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Volumetric classification: unveiling the true extent of rotator cuff tears

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Introduction: Rotator cuff injury diagnosis involves comprehensive clinical, physical, and imaging assessments, with magnetic resonance imaging (MRI) being pivotal for detecting and classifying these injuries. However, the absence of a universally accepted classification system necessitates a more precise approach, advocating for the use of three-dimensional (3D) modeling to better understand and categorize rotator cuff tears.

Methodology: This research was conducted as a prospective, single-institution study on 62 patients exhibiting full-thickness rotator cuff tears. Utilizing preoperative 1.5 T MRI, the study aimed to create a more detailed classification system based on volumetric and surface area measurements. Advanced 3D modeling software was employed to transform MRI data into precise 3D representations, facilitating a more accurate analysis of the lesions.

Results: The study unveiled a novel classification system rooted in volumetric and surface area assessments, revealing significant discrepancies in the existing two-dimensional classifications. Approximately 45% of the cases demonstrated inconsistencies between traditional classifications and 3D measurements. Notably, medium-sized lesions were often overestimated, while small and large lesions were consistently underestimated in their severity. The volumetric and surface area-based classifications provided a more accurate depiction, highlighting the limitations of relying solely on coronal plane assessments in MRI. Comparative analysis confirmed the improved accuracy of the 3D method.

Conclusion: The integration of 3D imaging and volumetric analysis offers novel advancement in diagnosing and classifying rotator cuff injuries. This study's findings challenge the conventional reliance on 2D MRI, proposing a more detailed and accurate classification system that enhances the precision of surgical planning and potentially improves patient outcomes. The incorporation of comprehensive 3D assessments into the diagnostic process represents a significant step forward in the orthopedic imaging field.

Level of evidence: Basic Science Study; Development and Validation of Classification System

Keywords: 3D rotator cuff; 3D classification; rotator cuff tear classification; MRI rotator cuff; rotator cuff tear; 3D classification of rotator cuff tears; 3D modeling in orthopedic diagnosis; surgical planning 3D images

Diagnosing rotator cuff injuries involves a thorough review of the patient's clinical history and physical assessments, alongside imaging evaluations. Magnetic resonance imaging (MRI) is the most commonly used technique to detect tears in the rotator cuff.[8]

This study was approved by the Ethics Committee in Federal University of São Paulo.

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MRI plays a pivotal role in determining the size and type of rotator cuff tear, providing essential details that aid in surgical planning. Despite its importance, there are multiple classification systems. Studies have evaluated the intra- and inter-rater variability of these classification systems, highlighting the need for a more consistent and reliable approach.[11] An ideal classification would be reproducible, foster clear communication among surgeons, and provide detailed insights into treatment approaches and prognoses.[10]

While imaging advancements have provided opportunities to better understand rotator cuff tears (RCTs), current methods typically display a two-dimensional (2D) view on a monitor, which can make interpreting the three-dimensional complexity of the anatomy difficult.[1,2] One promising approach to this challenge is through prototyping, specifically using three-dimensional (3D) modeling. By employing computer-aided design (CAD), physical 3D models of the anatomic structures can be created, offering a more tangible representation. This approach can significantly improve structural analysis, enable better classifications, and enhance surgical planning.[9]

In this study, the 3D reconstruction specifically targets the tendon and the associated defect, rather than the entire muscle-tendon complex. By generating detailed 3D representations of the tendon and its defects, a more precise understanding of the injury's extent and characteristics can be provided. Presently, there is no universally accepted classification system for rotator cuff tears (RCTs). Although existing classifications address certain aspects of the pathology, they are not comprehensive and lack critical details necessary for formulating an accurate treatment strategy and predicting patient outcomes. Consequently, none have achieved universal validation or adoption.[3] Currently, there is no widely accepted classification for RCTs. Although these classifications address specific details of the problem, they are not comprehensive and lack the essential details needed to establish an accurate treatment strategy and predict patient outcomes. Consequently, none have been universally validated or used.[3] Since 1944, with contributions from McLaughlin, DeOrio, and Cofield (1982), and Patte (1990), these classifications have described the one-dimensional length of a tendon tear, or the number of tendons torn. Along with arthroscopic reconstruction, the classification by Ellman and Gartsman does not leverage the 3D information on tear patterns obtained from preoperative MRI.[5]

The volume and surface area of a rotator cuff tear are important but often overlooked in favor of retraction characteristics. A comprehensive understanding of the cuff tear's volume and surface area requires a 3D perspective of the pathologic process, which is challenging to achieve with conventional 2D MRI. Given the importance of thorough preoperative planning, the primary objective was to validate a new interpretation based on the volume and surface area of a rotator cuff tear. Thus, the aim of this study was to validate the interpretation of the volume and surface area of rotator cuff injuries using 3D models, creating a new classification. The hypothesis posits that 3D models, compared to 2D MRI, refine the application of classifications for total tears based on 3D characteristics, enhance understanding and knowledge of rotator cuff injuries, help to determine the real size of the tear, and improve the precision of surgical planning.

Methodology

In this prospective, single-institution research, every participant was identified as having full-thickness rotator cuff tears caused by either trauma or degenerative rotator cuff tears. To be eligible for the study, participants needed to have a confirmed full-thickness tear of the supraspinatus. The study did not include patients with partial tears or those with past shoulder fractures or surgeries. The Research Ethics Committee gave its approval for this study, which was registered under the number 4.642.020.

MRI

A preoperative 1.5 T MRI was employed. The MRI scans were conducted using the following sequences and parameters, a standard practice for the institution: a coronal oblique proton-density turbo-spin-echo-weighted image (slice thickness of 3 mm; TR/TE range of 2100-2500/25-35), a T2-weighted fat suppression (slice thickness of 3 mm; TR/TE range of 3500-4000/55-60), a T1-weighted sagittal oblique (slice thickness of 3 mm; TR/TE range of 450-600/12-15), axial fat-suppressed proton density–weighted (slice thickness, 3 mm; TR/TE, 2100–2500/25–37), a T2 with weighted fat suppression (slice thickness of 3 mm; TR/TE range of 3500-4000/55-65), and a proton density with weighted axial fat suppression (slice thickness of 3 mm; TR/TE range of 2100-2500/25-37). The matrix was set at 256×256, and the field of view was 140 for all studies. The MRI was captured with the patient's arm positioned neutrally and adjacent to their body.[7] The MRI scans were analyzed by 2 radiologists with expertise in musculoskeletal treatments. They recorded the full dimensions of the lesions across the coronal (mediolateral [ML]) and sagittal (anteroposterior) planes. Anatomical Structure for 2D Measurement in the Sagittal Plane: The measurement is taken along the anteroposterior axis of the tendon, from the most anterior point of the tear to the most posterior point. This approach ensures an accurate assessment of the tear's extent in the sagittal plane. Anatomical Structure for 2D Measurement in the Coronal Plane: This measurement is taken from the original insertion point of the tendon at the greater tuberosity to the maximum observed retraction point of the tendon. This measurement in the coronal plane allows for a detailed analysis of tendon retraction.

Creation of images

The imaging data for each shoulder were transferred in the standardized Digital Imaging and Communications in Medicine format. The lead researcher, an experienced orthopedic surgeon, input the data into a MacBook Pro M1. For data processing, they used Slicer 3D software, a free, open-source program available

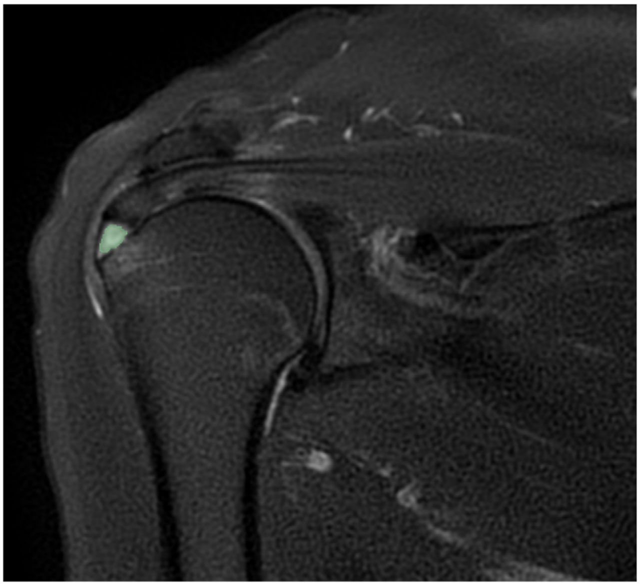

Figure 1 A coronal oblique MRI for a right shoulder with a 3D model of a rotator cuff tear: full-thickness tear in coronal view. The tear is marked in green for recognition when creating 3D. *MRI*, magnetic resonance imaging.

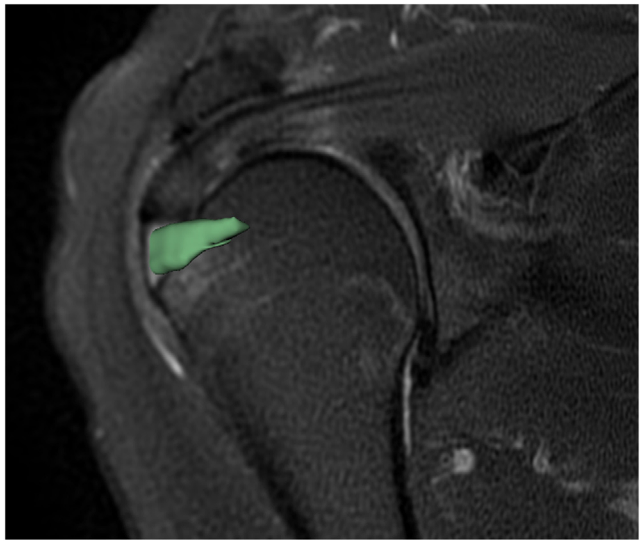

Figure 2 A coronal oblique MRI for a right shoulder with a 3D model of a rotator cuff tear: full-thickness tear in perspective view. Tear already created in 3D. Overlaying the resonance 2D image with 3D. *2D*, two-dimensional; *3D*, three-dimensional; *MRI*, magnetic resonance imaging.

under a Berkeley Software Distribution style license at slicer.org. This software interprets MRI data in Digital Imaging and Communications in Medicine format and transforms it into 3D visuals, providing precise manipulation capabilities for analyzing rotator cuff injuries. Notably, this software is designed to handle complex image processing tasks, particularly in clinical and medical research fields, serving as a versatile platform for the development and application of customized imaging solutions. All images transferred to the personal computer were done with patient consent, as indicated in the forms approved by the overseeing institution.

The *volume rendering module*, accessible via the soft tissue windows enabled interactive exploration of 3D imaging data. This module is equipped with sophisticated instrumentation for dynamically displaying extensive data volumes. It operates by applying a preset collection of parameters affecting opacity, coloring, and gradient transitions.

In this study, coronal oblique T2-weighted images were used to segment the image data, paving the way for the 3D reformation of each rotator cuff tear. Although sagittal and axial images can be used for the 3D reconstruction process, for the purposes of standardization and classification, coronal images were primarily utilized. This choice does not compromise the quality of the reconstruction, as the software is capable of simultaneously recognizing and integrating all imaging planes, ensuring comprehensive 3D models. The *Threshold tool* was subsequently utilized to specify a tailored range of intensity for the masking procedure (Fig. 1). This was followed by the transformation of the selected masked regions into a 3D representation. For several smaller masks discernible on the MRI, a *Smoothing* operation was implemented. This step was critical in segregating the lesions, as it addressed anomalies by smoothing out and filling in gaps within the images, ultimately refining the contours of the segmentation without losing fidelity to the original image data, as the smoothing only retracts unnecessary spicules. In cases where the images were incomplete, the edges of the rotator cuff were carefully delineated by hand at multiple points along the spectrum—from the points where the tendon fibers attach to the myotendinous junction. These manual modifications are semi-automated processes where the machine marks the specific locality based on the provided data, ensuring precision and maintaining fidelity to the original size.

After this detailed outlining, the *launch function* was activated to generate the 3D mold (Fig. 2). The entire 3D processing for each reconstruction was accomplished in 15 minutes, with an additional 4 minutes allocated for postprocessing.[15]

After creating the 3D image, the "Models" session file is exported. In this session, the file can be organized into folders, and display properties such as visibility, color, and opacity can be adjusted. Once the folder is selected, the file is analyzed by the Information panel, which provides model data including surface area (the calculated surface area of the model, in square millimeters), volume (the volume inside the surface model, in cubic millimeters), and the number of points and cells (number of vertices and cells in the surface model) (Figs. 3 and 4).

The lead author, tasked with the 3D reconstruction, utilized computer assistance to measure the overall lesions in the coronal (ML) and sagittal (anteroposterior) planes. Using the computer, the maximal distances from the tear in both planes were determined, calculating the span between the extremities of the lesion. The primary objective of the 3D reconstruction is to create a detailed model of the tendon and the defect, areas that are not intact. This approach is analogous to bony Bankart measurements, where bone loss is assessed by imagining the original bone structure. In the context of rotator cuff tears, the intact tendon is conceptualized, and the missing section, or defect, is modeled. The boundaries of the 3D models include the greater tuberosity and the imaginary extension of the torn tissue edges, such as the articular line and bursal line. Furthermore, the significance of

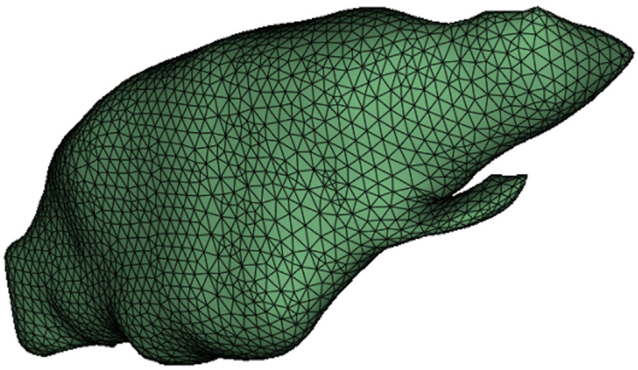

Figure 3 Geometric characteristics, volume, and surface area of the 3D models that were observed during the model data analysis. *3D*, three-dimensional.

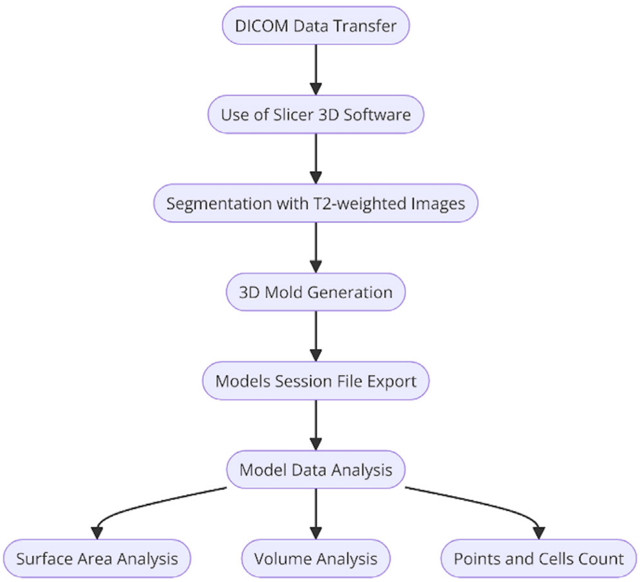

Figure 4 Diagram demonstrating the authors' entire methodology for performing the analysis of rotator cuff tears in 3D.

surface area in the study is multifaceted. While it might seem that measuring the entire mold's surface area could lead to double counting the surface of the greater tuberosity, the 3D contour of the torn edge provides valuable insights. This contour helps in understanding the complex geometry of the tear, which is essential for accurate classification and surgical planning. The 3D model is finalized manually in some cases to ensure precision, addressing any anomalies and refining the contours of the segmentation.

All rotator cuff tears were classified by orthopedic surgeons using the classic DeOrio and Cofield (1982) and Patte (1990) classification systems. Since arthroscopy was not evaluated, the Ellman and Gartsman analysis was not utilized (Table I).

Collected data

All collected data were input into an Excel spreadsheet, which included 2D and 3D measurements in millimeters, as well as surface area (in square millimeters) and volume (in cubic millimeters). (1)

Table I Measurements made by the different investigators

1. 2D plane measurement by MRI in coronal and sagittal planes
2. 3D measurement in coronal and sagittal planes
3. Rotator cuff tear surface area
4. Rotator cuff tear volume area
5. DeOrio and Cofield, and Patte classification

2D, two-dimensional; *3D*, three-dimensional; *MRI*, magnetic resonance imaging.
1- Measurements were made by radiologists; 2- by senior author; 3- by senior author and surgeons; and 4 and 5 - by surgeons.

The confidentiality of the information gathered during this study was strictly maintained, with access limited to the primary researcher and their team. This protected information included patient identities, MRI findings, 3D models, and classifications of rotator cuff tears. The execution of this study required no deviations from standard patient care, did not affect the frequency of outpatient clinic appointments, nor necessitated any supplementary diagnostic tests.

Statistical calculation

In this study, we set a significance level of 0.05 (5%). This means we accept a 5% risk of error in our statistical conclusions or, in other words, there's a 5% chance our conclusions might be incorrect due to statistical error. It's important to note that we relied on nonparametric statistical tests because we are dealing with data that might not follow a normal distribution, especially since we are analyzing the main outcome quantitative variables with the Kolmogorov–Smirnov test for sample sizes smaller than 100.

A key part of our analysis involved using Spearman's Correlation. This method helped us understand how closely related the volume and surface measurements are to the resonance, 3D imaging, and age variables. To further explore these relationships, we developed multivariate models, guided by the values of the shown coefficients.

To evaluate the effectiveness of our models, we used 2 specific statistics. The R^2 value, which ranges from 0% to 100%, tells us how accurately our model can predict outcomes. Additionally, we corrected for multiple comparisons using the Benjamini–Hochberg method. The higher the R^2, the better the model's predictive accuracy. Additionally, the ANOVA test was employed to determine if our model significantly deviates from zero – in simpler terms, whether it's predicting something meaningful or if it effectively predicts nothing. These statistics and their implications are summarized in the results tables for clearer understanding.

Results

This study included 62 patients – 30 men and 32 women – with a mean age of 60.4 years. One hundred patients were eligible between February 2022 and January 2024, and 38 of them were excluded. For small lesions, the average proportion of surface area to the ML diameter in MRI scans was approximately 31.99 mm^2/mm, while the volume proportion was around 20.11 mm^3/mm. In medium-sized lesions, these proportions were approximately 35.64 mm^2/mm for surface area and 30.30 mm^3/mm for volume. In a large-sized lesion (approximately 21%), these proportions were approximately 57.64 mm^2/mm for surface area and 61.02 mm^3/mm for volume. Twenty-eight patients (approximately 45%) showed discrepancies between the classic two-dimensional classifications and 3D information. Additionally, 22 patients (about 35%) had measurements in the coronal plane above 1 cm (medium sized), but their area or volume was less than 1000 mm^2 or mm^3. In 6 cases (about 10%, 46% for all large-sized lesions), measurements in the coronal plane were above 3 cm, yet their area or volume was less than 3000 mm^2 or mm^3. No injuries above 5 cm were recorded (Table II).

A key analysis conducted involved the use of Spearman's Correlation to assess the relationship between the results of volume and surface area with the parameters of resonance, 3D imaging, and age. All identified correlations proved to be statistically significant. Specifically, the correlation coefficients for resonance and 3D imaging were notably high, consistently surpassing 0.600, which allows researchers to categorize these as strong correlations. Furthermore, these correlations were all positive, suggesting that an increase in resonance or 3D imaging values is associated with higher volume and surface area measurements.

The Kruskal–Wallis test was used to compare the Patte and Cofield classifications in the results of quantitative factors (volume, surface area, MRI, 3D imaging, and age) (Tables III and IV).

Following the observed correlation between resonance and 3D imaging with the volume and surface area measurements, a multivariate linear regression model was developed. This model is designed to predict the volume or surface area values based on the results of either resonance or 3D imaging. Consequently, in this model, which aims to estimate volume and surface area using either resonance or 3D imaging data, the explanatory variables (independent variables) of AP (in millimeters) and ML (in millimeters) are deemed statistically significant.

$$\boldsymbol{Volume} = \mathbf{18,66} * \boldsymbol{MRI}\ (\boldsymbol{AP}) + \mathbf{68,63} * \boldsymbol{MRI}\ (\boldsymbol{ML})$$

$$\boldsymbol{Surface\ Area} = \mathbf{21,59} * \boldsymbol{MRI}\ (\boldsymbol{AP}) + \mathbf{53,68} * (\boldsymbol{MRI\ ML})$$

$$\boldsymbol{Volume} = \mathbf{30,41} * \mathbf{3D}\ (\boldsymbol{AP}) + \mathbf{60,59} * \mathbf{3D}\ (\boldsymbol{ML})$$

$$\boldsymbol{Surface\ Area} = \mathbf{27,36} * \mathbf{3D}\ (\boldsymbol{AP}) + \mathbf{50,07} * \mathbf{3D}\ (\boldsymbol{ML})$$

Volume = mm^3
Surface Area = mm^2

A multivariate cluster analysis was performed, aiming to group the subjects based on the similarity of variables, which, in this case, are volume and surface area. Using the Euclidean average linkage technique, we identified 3 groups, classified as shown in the table below. It was observed that the subjects in Group 1 have low volume and area values. The subjects in Group 3 possess the highest values and form the smallest group (Table V and Fig. 5).

Based on the proximity values, seen in the table above, between groups 1, 2, and 3, we can establish a new division and, consequently, a new classification.

Group 1 - Small Lesions: <1000 mm^2 or mm^3

Group 2 - Medium lesions: >1000 mm^2 or mm^3 - <3000 mm^2 or mm^3

Group 3 - Large Lesions: >3000 mm^2 or mm^3

Discussion

This study introduced a novel approach for analyzing rotator cuff tears, utilizing 3D models to improve the understanding and classification of these tears. The primary objective was to evaluate the surface area and volume as significant and novel variables in characterizing rotator cuff tears.

Surface area and volume are crucial yet understudied features. The understanding of this condition has significantly improved with the introduction of 3D imaging, revealing features that are still undetectable by traditional 2D MRI. This research contributes to the current trend of technological innovation in medical imaging and improves

Table II Complete description of quantitative factors

	Media	Median	Standard deviation	CV	Q1	Q3	IQR	Min	Max	N	IC
Volume (mm3)	847	299	1145	135%	153	1.046	893	30	4693	62	285
Surface area (mm2)	826	411	881	107%	244	989	744	79	3860	62	219
MRI (AP)	14	12.98	7.03	50%	9	18.16	9.16	3.1	34.28	62	1.75
MRI (ML)	18.62	15.69	12.43	67%	8.38	25.1	16.72	3	45	62	3.09
3D (AP)	16.58	14.51	7.74	47%	10.73	21.62	10.9	3.9	35.22	62	1.93
3D (ML)	19.34	14.72	13.06	68%	9	26.98	17.98	4.4	46.3	62	3.25
Age	60.4	61.5	9.3	15%	54.3	67	12.8	35	78	62	2.3

MRI, magnetic resonance imaging; *AP*, anteroposterior; *ML*, mediolateral; *IQR*, interquartile range.

Table III Compares Patte classification for volume, surface, MRI, 3D, and age

	Media	Median	Standard deviation	Q1	Q3	IQR	N	IC	*P* value
Volume									
Stage 1	148	121	107	65	173	108	25	42	*<.001*
Stage 2	670	448	519	285	979	694	25	204	
Stage 3	2672	2336	1357	1805	3858	2054	12	768	
Surface area									
Stage 1	210	200	99	139	268	129	25	39	*<.001*
Stage 2	739	684	425	388	975	587	25	167	
Stage 3	2290	2343	821	1710	2679	969	12	465	
MRI (AP)									
Stage 1	9.46	9	3.65	7.11	12	4.89	25	1.43	*<.001*
Stage 2	15.04	14.02	6.1	10.8	20	9.2	25	2.39	
Stage 3	21.28	21.83	7.54	17.2	25.75	8.55	12	4.27	
MRI (ML)									
Stage 1	7.79	7	4.06	4.77	10	5.23	25	1.59	*<.001*
Stage 2	19.85	19.52	6.43	15.42	22.76	7.34	25	2.52	
Stage 3	38.65	38.65	4.83	36.48	41.94	5.47	12	2.73	
3D (AP)									
Stage 1	11.41	11.36	3.78	9.1	13.7	4.6	25	1.48	*<.001*
Stage 2	17.64	16.72	6.42	13.64	21.71	8.07	25	2.52	
Stage 3	25.15	26.27	8.22	22.13	31.72	9.59	12	4.65	
3D (ML)									
Stage 1	8.7	7.6	4.38	6.42	9.57	3.15	25	1.72	*<.001*
Stage 2	19.22	18.79	6.36	14.02	21.88	7.86	25	2.49	
Stage 3	41.78	41.01	3.02	39.31	44.72	5.4	12	1.71	
Age									
Stage 1	57.3	55	8.8	54	63	9	25	3.5	.041
Stage 2	61.5	63	8.6	57	68	11	25	3.4	
Stage 3	64.6	67	10.1	63	69.5	6.5	12	5.7	

3D, three-dimensional; *2D*, two-dimensional; *MRI*, magnetic resonance imaging; *AP*, anteroposterior; *ML*, mediolateral; *IQR*, interquartile range.
Stage 1: Proximal stump close to bony insertion.
Stage 2: Proximal stump at level of humeral head.
Stage 3: Proximal stump at glenoid level.
Italicized *P*-values indicate statistically significant differences ($P < .05$).

the surgeon's capacity to classify, interpret, and make decisions based on images. As imaging software continues to advance, 3D imaging is poised to replace 2D imaging as the standard for rotator cuff tear analysis; this enhanced understanding will ultimately lead to improved treatment outcomes. The key advantages of 3D imaging for rotator cuff tear analysis are the visualization of the tear's 3D structure, including its depth and morphology, and the accurate measurement of the tear's surface area and volume.[7,15]

Two-dimensional MRI has demonstrated high sensitivity and specificity in evaluating rotator cuff conditions. However, some studies have reported lower accuracy rates. For instance, Gyftopoulos et al found that their 2D classification system yielded accuracy rates ranging from 61.8% to 70.6%. Furthermore, Bryant et al found that MRI underestimated the size of the lesions by 30%, while Teefey et al reported that the retraction and width measurements using MRI were, on average, 25% and 9% larger than those measured by arthroscopy, respectively. Gill et al reported that preoperative MRI underestimated tear sizes in 5 out of 44 cases (11%). These tears were reclassified from medium to large when evaluated intraoperatively. The authors suggested that this underestimation might be due to the three-dimensional nature of tears and the orientation of the MRI images, which may not fully capture the extent of the tear. The difference between the pre- and intraoperative measurements of tear size was statistically significant (0.3 cm; $P < .01$). In total, 23% of cases had nonidentical values for the pre- and intraoperative measurements of tear size, with 7 (16%) having a difference of 1 cm between the pre- and intraoperative measurements, and the remaining 3 (7%) presenting a difference of 2 cm. These findings indicate that preoperative MRI may not always accurately assess rotator cuff tear size, especially for tears that are not perpendicular to the MRI plane. This limitation should be taken into consideration when planning surgical interventions.[2,5-7,14,16]

Table IV Comparison of Cofield classification for volume, surface area, MRI, 3D, and age.

	Media	Median	Standard deviation	Q1	Q3	IQR	N	IC	*P* value
Volume									
Small	138	116	95	65	173	108	21	41	*<.001*
Medium	561	432	461	261	749	488	28	171	
Large	2608	2276	1320	1838	3716	1878	13	717	
Surface area									
Small	197	194	88	134	261	127	21	38	*<.001*
Medium	649	506	410	365	848	483	28	152	
Large	2223	2150	823	1591	2646	1055	13	447	
MRI (AP)									
Small	9.2	8.67	3.85	6.91	12	5.09	21	1.65	*<.001*
Medium	14.19	13.93	5.81	10.2	17.82	7.62	28	2.15	
Large	21.33	21.96	7.22	17.76	25.35	7.59	13	3.92	
MRI (ML)									
Small	7.4	6.36	4.11	4.06	8.6	4.54	21	1.76	*<.001*
Medium	17.9	17.72	6.43	12.34	22.08	9.74	28	2.38	
Large	38.31	37.3	4.77	35.32	41.37	6.05	13	2.59	
3D (AP)									
Small	11.15	10.71	4.01	8.1	13.7	5.6	21	1.71	*<.001*
Medium	16.48	15.4	5.74	12.64	20.29	7.65	28	2.13	
Large	25.58	27.12	8.02	22.39	31.35	8.96	13	4.36	
3D (ML)									
Small	8.51	7.1	4.66	6.04	9.4	3.36	21	2	*<.001*
Medium	17.77	17.07	6.91	12.46	21.62	9.16	28	2.56	
Large	40.25	40.84	6.23	38.42	44.69	6.27	13	3.39	
Age									
Small	59.3	60	7.3	55	65	10	21	3.1	.337
Medium	60.1	61.5	9.5	54	67.3	13.3	28	3.5	
Large	62.8	67	11.7	60	69	9	13	6.3	

3D, three-dimensional; *2D*, two-dimensional; *MRI*, magnetic resonance imaging; *AP*, anteroposterior; *ML*, mediolateral; *IQR*, interquartile range.
Small <1 cm; medium 1-3 cm; large 3-5 cm.
Italicized *P*-values indicate statistically significant differences ($P < .05$).

Table V Complete description of clusters for volume and area

	Volume			Area		
	Group 1	Group 2	Group 3	Group 1	Group 2	Group 3
Media	297	1802	4306	383	1772	3078
Median	216	1850	4408	283	1670	2958
Standard deviation	259	577	428	263	529	613
Q1	118	1343	4143	196	1403	2619
Q3	417	2087	4571	476	2084	3418
IQR	300	744	428	281	681	799
Min	30	*979*	3716	79	*975*	2536
Max	*1169*	*2918*	4693	*989*	*2777*	3860
N	46	12	4	46	12	4
IC	75	327	419	76	300	601

IQR, interquartile range
The regions highlighted in italics are the intersections of the groups for separating the classifications.

This data revealed a consistent proportionality between the volume and surface area to the ML diameter, with a noticeable difference in the ratios for small, medium, and large-sized lesions. This disparity highlights the inadequacy of relying solely on the coronal plane for shoulder MRI examinations, as classical classifications tend to do. The sagittal plane, often overlooked, appears to be crucial for a more accurate assessment of lesion severity and extent. The analysis suggests that the predominant use of the coronal plane in MRI might lead to underestimations for small

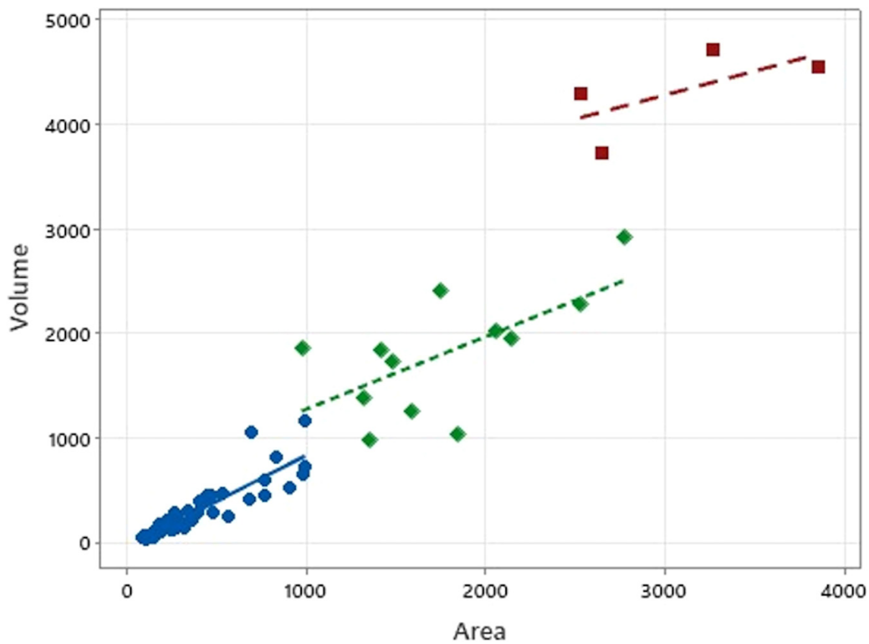

Figure 5 Volume x surface area, separated into Group 1 (*Blue*, smaller lesions), Group 2 (*Green*, medium lesions), Group 3 (*Red*, Larger lesions).

lesions and overestimations for medium and large-sized lesions regarding the true size and complexity of rotator cuff tears. Consequently, integrating both coronal and sagittal planes in MRI assessments, along with advanced 3D imaging, can provide a more detailed and accurate representation of the pathological anatomy, thereby aiding in the formulation of a more effective and tailored treatment strategy. Stirma et al recently demonstrated the superior performance of 3D measurements over MRI in the sagittal plane for evaluating rotator cuff tears. According to their research, 3D imaging of the rotator cuff could be a valuable technique for a more comprehensive examination, characterization, and understanding of these injuries. This enhanced precision in diagnosing rotator cuff tears may ultimately lead to more effective treatment planning.[12]

The use of volumetric and surface measurements yielded data that were reliable concerning the lesion, with statistical significance ($P < .01$). Upon analyzing this data, a multivariate linear regression model was developed to approximate these characteristics, as initially identified through two-dimensional resonance imaging, with Volume = 18.66 * MRI (AP) + 68.63 * MRI (ML)/Surface Area = 21.59 * MRI (AP) + 53.68 * (MRI ML). After the analysis was completed, the participants were divided into 3 groups, as shown in Table IV. The diagnosis and treatment of rotator cuff injuries could be significantly improved by this new visualization technique. Further research is necessary to fully explore the potential of this visualization technique in the clinical context. Stirma et al recently introduced a method that combines Fascia Lata autografts with 3D printing technology and surface area analyzes to improve rotator cuff reconstruction. This approach utilizes 3D models to gain a better understanding of the unique features and size of rotator cuff injuries, thereby enhancing the accuracy in selecting the appropriate graft size and defining the surface area needed for superior capsule reconstruction.[4,13]

It is crucial to recognize certain limitations inherent to this method. While 3D offers a static perspective, it cannot simulate the dynamic movement of the tear, as arthroscopic visualization does, which is crucial for comprehending the tendon realignment within its anatomical footprint. Further validation of these findings and exploration of their correlation with arthroscopic classifications necessitate research involving a larger sample size.

The limitations of 2D imaging in accurately assessing rotator cuff tears, highlighted by inconsistencies in the literature and the imprecision of lesion measurements, have necessitated the exploration of alternative imaging methods. Three-dimensional imaging emerges as a promising approach to enhance diagnostic accuracy. This study introduces an innovative method for evaluating rotator cuff tears through 3D modeling, facilitating a detailed assessment of the tear's volume and surface area. This technique provides insights beyond those achievable with conventional 2D MRI, enabling a comprehensive evaluation of tear volume and surface area. Our method offers a significant improvement in measuring the true extent of rotator cuff injuries, which is crucial for surgical planning and improving patient outcomes. While this study focuses on tear metrics, evaluating the correlation between tear volume and muscle volume is an important next step. This approach could further enhance the predictive value of the classification system and will be the focus of future research. The process of converting 2D data to 3D models does not carry a risk of human error, as it is entirely automated by the software. The smoothing configuration is specifically designed to minimize sharp contours and improve the accuracy of the analysis. Further validation through large-scale studies is necessary to establish the clinical utility of this technology, and conducting inter- and intra-observer validation studies to assess the consistency of volume and surface area measurements of lesions by different surgeons at various times is essential.

Conclusion

The present study marks a significant advancement in the assessment of rotator cuff injuries. By focusing on the volume and surface area of rotator cuff tears, provides a more detailed and accurate understanding of the injury, overcoming the limitations of traditional 2D MRI. The introduction of a new classification system based on these 3D measurements, which categorizes lesions as small, medium, or large based on volume and surface area, offers a more precise and reliable method. This innovation paves the way for further advancements in medical imaging and the development of more effective treatment strategies, ultimately leading to improved patient outcomes.

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