



## Ultrasonography-Guided Phenotyping of Rotator Cuff-Related Shoulder Pain and Its Impact on Tailored Rehabilitation Outcomes

\*Dr. Md. Nadim Kamal<sup>1</sup>, Dr. Ziaur Rahman Chowdhury<sup>2</sup>, Dr. Md. Abdul Kalam Azad<sup>3</sup>, Dr. Nadia Rahman<sup>4</sup>, Dr. Badrunnesa Ahmed<sup>5</sup>, Dr. Mohammad Golam Nobil<sup>6</sup>, Dr. Md. Imamur Rashid<sup>7</sup>

<sup>1</sup>Associate Professor, Department of Physical Medicine and Rehabilitation, Bangladesh Medical University, Dhaka, Bangladesh

<sup>2</sup>Associate Professor, Department of Physical Medicine and Rehabilitation, Bangladesh Medical University, Dhaka, Bangladesh

<sup>3</sup>Associate Professor, Department of Physical Medicine and Rehabilitation, Bangladesh Medical University, Dhaka, Bangladesh

<sup>4</sup>Associate Professor, Department of Physical Medicine and Rehabilitation, Bangladesh Medical University, Dhaka, Bangladesh

<sup>5</sup>Associate Professor, Department of Physical Medicine and Rehabilitation, Bangladesh Medical University, Dhaka, Bangladesh

<sup>6</sup>Associate Professor, Department of Physical Medicine and Rehabilitation, Bangladesh Medical University, Dhaka, Bangladesh

<sup>7</sup>Associate Professor, Department of Physical Medicine and Rehabilitation, Bangladesh Medical University, Dhaka, Bangladesh

**Corresponding Author:** Dr. Md. Nadim Kamal, Associate Professor, Department of Physical Medicine and Rehabilitation, Bangladesh Medical University, Dhaka, Bangladesh

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### KEYWORDS

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### ABSTRACT:

**Background:** Rotator cuff-related shoulder pain is a prevalent cause of musculoskeletal disability among middle-aged and older adults. It encompasses heterogeneous structural pathologies, including tendinopathy, tears, bursitis and calcific changes. Conventional management often applies uniform rehabilitation protocols despite structural variability. Ultrasonography offers an accessible modality for structural phenotyping that may facilitate tailored treatment strategies. This study aimed to evaluate ultrasonography-guided phenotyping of rotator cuff-related shoulder pain and its impact on outcomes following tailored rehabilitation.

**Methods:** This prospective observational study was conducted in the Department of Physical Medicine and Rehabilitation at Bangladesh Medical University (BMU), Dhaka, Bangladesh, from July to December 2025. The study included 30 consecutive patients diagnosed with rotator cuff-related shoulder pain who attended the outpatient rehabilitation clinic were included in this study. Participants underwent high-resolution shoulder ultrasonography and were categorized into structural phenotypes. A 12-week tailored rehabilitation program was implemented. Pain (VAS), function (Constant-Murley score, SPADI) and active forward elevation were assessed at baseline and 12 weeks.

**Results:** Partial-thickness tears were most common (36.7%), followed by isolated tendinopathy (23.3%) and full-thickness tears (20.0%). Significant improvements were observed in VAS (-3.9), Constant score (+34.9), SPADI (-31.1) and forward elevation (+60°) (all  $p < 0.001$ ). MCID achievement was highest in bursitis and calcific phenotypes (100%) and lowest in full-thickness tears (50%).

**Conclusion:** Ultrasonography-guided phenotyping combined with tailored rehabilitation was associated with significant clinical improvement. Structural stratification may enhance precision in conservative management of rotator cuff-related shoulder pain.



## Introduction

Rotator cuff-related shoulder pain is one of the most common causes of musculoskeletal consultation in middle-aged and older adults [1]. It encompasses a spectrum of structural and functional disorders involving the rotator cuff tendons and subacromial structures [2]. The condition is associated with pain, reduced range of motion and functional limitation, significantly affecting quality of life and work productivity [3]. Despite its high prevalence, diagnostic terminology and classification remain inconsistent, leading to heterogeneity in management strategies [4].

Structural abnormalities such as tendinopathy, partial- or full-thickness tears and subacromial bursitis frequently coexist and may contribute variably to symptoms [5]. High-resolution ultrasonography has emerged as a reliable and accessible imaging modality for evaluating rotator cuff pathology [6]. Systematic reviews have demonstrated comparable diagnostic accuracy between ultrasonography and magnetic resonance imaging for detecting rotator cuff tears [7]. In addition, ultrasonography allows dynamic assessment and real-time evaluation of subacromial space parameters, enhancing its clinical utility [8].

However, structural findings do not consistently correlate with pain severity or disability [9]. Contemporary perspectives emphasize that rotator cuff-related shoulder pain is multifactorial, involving inflammatory, mechanical and neurophysiological mechanisms [10,11]. Central sensitization and altered pain processing have been documented in a subset of patients with chronic shoulder pain [12,13]. This complexity underscores the need for more individualized approaches rather than uniform treatment algorithms.

Conservative management, particularly exercise-based rehabilitation, remains the cornerstone of treatment. Large randomized trials have shown that progressive exercise yields outcomes comparable to surgical interventions in many patients with subacromial pain syndromes [14,15]. Nevertheless, response to rehabilitation varies and certain structural phenotypes may influence prognosis and therapeutic response [16].

Ultrasound-guided phenotyping offers an opportunity to stratify patients based on structural characteristics and tailor interventions accordingly. Prior studies suggest

that imaging-informed treatment strategies may improve short-term outcomes compared to non-stratified care [17]. Yet, evidence regarding phenotype-specific rehabilitation responses in rotator cuff-related shoulder pain remains limited, particularly in South Asian populations.

Therefore, this study aimed to evaluate ultrasonography-guided phenotyping of rotator cuff-related shoulder pain and to determine its impact on tailored rehabilitation outcomes. By correlating structural phenotypes with clinical improvement, the study seeks to contribute to precision-oriented rehabilitation strategies in musculoskeletal practice.

## Materials & Methods

This prospective observational study was conducted in the Department of Physical Medicine and Rehabilitation at Bangladesh Medical University (BMU), Dhaka, Bangladesh, from July to December 2025. The study included 30 consecutive patients diagnosed with rotator cuff-related shoulder pain who attended the outpatient rehabilitation clinic during the study period were included in this study.

### Sample Selection

#### Inclusion criteria:

- Age  $\geq 40$  years.
- Clinical diagnosis of rotator cuff-related shoulder pain.
- Symptom duration  $\geq 3$  months.
- Positive clinical tests suggestive of rotator cuff pathology.
- Ability to participate in a structured rehabilitation program.

#### Exclusion criteria:

- Previous shoulder surgery.
- Acute traumatic shoulder dislocation or fracture.
- Systemic inflammatory or rheumatologic disease.
- Cervical radiculopathy or neurological deficit affecting the upper limb.
- Severe glenohumeral osteoarthritis.



### Data Collection Procedure

Eligible patients were screened through detailed clinical evaluation, including history, physical examination and standardized shoulder tests. Baseline demographic data, symptom duration and dominant side involvement were recorded using a structured case record form. Pain intensity was measured using a 10-point Visual Analogue Scale (VAS). Functional disability was assessed using the Shoulder Pain and Disability Index (SPADI) and the Constant–Murley score. Active forward elevation was measured with a standard goniometer by a trained physiotherapist to ensure consistency.

All participants underwent high-resolution musculoskeletal ultrasonography performed by an experienced radiologist using a linear transducer. Static and dynamic assessments were conducted to identify tendon integrity, bursitis and calcific deposits. Based on ultrasonographic findings, patients were categorized into predefined structural phenotypes. A tailored rehabilitation program was designed according to phenotype, incorporating progressive strengthening,

mobility exercises and condition-specific interventions. The program was delivered over 12 weeks with supervised sessions and home-based components.

Outcome measures were reassessed at 12 weeks using the same instruments and procedures as the baseline evaluation. Standardized instructions were provided during all assessments to enhance reliability. Written informed consent was obtained from all participants before enrollment. Confidentiality of patient information was maintained by anonymizing data and restricting access to study records.

### Statistical Analysis

Data were analyzed using SPSS version 25.0. Descriptive statistics were used to summarize demographic and clinical variables. Continuous variables were expressed as mean  $\pm$  standard deviation. Paired t-tests were applied to compare baseline and 12-week outcomes. Mean differences with 95% confidence intervals were calculated. A p-value  $<0.05$  was considered statistically significant.

## Results

**Table 1. Baseline Demographic and Clinical Characteristics (n = 30)**

Variable		Frequency (n)	Percentage (%)
Age group (years)	40–49	8	26.7
	50–59	13	43.3
	$\geq 60$	9	30.0
	Mean $\pm$ SD	53.1 $\pm$ 8.2	
Sex	Male	18	60.0
	Female	12	40.0
Dominant shoulder affected	Yes	19	63.3
	No	11	36.7
Symptom duration (months)	3–6 months	20	66.7
	>6 months	10	33.3
	Mean $\pm$ SD	5.1 $\pm$ 1.9	
Baseline Pain (VAS 0–10)		7.1 $\pm$ 1.3	
Baseline SPADI Total Score		65.8 $\pm$ 9.4	



Table 1 presents the demographic and baseline clinical profile of the participants. The mean age was  $53.1 \pm 8.2$  years, with 43.3% aged 50–59 years. Males constituted 60.0% of the cohort. The dominant shoulder was affected in 63.3% of cases. Most participants (66.7%) reported

symptom duration between 3 and 6 months, with a mean duration of  $5.1 \pm 1.9$  months. The mean baseline VAS pain score was  $7.1 \pm 1.3$  and the mean SPADI total score was  $65.8 \pm 9.4$ .

**Table 2. Distribution of Ultrasonography-Based Rotator Cuff Phenotypes (n = 30)**

Phenotype	Frequency (n)	Percentage (%)
Isolated Tendinopathy (no tear)	7	23.3
Partial-Thickness Rotator Cuff Tear	11	36.7
Full-Thickness Rotator Cuff Tear	6	20.0
Predominant Subacromial–Subdeltoid Bursitis (intact cuff)	4	13.3
Calcific Tendinopathy	2	6.7

Table 2 describes the structural phenotypes identified by ultrasonography. Partial-thickness rotator cuff tears were the most common finding (36.7%). Isolated tendinopathy without tear accounted for 23.3% of cases. Full-thickness

tears were identified in 20.0% of participants. Predominant subacromial–subdeltoid bursitis with intact cuff was observed in 13.3%. Calcific tendinopathy was present in 6.7% of patients.

**Table 3. Overall Changes in Clinical Outcomes from Baseline to 12 Weeks (n = 30)**

Outcome	Baseline (Mean $\pm$ SD)	12 Weeks (Mean $\pm$ SD)	Mean Change (95% CI)	p-value
VAS Pain	$7.1 \pm 1.3$	$3.2 \pm 1.5$	$-3.9$ ( $-4.6$ to $-3.2$ )	<0.001
Constant–Murley Score	$44.2 \pm 11.6$	$79.1 \pm 10.8$	$+34.9$ ( $29.8$ to $40.0$ )	<0.001
SPADI Total Score	$65.8 \pm 9.4$	$34.7 \pm 10.2$	$-31.1$ ( $-35.6$ to $-26.6$ )	<0.001
Active Forward Elevation ( $^{\circ}$ )	$88 \pm 21$	$148 \pm 17$	$+60$ ( $52$ to $68$ )	<0.001

Table 3 shows significant improvements across all measured outcomes after 12 weeks. Mean VAS pain decreased from  $7.1 \pm 1.3$  to  $3.2 \pm 1.5$ , with a mean change of  $-3.9$  (95% CI:  $-4.6$  to  $-3.2$ ;  $p < 0.001$ ). The Constant–Murley score improved from  $44.2 \pm 11.6$  to  $79.1 \pm 10.8$ , reflecting a mean increase of  $34.9$  (95% CI:  $29.8$  to  $40.0$ ;

$p < 0.001$ ). The SPADI total score decreased from  $65.8 \pm 9.4$  to  $34.7 \pm 10.2$ , with a mean reduction of  $-31.1$  (95% CI:  $-35.6$  to  $-26.6$ ;  $p < 0.001$ ). Active forward elevation improved from  $88 \pm 21$  degrees to  $148 \pm 17$  degrees, with a mean gain of  $60$  degrees (95% CI:  $52$  to  $68$ ;  $p < 0.001$ ).

**Table 4. Phenotype-Specific Clinical Improvements and Achievement of MCID**

Phenotype	n	VAS Change (Mean $\pm$ SD)	Constant Score Change (Mean $\pm$ SD)	MCID Achieved n (%)
Isolated Tendinopathy	7	$-4.5 \pm 1.1$	$+38.2 \pm 9.4$	6 (85.7)



Partial Tear	11	$-4.2 \pm 1.3$	$+36.1 \pm 10.2$	9 (81.8)
Full Tear	6	$-3.0 \pm 1.4$	$+25.3 \pm 8.7$	3 (50.0)
Bursitis Predominant	4	$-4.6 \pm 1.0$	$+37.5 \pm 8.1$	4 (100)
Calcific Tendinopathy	2	$-4.8 \pm 0.9$	$+40.4 \pm 6.3$	2 (100)

Table 4 presents outcome changes stratified by ultrasonographic phenotype. Isolated tendinopathy showed a mean VAS reduction of  $-4.5 \pm 1.1$  and Constant score increase of  $+38.2 \pm 9.4$ , with 85.7% achieving MCID. Partial-thickness tears demonstrated a VAS reduction of  $-4.2 \pm 1.3$  and Constant score increase of  $+36.1 \pm 10.2$ , with 81.8% achieving MCID. Full-thickness tears had smaller improvements, with VAS change  $-3.0 \pm 1.4$  and Constant increase  $+25.3 \pm 8.7$  and 50.0% achieving MCID. Bursitis-predominant cases and calcific tendinopathy showed the largest improvements, with 100% achieving MCID.

### Discussion

The present study demonstrated that ultrasonography-guided phenotyping of rotator cuff-related shoulder pain was associated with significant improvements in pain, function and range of motion following tailored rehabilitation. Overall pain reduction and functional gains were substantial, with most participants achieving minimal clinically important differences, particularly in non-full-thickness phenotypes. These findings support the clinical value of structural stratification in guiding conservative management.

Rotator cuff-related shoulder pain represents a heterogeneous clinical entity encompassing tendinopathy, partial tears, full-thickness tears, bursitis and calcific pathology [1]. Bedi et al. described the continuum of rotator cuff disease and emphasized that structural variation may influence symptom severity and prognosis [3]. In the present cohort, partial-thickness tears were the most prevalent phenotype, followed by isolated tendinopathy, which aligns with epidemiological observations in middle-aged populations [5]. The mean age and chronicity profile of participants also correspond to recognized risk patterns for degenerative cuff pathology.

High-resolution ultrasonography served as the primary imaging modality for phenotyping in this study. Roy et

al. reported that ultrasonography demonstrates diagnostic accuracy comparable to magnetic resonance imaging for detecting rotator cuff tears [7]. Similarly, Zheng et al. highlighted its reliability in identifying tendon and bursal abnormalities in clinical practice [6]. The distribution of phenotypes in this study underscores ultrasonography's utility in differentiating structural subgroups that may respond variably to rehabilitation.

Significant reductions in VAS pain and SPADI scores were observed across the entire sample. These improvements are consistent with evidence supporting exercise-based rehabilitation as the cornerstone of management for rotator cuff-related disorders [18]. The GRASP trial by Hopewell et al. showed that progressive exercise yields meaningful clinical benefits in patients with rotator cuff disorders [14]. Moreover, Babatunde et al. demonstrated that conservative interventions achieve outcomes comparable to surgical strategies in many cases of subacromial pain [18]. The magnitude of improvement in Constant-Murley scores in the present study parallels these findings and reinforces the effectiveness of structured rehabilitation.

Phenotype-specific analysis revealed that patients with isolated tendinopathy, partial-thickness tears, bursitis-predominant pathology and calcific tendinopathy exhibited greater improvements compared to those with full-thickness tears. This observation aligns with the biological plausibility that partial structural disruption retains greater healing and adaptive potential than complete tendon discontinuity [3]. Lädermann et al. emphasized that full-thickness tears, particularly larger lesions, often demonstrate reduced functional recovery with nonoperative management [19]. The lower proportion of MCID achievement among full-thickness tear cases in this study reflects this trend.

Calcific tendinopathy and bursitis-predominant phenotypes demonstrated particularly robust responses. Louwerens et al. reported that calcific deposits may be associated with acute inflammatory phases that respond



favorably to conservative or targeted interventions [20]. Chillemi et al. highlighted the role of subacromial bursa inflammation in pain generation, suggesting that reduction of inflammatory burden may substantially relieve symptoms [21]. The pronounced improvements observed in these subgroups may therefore reflect responsiveness to anti-inflammatory and mobility-focused rehabilitation strategies.

Although structural imaging was central to phenotyping, pain perception is recognized as multifactorial. Dean et al. discussed the neurobiological mechanisms contributing to shoulder pain, including biochemical mediators and neural sensitization [10]. Evidence of altered central pain processing has been documented in chronic shoulder pain populations [12,13]. The consistent improvements across phenotypes in this study suggest that addressing mechanical and functional impairments through tailored exercise may modulate both peripheral and central contributors to pain.

The concept of phenotyping has gained increasing attention in musculoskeletal medicine. Meisingset et al. proposed that subgroup identification may enhance prognostic precision and treatment targeting in musculoskeletal disorders [22]. Ottenheim et al. demonstrated that ultrasound-informed treatment strategies may improve short-term outcomes in acute shoulder pain [17]. The present findings extend this perspective by illustrating that structural phenotyping combined with individualized rehabilitation may yield clinically meaningful benefits in chronic rotator cuff-related shoulder pain.

Notably, improvements in active forward elevation were substantial, reflecting restoration of shoulder mechanics. Michener et al. reported that subacromial space parameters and supraspinatus characteristics assessed by ultrasonography are associated with functional impairment [23]. Rehabilitation targeting scapulothoracic control, rotator cuff strength and mobility likely contributed to the observed gains in range of motion.

Collectively, these findings support a precision-oriented approach to conservative management. While structural pathology alone does not fully explain symptom burden, integrating ultrasonographic phenotyping into rehabilitation planning appears to enhance clinical responsiveness. The differential outcomes observed

across phenotypes underscore the importance of individualized assessment rather than uniform protocols in rotator cuff-related shoulder pain.

## Limitations and Recommendations

The small sample size and short follow-up period may limit generalizability of the findings. Larger multicenter studies with longer-term follow-up are recommended to validate phenotype-specific rehabilitation responses and explore integration with biopsychosocial pain profiling.

## Conclusion

Ultrasonography-guided phenotyping of rotator cuff-related shoulder pain enables structural stratification that supports tailored rehabilitation planning. Significant improvements in pain, function and range of motion were observed over 12 weeks, particularly in tendinopathy, partial-tear, bursitis and calcific phenotypes. Full-thickness tears demonstrated comparatively smaller gains. These findings suggest that imaging-informed, individualized rehabilitation may enhance clinical outcomes in patients with chronic rotator cuff-related shoulder pain.

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