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Morphometric analysis of avulsion injuries and their correlation with rotator cuff dysfunction: A clinical and radiological study

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Abstract
Background: Avulsion injuries of the rotator cuff present significant challenges in orthopedic practice. While advanced imaging has enhanced diagnostic capabilities, the relationship between morphometric parameters of these injuries and functional outcomes remains poorly understood.
Methods: This prospective observational study included 94 patients (57 males, 37 females; mean age 48.6±11.3 years) with radiologically confirmed avulsion injuries of the rotator cuff. Comprehensive clinical assessment included Visual Analog Scale (VAS) for pain, Disabilities of the Arm, Shoulder and Hand (DASH) questionnaire, and Constant-Murley score. Radiological evaluation comprised standardized radiographs, 3.0-Tesla MRI, and in selected cases, MR arthrography and ultrasonography. Morphometric parameters measured included avulsion dimensions, displacement distance, gap area, tissue retraction, muscle atrophy, and fatty infiltration index. Statistical analysis examined correlations between morphometric parameters and functional outcomes.
Results: Subscapularis avulsions demonstrated the largest dimensions and greatest displacement compared to supraspinatus and infraspinatus injuries ($p<0.05$). Displacement distance and tissue retraction grade showed the strongest correlations with functional outcomes (r=0.56-0.67, $p<0.001$). Multiple regression analysis identified displacement distance (β=0.36, $p<0.001$) and tissue retraction grade (β=0.31, $p<0.001$) as the strongest independent predictors of DASH scores ($R^2=0.73$). Chronic injuries exhibited significantly worse morphometric parameters than acute cases, particularly regarding fatty infiltration (1.69±0.78 vs. 0.83±0.52, $p<0.001$). Radiological measurements demonstrated excellent correlation with intraoperative findings (ICC=0.83-0.92).
Conclusion: Morphometric analysis of avulsion injuries provides valuable insights into structure-function relationships in rotator cuff pathology. Displacement distance and tissue retraction grade represent the most significant predictors of functional disability, with chronicity substantially influencing morphometric parameters. These findings may guide clinical decision-making regarding treatment timing and approach.

Keywords: Rotator cuff injuries, shoulder joint, magnetic resonance imaging, musculoskeletal physiological phenomena, biomechanical phenomena, tendon injuries

Introduction
Shoulder lesions represent significant clinical challenges in orthopedic practice due to their complex nature and the potential for long-term rotator cuff dysfunction. These injuries are often characterized by osseous changes replacing soft tissue, typically resulting from acute trauma or repetitive microtrauma to the shoulder joint.
The rotator cuff, composed of the supraspinatus, infraspinatus, teres minor, and subscapularis muscles, plays a crucial role in shoulder stability and function. Involvement of these structures in such injuries can severely impair shoulder biomechanics and overall functional capacity.
However, the relationship between the morphometric characteristics of these lesions and the development of rotator cuff dysfunction remains poorly understood. Quantitative analysis of their size, shape, and spatial orientation offers a promising approach to better characterize these injuries and predict clinical outcomes.
Several studies have explored different aspects of rotator cuff pathology. Moosmayer *et al.* demonstrated that the size and location of rotator cuff tears significantly affect functional outcomes following surgical repair.

Fukuda *et al*. established a correlation between tear patterns and shoulder deficits. However, few studies have specifically investigated the morphometric properties of shoulder lesions associated with rotator cuff dysfunction.

This variability in presentation creates diagnostic challenges and complicates treatment decisions. Furthermore, the natural history of these injuries is unpredictable some patients experience spontaneous improvement, while others develop progressive loss of rotator cuff function.

Matthews *et al*. highlighted the advantages of MRI in visualizing the extent of tissue disruption and underlying bony changes. Ultrasound has also proven to be a valuable complementary tool, offering dynamic evaluation capabilities and greater accessibility.

Integration of clinical and radiological findings is essential for comprehensive assessment and optimal management planning.

The aim of this study is to address existing knowledge gaps by performing a detailed morphometric analysis of shoulder lesions and examining their correlation with rotator cuff dysfunction. By investigating these relationships, we aim to enhance diagnostic accuracy, improve prognostic assessments, and optimize treatment strategies for patients with these complex shoulder injuries.

Methodology

This prospective observational study was conducted at the Department of Orthopedic Surgery at University Medical Center between January 2022 and December 2023. The study protocol was approved by the Institutional Ethics Committee (approval number: ORTHO-2021-453), and written informed consent was obtained from all participants prior to enrollment. The study adhered to the ethical principles outlined in the Declaration of Helsinki.

A total of 128 patients who presented with clinical features suggestive of avulsion injuries of the shoulder joint were initially screened for eligibility. The inclusion criteria comprised adults aged 18-70 years with acute or chronic shoulder pain following trauma, clinical evidence of rotator cuff dysfunction, and radiological confirmation of avulsion injury. Patients with previous shoulder surgery, inflammatory arthropathy, glenohumeral arthritis, neuromuscular disorders affecting the upper extremity, concomitant labral or biceps pathology, or inability to comply with the study protocol were excluded. After applying these criteria, 94 patients (57 males and 37 females, mean age 48.6±11.3 years) were included in the final analysis.

A comprehensive clinical assessment was performed by two fellowship-trained shoulder surgeons who were blinded to the radiological findings. The assessment included detailed history taking, shoulder examination using standardized protocols, and evaluation of rotator cuff function through specific clinical tests. Pain was quantified using the Visual Analog Scale (VAS), while functional disability was assessed using the Disabilities of the Arm, Shoulder and Hand (DASH) questionnaire and the Constant-Murley score. Shoulder strength was measured using a calibrated digital dynamometer (MicroFET2, Hoggan Health Industries and West Jordan, UT, USA) for forward flexion, abduction, external rotation, and internal rotation. Each measurement was repeated three times, and the average value was recorded.

Radiological evaluation comprised a standard series of plain radiographs, including anteroposterior views in neutral, internal, and external rotation, axillary lateral view, and scapular Y view. All patients underwent high-resolution MRI of the affected shoulder using a 3.0-Tesla MRI system (Siemens Magnetom Skyra, Erlangen, Germany) with a dedicated shoulder coil. The imaging protocol included T_1-weighted sequences in axial, coronal, and sagittal planes, T_2-weighted fat-suppressed sequences in coronal and sagittal planes, and proton density-weighted sequences in axial plane. In 43 patients with suspected partial avulsions, additional MR arthrography was performed using gadolinium contrast medium.

The morphometric analysis of avulsion injuries was conducted independently by two experienced musculoskeletal radiologists who were blinded to the clinical data. Disagreements were resolved by consensus with a third radiologist. The parameters measured included: (1) avulsion size (anteroposterior and mediolateral dimensions), (2) displacement distance from the original bony attachment, (3) gap area between the avulsed tissue and bone, (4) tissue retraction degree, (5) muscle atrophy grade according to Goutallier classification, and (6) fatty infiltration index. These measurements were performed using specialized medical imaging software (OsiriX MD, Pixmeo SARL, Geneva, Switzerland) with standardized calibration.

Three-dimensional reconstructions were generated for 68 patients to better visualize the spatial relationships of the avulsed tissues. Ultrasonographic assessment was additionally performed in 57 patients using a high-frequency linear transducer (6-15 MHz) to evaluate dynamic aspects of the injured structures. The integrity of the remaining rotator cuff was documented, and any associated pathologies were noted.

Statistical analysis was performed using SPSS version 26.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics were calculated for demographic and clinical variables. The reliability of morphometric measurements was assessed using intraclass correlation coefficients. Pearson or Spearman correlation coefficients were computed to examine relationships between morphometric parameters and clinical outcomes. Multiple linear regression analysis was conducted to identify predictors of functional disability. Subgroup analyses were performed based on injury acuity (acute vs. chronic) and anatomical location (supraspinatus vs. infraspinatus vs. subscapularis). Statistical significance was set at $p<0.05$, and all tests were two-tailed.

To validate the clinical relevance of the morphometric findings, a follow-up assessment was conducted at 6 months post-diagnosis in 87 patients (92.6% follow-up rate). Treatment decisions were based on standard clinical protocols and were documented for correlation analysis. Patients receiving surgical intervention (N=53) underwent standardized procedures by the same surgical team, with intraoperative findings recorded for comparison with preoperative imaging measurements.

Results

Demographic and Clinical Characteristics

The demographic and clinical characteristics presented in Table 1 reveal a study population with a mean age of 48.6±11.3 years, with male predominance (60.6%). The majority of patients (67.0%) sustained injuries to their dominant shoulder. Falls on an outstretched hand represented the most common mechanism of injury (44.7%), followed by direct trauma to the shoulder (33.0%). Patients presented with moderate to severe symptoms, as evidenced by the mean VAS pain score of 6.7±1.8, DASH score of 61.4±14.2, and Constant-Murley score of 48.3±13.7, indicating significant functional impairment.

Table 1: Demographic and clinical characteristics of study participants (N=94)

Characteristic	Value
Age, years (mean ± SD)	48.6±11.3
Sex, n (%)	
Male	57 (60.6%)
Female	37 (39.4%)
Dominant side affected, n (%)	63 (67.0%)
Mechanism of injury, n (%)	
Fall on outstretched hand	42 (44.7%)
Direct trauma to shoulder	31 (33.0%)
Forceful external rotation	14 (14.9%)
Repetitive overhead activity	7 (7.4%)
Duration of symptoms, months (mean ± SD)	3.8±2.6
VAS pain score (mean ± SD)	6.7±1.8
DASH score (mean ± SD)	61.4±14.2
Constant-Murley score (mean ± SD)	48.3±13.7

Morphometric Parameters of Avulsion Injuries

Table 2 illustrates the morphometric characteristics of avulsion injuries across different anatomical locations. Subscapularis avulsions demonstrated the largest dimensions (anteroposterior: 20.1±6.2 mm; mediolateral: 17.3±5.1 mm) and greatest displacement distance (10.5±3.6 mm) compared to supraspinatus and infraspinatus avulsions. Similarly, subscapularis injuries exhibited the highest proportion of severe tissue retraction (26.1% grade 3) and muscle atrophy (13.0% grade 3), along with the highest fatty infiltration index (1.43±0.84). Infraspinatus avulsions consistently demonstrated the least severe morphometric parameters. These differences across anatomical locations were statistically significant (p<0.05), highlighting the variable presentation and potential prognostic implications based on the specific rotator cuff component involved.

Table 2: Morphometric characteristics of avulsion injuries by anatomical location

Parameter	Supraspinatus (N=43)	Infraspinatus (N=28)	Subscapularis (N=23)	P-Value
Anteroposterior dimension, mm (mean ± SD)	18.4±5.3	16.7±4.8	20.1±6.2	0.037*
Mediolateral dimension, mm (mean ± SD)	15.2±4.6	13.8±3.9	17.3±5.1	0.029*
Displacement distance, mm (mean ± SD)	9.7±3.2	7.9±2.8	10.5±3.6	0.022*
Gap area, mm² (mean ± SD)	176.3±48.5	154.8±42.7	195.6±53.4	0.018*
Tissue retraction, n (%)				0.041*
Grade 1 (minimal)	18 (41.9%)	16 (57.1%)	8 (34.8%)	
Grade 2 (moderate)	17 (39.5%)	9 (32.1%)	9 (39.1%)	
Grade 3 (severe)	8 (18.6%)	3 (10.7%)	6 (26.1%)	
Muscle atrophy grade, n (%)				0.032*
Grade 0	14 (32.6%)	11 (39.3%)	6 (26.1%)	
Grade 1	17 (39.5%)	12 (42.9%)	8 (34.8%)	
Grade 2	9 (20.9%)	4 (14.3%)	6 (26.1%)	
Grade 3	3 (7.0%)	1 (3.6%)	3 (13.0%)	
Fatty infiltration index (mean ± SD)	1.28±0.76	0.94±0.68	1.43±0.84	0.026*

*Statistically significant (p<0.05)

Correlation between morphometric parameters and clinical outcomes

Table 3 demonstrates strong correlations between morphometric parameters and functional outcomes. Displacement distance showed the strongest correlation with VAS pain scores (r=0.56, p<0.001), DASH scores (r=0.63, p<0.001), and Constant-Murley scores (r=-0.59, p<0.001), suggesting that greater displacement is associated with worse pain and functional limitation. Tissue retraction grade exhibited even stronger correlations with all three clinical outcome measures (VAS: r=0.61, DASH: r=0.67, Constant-Murley: r=-0.64; all p<0.001), highlighting its potential value as a prognostic indicator. Notably, all measured morphometric parameters showed statistically significant correlations with clinical outcomes, underscoring the relevance of comprehensive morphometric analysis in clinical assessment.

Table 3: Correlation between morphometric parameters and functional outcomes

Morphometric Parameter	VAS Pain Score		DASH Score		Constant-Murley Score	
	R	P-Value	R	P-Value	R	P-Value
Anteroposterior dimension	0.31	0.008**	0.37	0.002**	-0.35	0.004**
Mediolateral dimension	0.28	0.012*	0.34	0.005**	-0.32	0.007**
Displacement distance	0.56	< 0.001**	0.63	<0.001**	-0.59	< 0.001**
Gap area	0.48	< 0.001**	0.52	<0.001**	-0.49	< 0.001**
Tissue retraction grade	0.61	< 0.001**	0.67	<0.001**	-0.64	< 0.001**
Muscle atrophy grade	0.52	< 0.001**	0.59	<0.001**	-0.57	< 0.001**
Fatty infiltration index	0.47	< 0.001**	0.54	<0.001**	-0.51	< 0.001**

*p<0.05, **p<0.01, r=Pearson's correlation coefficient

Predictors of Functional Disability

The multiple linear regression analysis in Table 4 identifies the independent predictors of functional disability as measured by the DASH score. Displacement distance emerged as the strongest predictor (β=0.36, p<0.001), followed by tissue retraction grade (β=0.31, p<0.001) and muscle atrophy grade (β=0.23, P=0.004). Age and duration of symptoms also remained significant independent predictors in the multivariate model, suggesting their additive contribution to functional impairment. The model explained 73% of the variance in DASH scores (adjusted R^2=0.71), indicating robust predictive capability based on the measured parameters.

Table 4: Multiple linear regression analysis for predictors of dash score

Predictor Variable	Unstandardized Coefficient (B)	Standard Error	Standardized Coefficient (β)	P-Value
Constant	23.47	4.86	-	< 0.001
Displacement distance	2.83	0.57	0.36	< 0.001
Tissue retraction grade	7.94	1.89	0.31	< 0.001
Muscle atrophy grade	4.58	1.52	0.23	0.004
Fatty infiltration index	3.76	1.61	0.18	0.021
Age	0.16	0.07	0.14	0.032
Duration of symptoms	0.92	0.31	0.17	0.004

R^2=0.73, Adjusted R^2=0.71, F=38.42, p<0.001

Comparison of Acute vs. Chronic Injuries

Table 5 compares acute and chronic avulsion injuries, revealing significantly worse morphometric parameters in chronic cases. Chronic injuries demonstrated greater anteroposterior (19.6±5.7 mm vs. 16.8±4.9 mm, P=0.007) and mediolateral dimensions (16.7±4.8 mm vs. 14.2±4.1 mm, P=0.010), as well as substantially increased displacement distance (11.2±3.5 mm vs. 7.9±2.7 mm, p<0.001). The median tissue retraction and muscle atrophy grades were both higher in chronic injuries (grade 2 vs. grade 1, p<0.001). Most notably, the fatty infiltration index was approximately twice as high in chronic compared to acute injuries (1.69±0.78 vs. 0.83±0.52, p<0.001), suggesting progressive tissue degeneration over time.

Table 5: Comparison of morphometric parameters between acute and chronic avulsion injuries

Parameter	Acute Injuries (N=51)	Chronic Injuries (N=43)	Mean Difference	95% CI	P-Value
Anteroposterior dimension, mm	16.8±4.9	19.6±5.7	2.8	0.9 to 4.7	0.007**
Mediolateral dimension, mm	14.2±4.1	16.7±4.8	2.5	0.7 to 4.3	0.010*
Displacement distance, mm	7.9±2.7	11.2±3.5	3.3	2.0 to 4.6	< 0.001**
Gap area, mm²	153.2±43.6	196.8±51.3	43.6	24.9 to 62.3	< 0.001**
Tissue retraction grade (median)	1	2	-	-	< 0.001**
Muscle atrophy grade (median)	1	2	-	-	< 0.001**
Fatty infiltration index	0.83±0.52	1.69±0.78	0.86	0.59 to 1.13	< 0.001**

*p<0.05, **p<0.01 CI=Confidence Interval

Radiological and Surgical Findings Correlation

Table 6 demonstrates excellent correlation between preoperative radiological measurements and intraoperative findings in the surgical subgroup (N=53). All measured parameters showed high intraclass correlation coefficients (ICC ranging from 0.83 to 0.92), with the anteroposterior dimension demonstrating the strongest agreement (ICC=0.92). While small systematic differences were observed between radiological and intraoperative measurements (with intraoperative measurements consistently slightly larger), these differences were minimal and within clinically acceptable limits. This high level of concordance validates the accuracy of the radiological assessment methods employed in this study.

Table 6: Correlation between preoperative radiological measurements and intraoperative findings (N=53)

Parameter	Radiological Measurement	Intraoperative Measurement	Mean Difference	95% CI	ICC
Anteroposterior dimension, mm	18.2±5.4	19.1±5.8	0.9	0.3 to 1.5	0.92
Mediolateral dimension, mm	15.6±4.7	16.3±5.0	0.7	0.2 to 1.2	0.90
Displacement distance, mm	9.8±3.3	10.5±3.7	0.7	0.3 to 1.1	0.87
Gap area, mm²	178.4±49.1	192.3±54.6	13.9	6.8 to 21.0	0.85
Tissue retraction grade (concordance)	-	-	-	-	0.83

ICC=Intraclass Correlation Coefficient

Discussion

Our study provides comprehensive morphometric analysis of avulsion injuries of the rotator cuff and their correlation with clinical dysfunction. The results reveal significant associations between specific morphometric parameters and functional outcomes, with displacement distance and tissue retraction grade emerging as the strongest predictors of disability.

The observed predominance of subscapularis avulsions with greater dimensions and displacement is consistent with findings by Nove-Josserand *et al*., who reported that subscapularis tears often present with more extensive tissue disruption compared to poster superior rotator cuff injuries [11]. This may be attributed to the unique biomechanical properties and anatomical characteristics of the subscapularis tendon. Kim *et al*. demonstrated that the subscapularis has a more complex fiber architecture and greater tensile strength than other rotator cuff components, potentially leading to more substantial tissue displacement when avulsion occurs [12]. The strong correlation between displacement distance and clinical outcomes in our study aligns with the work of Teefey *et al*., who identified tendon retraction as a critical determinant of functional impairment in rotator cuff injuries [13]. Similarly, our findings regarding tissue retraction echo those of Patte, whose classification system highlighted the prognostic significance of retraction in rotator cuff tears [14]. Our data extend these observations by providing specific quantitative parameters and establishing their relative contributions to functional disability through multivariate analysis.

The significant differences observed between acute and chronic avulsion injuries merit particular attention. The substantially higher fatty infiltration index in chronic injuries (1.69±0.78 vs. 0.83±0.52, p<0.001) supports the time-dependent degeneration model proposed by Goutallier *et al*., who described progressive fatty infiltration as a consequence

of chronic rotator cuff dysfunction.[15] Melis *et al*. similarly reported that fatty infiltration increases at a rate of approximately one grade every 3 years following rotator cuff tears, particularly in the supraspinatus and infraspinatus muscles [16]. Our findings suggest that this degenerative process may also affect avulsed tissues in a time-dependent manner, emphasizing the importance of early intervention.

The muscle atrophy patterns identified in our morphometric analysis correspond with those reported by Thomazeau *et al*., who utilized the occupation ratio to quantify supraspinatus atrophy following rotator cuff tears [17]. Interestingly, our data indicate that atrophy patterns may vary across different rotator cuff components, with the subscapularis showing the highest proportion of severe atrophy (13.0% grade 3). This anatomical variability in muscular response to avulsion injury has not been extensively explored in previous literature and represents a novel finding with potential implications for targeted rehabilitation strategies.

The high correlation between preoperative radiological measurements and intraoperative findings (ICC ranging from 0.83 to 0.92) validates the accuracy of our imaging protocols. This level of concordance exceeds that reported by Davidson *et al*., who found moderate agreement (kappa=0.67) between MRI and arthroscopic assessment of rotator cuff tears [18]. Our superior results may be attributed to the use of high-resolution 3.0-Tesla MRI and the complementary application of multiple imaging modalities, including MR arthrography and dynamic ultrasonography in selected cases.

Our regression model identified displacement distance (β=0.36, p<0.001) and tissue retraction grade (β=0.31, p<0.001) as the strongest independent predictors of DASH scores. This finding is partially supported by Collin *et al*., who demonstrated that acromiohumeral distance and tendon retraction were significant predictors of functional outcomes following rotator cuff repair [19]. However, Collin's study did not include detailed morphometric analysis of avulsion injuries specifically. Our results suggest that morphometric parameters may have even greater prognostic value in avulsion injuries than in standard rotator cuff tears, potentially due to the unique pathomechanics and healing patterns of avulsed tissues.

The significant correlation between gap area and functional outcomes (VAS: r=0.48, DASH: r=0.52, Constant-Murley: r=-0.49; all p<0.001) suggests that three-dimensional assessment of tissue defects may provide additional prognostic information beyond linear measurements. This concept aligns with the findings of Funakoshi *et al*., who demonstrated that three-dimensional analysis of rotator cuff tears using MRI provided superior predictive value for functional outcomes compared to conventional two-dimensional assessment [20]. The implementation of advanced imaging techniques, including 3D reconstructions as employed in our study, may therefore enhance preoperative planning and prognostic accuracy.

The observed influence of patient age on functional outcomes (β=0.14, P=0.032 in regression model) is consistent with the findings of Boileau *et al*., who reported age as a significant factor affecting healing rates and functional recovery following rotator cuff repair [21]. However, our data suggest that morphometric parameters have substantially greater predictive value than demographic factors, indicating that tissue characteristics may supersede age-related considerations in clinical decision-making.

The association between fatty infiltration index and functional impairment in our study (r=0.54 with DASH scores, p<0.001) supports the observations of Gladstone *et al*., who identified fatty infiltration as a critical determinant of outcomes following rotator cuff repair [22]. However, while Gladstone emphasized the irreversibility of fatty infiltration, our findings of significantly different infiltration indices between acute and chronic cases (0.83±0.52 vs. 1.69±0.78, p<0.001) suggest a window of opportunity for intervention before extensive fatty changes occur. This temporal relationship has important clinical implications for optimizing treatment timing.

The comprehensive nature of our morphometric analysis provides several advantages over previous studies. Matthews *et al*. examined histological changes in rotator cuff tears but did not correlate these with detailed morphometric parameters or functional outcomes [9]. Similarly, Mall *et al*. investigated the progression of asymptomatic rotator cuff tears but focused primarily on tear size rather than comprehensive morphometric assessment [8]. Our integration of multiple morphometric parameters with standardized functional outcome measures offers a more nuanced understanding of structure-function relationships in avulsion injuries.

Several limitations of our study warrant consideration. The cross-sectional design precludes definitive conclusions regarding causality. Longitudinal studies are needed to elucidate the temporal relationships between morphometric changes and functional deterioration. Additionally, while our imaging protocols demonstrated excellent correlation with intraoperative findings, histological assessment was not performed to validate tissue quality measurements. Future studies incorporating tissue biopsies could provide additional insights into the relationship between morphometric parameters and underlying histopathological changes.

Conclusion

This comprehensive morphometric analysis of avulsion injuries demonstrates strong correlations between specific morphometric parameters and rotator cuff dysfunction. Displacement distance and tissue retraction grade emerged as the strongest predictors of functional disability, with subscapularis avulsions exhibiting the most severe morphometric characteristics. The significant differences between acute and chronic injuries highlight the time-dependent deterioration of avulsed tissues, emphasizing the importance of early intervention. These findings provide clinically relevant morphometric criteria that may guide treatment decisions and prognostic assessments, potentially improving outcomes for patients with these challenging shoulder injuries.

Conflict of Interest

Not available

Financial Support

Not available

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