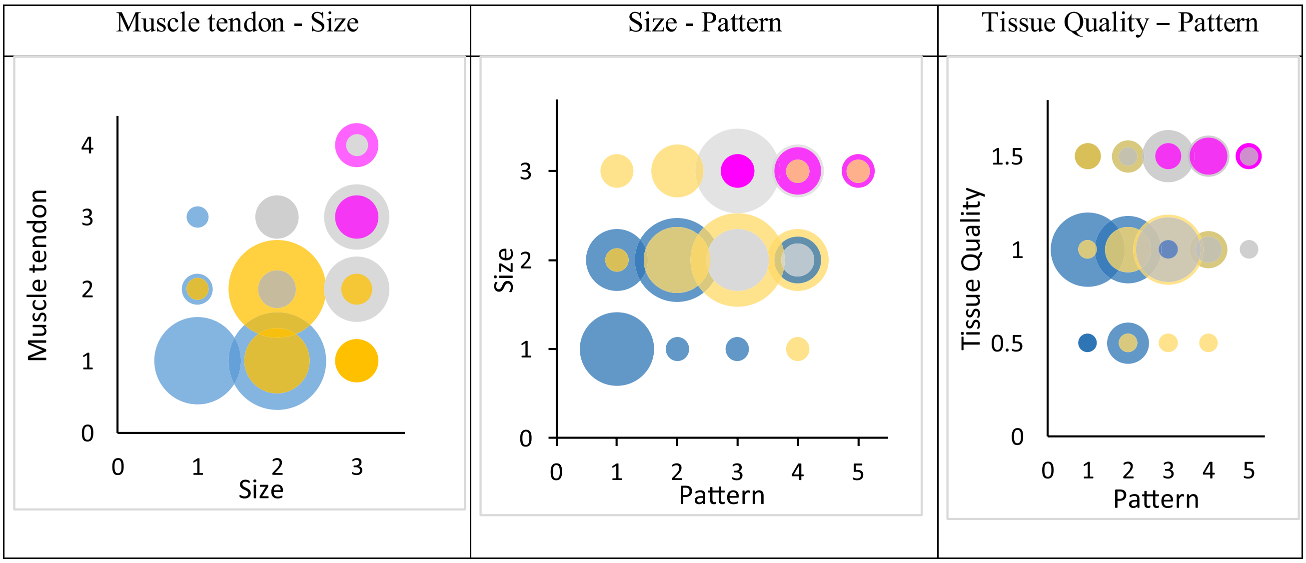
A significant ($p \leq 0.001$) pain reduction was immediately achieved in ΔV I–III with an average preoperative VAS score of 5.3 ± 1.7 and a postoperative VAS score of 3.1 ± 1.5. This significant, immediate pain and discomfort reduction were not achieved in ΔV IV (VAS: 5.1 ± 1.7; $p = 0.544$). Nevertheless, 1 year after the initial intervention pain had

Table 4 Summary of scoring according to ARoCuS criteria

Category ΔV	Number ($n = 146$)	Percentage of total	Side		Muscle tendon				Size			Tissue quality			Pattern					Mobilization		
			R	L	SS	SSC	IS	TM	S	M	L	0.5	1	1.5	1	2	3	4	5	Mob	Red mob	Immob
I	32	21	16	16	30	1	1	0	20	7	5	5	21	6	22	9	1	0	0	0	0	0
II	68	47	35	33	32	33	3	0	4	54	10	6	46	16	4	29	19	15	1	15	0	0
III	37	25	21	16	0	18	18	1	0	11	26	1	19	17	0	1	25	8	3	9	2	0
IV	9	6	5	4	0	0	5	4	0	0	9	0	0	9	0	0	2	5	2	0	4	3

Muscle tendon: The torn tendons with the highest rank were counted; SS (Supraspinatus), SSC (Subscapularis), IS (Infraspinatus), TM (Teres minor). Size: S (small), M (medium), L (large) size of the tear; Tissue quality: 0.5 (sharp, clear edge), 1 (some fraying), and 1.5 (severe fraying). Pattern: a (slit), b (partial thickness), c (crescent shaped), d (L/T shaped), and e (massive). Mobilization of the torn tendon: mob (mobilization), red mob (reduced mobilization), immob (immobilization). Different ΔV categories were highlighted by specific colors: ΔV I: blue, ΔV II: orange, ΔV III: gray, ΔV IV: pink

Table 5 ARoCuS criteria were plotted against each other: Muscle tendon *(1 = Supraspinatus, 2 = Subscapular, 3 = Infraspinatus and 4 = Teres minor)* against Size *(1 = Small, 2 = Medium, 3 = Large)*; Size against pattern *(1 = Articular partial tear, 2 = Bursal partial tear, 3 = Crescent shaped, 4 = L/T shaped, 5 = Massive tear)* and Tissue Quality *(1 = Sharp edged, 2 = Some fraying, 3 = Severe fraying)* against pattern. For better visualization of clusters, different Δ*V* categories were highlighted by specific colors: Δ*V* I: blue, Δ*V* II: orange, Δ*V* III: gray, Δ*V* IV: pink. The areas of the circles equal to the total number of cases in each subcategory. *Off-note:* Classifications that regard only one or two dimensions that are presented here, cannot subcluster the tears sufficiently and may thus result in improper treatment decisions



decreased in this group significantly (VAS score 2.1 ± 1.1; $p \leq 0.001$). For the 58 patients of the 2-year follow-up, significant pain reduction was observed with respect to the 1-year control (VAS 0.5 ± 0.8; $p \leq 0.001$).

At the first consultation, the mean normalized Constant score was 44.4 ± 9.1. There was a significant difference between the normalized Constant scores of Δ*V* I–III and Δ*V* categorized tears ($p = 0.017$) that was maintained throughout all points of follow-up. Yet, a significant increase was observed in all Δ*V* categories after 1 year (86.6 ± 7.9; $p \leq 0.001$). The two-year follow-up did not show any significant changes with regard to the 1-year results.

Up to date, 10 patients have undergone revision surgery. The highest incidence (50%) of revision surgery was observed in patients with an initial Δ*V* IV classification.

Discussion

Multiple scores and classifications both clinical and radiological have been introduced to describe rotator cuff tears [18–20]. As rotator cuff tears origin most often close to the footprint of the affected tendon, it would be sufficient to describe the location of the tear by naming the torn tendon [21]. This idea was principally pursued by Ellman [2] who described rotator cuff tears by naming the appropriate torn tendons. Patte [22] refrained from this concept and classified patterns of torn tendons in combination with the topography in the sagittal and coronal plane as well as the state of the LHBT. This concept was simplified by Harryman who noted only the number of tendons involved in the tear to be important in order to have a measure for the extent of the surgical procedure necessary for repair [23]. The etiopathologic important differentiation between articular and bursal-sided partial thickness tears was promoted by Habermeyer et al. [4]. Those tears were described according to the tears dimensions in a sagittal and a coronal plane, which resulted in a novel classification. Habermeyer's study also demonstrated a high correlation between the Ellman's and the Snyder's classifications. As the Ellman's as well as the Snyder's classification demonstrated to provide insufficient respective imprecise information, there is the risk of developing classifications and scoring systems that are either not reproducible or too specific, e.g., describe only partial problems and situations but are not utilizable for rotator cuff tears as a whole [4, 24].

A completely other concept are classifications that are based on radiographic findings. This was done by Thomazeau et al. [18] who prognosticated the atrophy of the rotator cuff muscles by the ratio of the area of the muscle belly to the area of the appropriate Fossa shaped by the Scapula. A similar approach was made by Zanetti et al. [25] introducing the "tangent sign" as indicator for an atrophic supraspinatus muscle. Goutallier [19] and Fuchs [20] added to this knowledge by evaluating the fatty infiltration of the rotator cuff muscles using CT or MRI, respectively. As surgical decisions are most often based on intraoperative findings those classifications are of less use for the final surgical decision but are of importance for the primary diagnosis and the preoperative planning.

In the context of those established classifications, we believe, however, that in order to describe a rotator cuff tear in sufficient detail and concomitant clinical practicality it is crucial to define and analyze its most important characteristics separately and modular [26].

The modular design of the ARoCuS allows a subclustering of rotator cuff tears, which suggests that existing classifications are partially misleading as they do not weight different tear's characteristics and may thus result in an improper treatment (Table 5).

ARoCuS is a 5-part, 18-item scoring system leading to an overall ARoCuS value that can be categorized into four categories ΔV (ARoCuS grade, Fig. 3) with increasing tear's extent. Furthermore, ARoCuS allows the standardized documentation of rotator cuff tears using a 4 (5) digit code, with each digit (part) representing one of the essential criteria of the tear.

M (Muscle tendon)

Most rotator cuff tears involve primarily the supraspinatus muscle [27]. With increasing extent of the tear, subscapular,

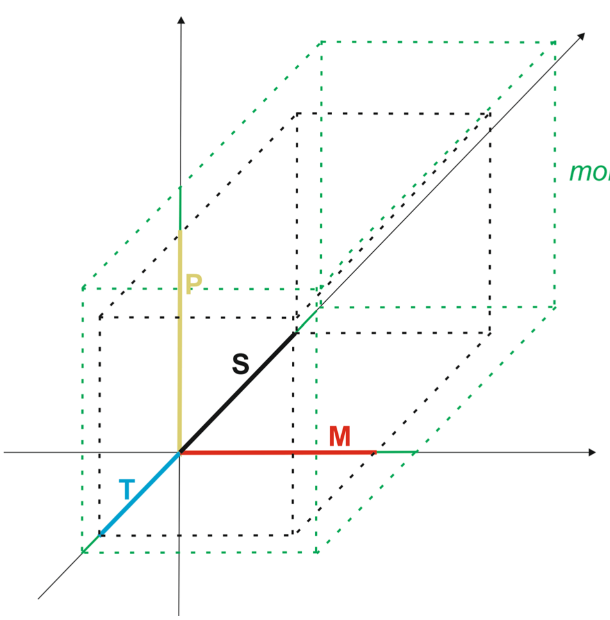


Fig. 3 For purposes of comprehension, ΔV (ARoCuS value) is presented as a cubic shaped volume, which is a function of the vectors of muscle tendon (*M*), size (*S*), tissue quality (*T*) and pattern (*P*). In cases of *L*-/*T*-shaped or massive rotator cuff tears, the mobilization factor (mob) modifies this volume to a certain extent. Certain cut-off values for the volume result in a different ΔV category (I–IV)

infraspinatus and teres minor muscle are affected as well. This is why specific ranks were attributed to each muscle.

S (Size)

A small diameter of a tear indicates usually an easier refixation compared to a tear with a large diameter. To keep the classification simple, only three items (small, medium and large) were used for the ARoCuS.

T (Tissue quality)

The tissue quality of the torn tendon contributes essentially to the stability of the suture. Again, to keep the classification system simple only three items (clear edge, some fraying and severe fraying) were included in the ARoCuS.

P (Pattern)

A rotator cuff tear can have different shapes/patterns, within a spectrum reaching from partial thickness tears to complete ruptures. Those are associated with different efforts of re-fixation. To describe the most common patterns (partial thickness tears, crescent-shaped tears, *L*-/*T*-shaped tears and massive tears), five items are available for the ARoCuS.

mob (Mobilization)

Retracted tendons can be atrophic and crooked with surrounding tissue, re-fixation in these cases depends upon the general degree of mobilization of the tendon. Therefore, three items (mobilization, reduced mobilization and immobilization) were included into the ARoCuS. This digit/part is only available for *L*-/*T*-shaped and massive/complete tears, as it is typically not a problem of partial thickness or crescent-shaped tears.

One shortcoming of this study may be the treatment via a "mini-open" approach [10, 28] for re-fixation (while the tear's exploration was done by scope), as other surgeons may prefer all-arthroscopic solutions and other re-fixation techniques [29]. Another limitation of this study may be the relatively short time of follow-up. However, we were able to establish statistically significant relationships between the ΔV category and the clinical appearance (initial, normalized Constant score) and found significant improvements in clinical outcome as well as in pain reduction. One may argue that the time to intervention is a crucial factor for the outcome and that this study did not primarily differentiate between traumatic and degenerative tears. We believe, however, that both factors are only surrogate measures for observed tissue quality and degree of mobilization. As the ARoCuS is a purely surgical, we abstained from the determination of the intraobserver agreement as it imposes several problems (e.g., actual arthroscopic examination vs. evaluation of a video). Noteworthy, the interobserver agreement and reliability of the ARoCuS was very high in all its dimensions. Thus, it can be considered to have clinical relevance not only for academic purposes but for the clinical routine as well. It may gain further practicability in a future mobile phone app that allows documentation via drop-down menu.

In a next step, a better understanding for ΔV IV categorized tears and their differentiated treatment has to be developed. Yet, larger cohorts will be necessary to present reliable data and conclusions. Therefore, continued prospective recruitment and analysis is ongoing.

Besides the treatment of the rotator cuff tear itself, there are often concomitant injuries whose treatment is crucial for the overall success of a surgical cuff repair. Pathologic changes of the LHBT [30, 31], SLAP lesions [32] and changes of the acromioclavicular joint or the acromion itself have to be assessed and addressed properly. Finally, the proposed treatment algorithm does not impose a strict rule to be followed; it may rather serve as a supporting guideline.

Conclusion

We conclude that the modular categorization of rotator cuff tears according to the ARoCuS criteria is reliable in predicting clinical prognosis when taking stage-adapted treatment measures and is suitable for a standardized documentation of rotator cuff tears.

Compliance with ethical standards

Conflict of interest There are no conflicts of interests.

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