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Range of Motion as a Predictor of Clinical Shoulder Pain During Recovery From Delayed-Onset Muscle Soreness

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Context: Athletic trainers use clinical pain and range of motion (ROM) to gauge recovery after musculoskeletal injury. Limited evidence to date suggests which shoulder ROM measures can predict symptomatic relief and functional recovery after delayed-onset muscle soreness (DOMS).

Objective: To determine whether shoulder passive internal rotation, passive external rotation, active abduction, and active flexion and evoked pain with abduction are associated with resting pain experienced after exercise-induced DOMS.

Design: Descriptive laboratory study.

Setting: Controlled research laboratory.

Patients or Other Participants: A total of 110 healthy, right-hand–dominant participants (44 men: age = 25.39 ± 7.00 years, height = 178.93 ± 7.01 cm, weight = 78.59 ± 14.04 kg; 66 women: age = 22.98 ± 6.11 years, height = 164.64 ± 6.94 cm, weight = 61.86 ± 11.67 kg).

Intervention(s): Participants completed an exercise-induced DOMS protocol for the external rotators of the dominant shoulder to replicate muscle injury.

Main Outcome Measure(s): Current resting pain was assessed daily for 96 hours using the Brief Pain Inventory. We evaluated functional recovery with measures of ROM in abduction, internal rotation, external rotation, and flexion. Evoked pain with active abduction was reported, and the pain rating served as the dependent variable in the regression model.

Results: Impairment measures explained resting pain at 48 ($R^2 = 0.392$) and 96 hours ($R^2 = 0.164$). Abduction and internal-rotation ROM and evoked pain with abduction predicted resting pain at 48 hours ($P < .001$). At 96 hours, evoked pain with abduction of the injured arm ($P < .001$) was the significant contributor to resting pain.

Conclusions: These models suggest that resting pain after experimentally induced DOMS occurs at 48 hours and is associated with specific ranges of motion and evoked pain with abduction.

Key Words: upper extremity, glenohumeral joint, functional impairment

Key Points

- At 48 hours after exercise-induced delayed-onset muscle soreness, abduction and internal-rotation range of motion and evoked pain with abduction all predicted resting pain.
- At 96 hours, the most significant predictor of resting pain was evoked pain with abduction.
- Controlling pain after initial injury while restoring range of motion in abduction and internal rotation may speed the recovery process.

Shoulder disorders are a common cause of persistent musculoskeletal pain.[1,2] The prevalence of shoulder injury in the general population is reported[3,4] to be between 7% and 25%. Similarly, athletes involved in upper extremity-intensive sports (eg, swimming, baseball, tennis, volleyball) experience musculoskeletal shoulder injury at a rate[5,6] of approximately 20%. Musculoskeletal shoulder dysfunction can be characterized functionally by restricted active and passive range of motion (ROM) along with pain and functional loss.[7] Traditionally, athletic trainers use measures of ROM and pain to gauge the extent of recovery after musculoskeletal injury. However, outcomes of shoulder conditions can be unfavorable and inconsistent and include chronic pain, disability, and reinjury of the joint. Only 50% of shoulder injuries resolve within the first 6 months, with 40% of cases persisting for more than 12 months.[3,8] Therefore, establishing which outcome measures are most reliable for evaluating shoulder disability and aiding in predicting functional recovery from injury will be beneficial.

Research[9–12] has been conducted on the reliability and accuracy of diagnostic testing such as magnetic resonance imaging, ultrasonography, radiographs, arthrography, and computed tomography. However, such testing is expensive, and access to equipment is limited and not always convenient.[13] Hence, it is necessary to establish reliable impairment measures that can be applied clinically to ensure full recovery from shoulder disability. Impairment measures may include glenohumeral (GH) ROM assessment, pain evaluation, muscle-point tenderness, and self-reported disability questionnaires. A host of orthopaedic special tests can be used to evaluate the presence or absence of injury, but functional testing is required to accurately track the patient's progress and the extent of functional

Table 1. Participants' Descriptive Statistics

Variable	Value
Sex, men/women, n (%)	44/66 (40/60)
Age, y (mean ± SD)	24.2 ± 6.6
Height, cm (mean ± SD)	171.8 ± 6.9
Weight, kg (mean ± SD)	70.2 ± 12.9

recovery. Range of motion in active and passive flexion, extension, abduction, and adduction should be evaluated.[13] Evoked pain with active movement should also be monitored, given that pain between 60° and 100° of abduction is classified as a "painful arc" and may reflect rotator cuff injury. Although these impairment measures are used regularly, limited evidence indicates which ROM measures better predict symptomatic relief and track functional recovery after injury.

We used an exercise-induced delayed-onset muscle soreness (DOMS) model in a group of otherwise healthy volunteers to identify the most reliable impairment measures for predicting recovery after shoulder-muscle injury. Exercise-induced DOMS produces signs and symptoms similar to acute injury, with pain and impairment peaking at 24 to 48 hours postinjury and full resolution within 5 to 7 days.[14,15] The exercise-induced DOMS model mimics the cellular and functional processes observed in acute musculoskeletal injury.[15–19] Such processes include loss of ROM and strength, resting pain (as assessed using the Brief Pain Inventory [BPI]), disability with activities of daily living, and localized swelling followed by signs of healing within 72 hours of injury.[15,20,21] Therefore, our primary objective was to determine whether passive internal-rotation and external-rotation, active-abduction, and flexion ROM of the shoulder and evoked pain with abduction were associated with self-reported resting pain (as noted on BPI) experienced after exercise-induced DOMS.

METHODS

Participants

The university's institutional review board for human participants approved this study. All volunteers provided informed consent before the study. Participants were otherwise healthy men and women of various racial and ethnic backgrounds (n = 110; Table 1). They were recruited from the university population and consisted of undergraduate and graduate students, faculty, and staff. Exclusion criteria were a history of any of the following: (1) previous or current neck or shoulder pain, (2) sensory or motor impairment to the upper extremity, (3) regular involvement in upper extremity resistance weight training in the past 6 weeks, (4) currently or regularly taking pain medication, or (5) previous upper extremity surgery. All self-report measures, including demographic information and BPI, were obtained on a private and secure computer. All study participants completed an identical experimental protocol (Table 2) and arrived at the laboratory at the same time each day. We assessed outcome variables and all impairment measures in identical order on each visit.

Shoulder-Fatigue Protocol

Shoulder pain and functional impairment were induced with a controlled concentric-eccentric resistance-exercise protocol using a commercial isokinetic testing and exercise device (model Kin-Com; Isokinetic International, Chattanooga, TN). The isokinetic exercise protocol was based on other studies[19,22,23] using similar equipment and had been previously used in our laboratory.[24–26] Participants were placed in the Kin-Com in an upright seated position with the torso strapped into the chair to isolate movement of the dominant shoulder. Two straps crossed the participant's torso and an additional strap crossed the lap to limit all movement per the manufacturer's recommendations. The dominant arm was then placed in the scapular plane, with the elbow at 90° of flexion because this position has been associated with high test-retest reliability and is believed to result in decreased impingement of the greater tuberosity under the acromion process.[22,27]

We determined maximal voluntary isometric force (MVIF) production by having the participant perform 3 consecutive isometric actions in external rotation for 5 seconds at a time. Participants were instructed to perform the actions with maximal effort and were provided with oral encouragement throughout the procedure. A 30-second recovery period was given between trials. The average of the 3 MVIF trials was used for analysis.

After MVIF testing, each participant was given a 1-minute rest and then completed a familiarization test for the isokinetic exercise protocol: 10 repetitions of concentric-eccentric actions in shoulder external rotation at a speed of 100°/s to become familiar with the testing apparatus and the accommodating resistance. For the exercise protocol, the angular velocity was lowered to 60°/s for 3 sets of 10 repetitions. A 30-second recovery period was provided between sets. Maximal voluntary isometric force measurements were then repeated as described previously. If the participant was no longer able to produce an average MVIF of at least 50% of the initial effort, he or she was considered fatigued. The standard of 50% or less of MVIF was a consistent indicator of muscular fatigue in previous research.[19,22,28,29] However, if the participant could still

Table 2. Experimental Protocol

Day (h)				
1 (Injury Induction)[a]	2 (24)	3 (48)	4 (72)	5 (96)
Baseline BPI	BPI	BPI	BPI	BPI
Baseline ROM	ROM	ROM	ROM	ROM
Baseline evoked pain with abduction	Evoked pain with abduction	Evoked pain with abduction	Evoked pain with abduction	Evoked pain with abduction

Abbreviations: BPI, Brief Pain Inventory; ROM, range of motion.

[a] All baseline values were measured before injury induction.

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generate more than 50% of the initial MVIF, he or she performed additional sets of 10 repetitions until less than 50% of the initial MVIF was met.

Outcome Measure: Resting Pain

We asked participants to assess resting-pain intensity for 96 hours after injury using the BPI. The BPI[30] measures pain intensity on an 11-point numerical rating scale (0–10) in 3 conditions: worst pain in the past 24 hours, least pain in the past 24 hours, and current pain. The BPI has been deemed valid and reliable in multiple populations, as well as in patients experiencing nonmalignant pain.[31] It also has good test-retest reliability, especially over short periods of time.[32] We used only the current pain intensity for analysis because induced muscle pain typically peaks within 48 hours and dissipates by 96 hours. Using the current pain rating also allowed us to correlate evoked pain with ROM in abduction with resting pain at the time of evaluation.

Explanatory Variables and Impairment Measures

Active ROM. We measured active ROM in abduction and flexion of the GH joint daily for 96 hours after injury using a standard goniometer with the participant in an upright standing position. The participant was instructed to lift the arm in abduction and flexion "as high as you can," without flexing or side bending at the torso. Abduction was assessed in the frontal plane and flexion assessed in the sagittal plane. The stationary arm of the goniometer was fixed along the torso, with the axis of the GH joint serving as the rotation point. The humerus served as the moment arm for measurement. We took 3 measures of active abduction and flexion; the largest measure was considered the final active shoulder ROM. Using a goniometer to assess shoulder ROM is a common clinical method with adequate reliability.[33–35] All ROM measurements were conducted by the same experienced examiner, a certified athletic trainer who had received standardized training from the senior investigator. Past researchers[36] have shown that using a standardized goniometric measure augments measurement accuracy to acceptable levels.

Evoked Pain Intensity. Each participant provided an evoked-pain intensity rating for pain experienced with active abduction. A rating of 0 indicated *no pain*, and a rating of 100 indicated *worst pain imaginable*. After the examiner took 3 measurements of active ROM in abduction, the participant was asked to rate the greatest amount of evoked pain he or she experienced during the maneuver.

Passive ROM. The examiner also measured passive ROM in internal and external rotation of the GH joint. The participant was placed in the supine position on a padded table that served to fix the scapula and allow for passive GH joint rotation. The shoulder was abducted to 90° for all rotation measures, with the elbow slightly off the table and flexed to 90°. The examiner held the stationary arm of the goniometer perpendicular to the floor and aligned the moment arm with the styloid process of the ulna. The participant was then instructed to relax while 3 trials of internal and external passive ROM were performed; the highest of the 3 readings was taken as the passive ROM in the dominant shoulder.

Data Analysis

We performed all data analyses using PASW for Windows (version 18.0; SPSS Inc, Chicago, IL). Significance for all statistics was set at $\alpha = .05$. Summary statistics were calculated for all demographic, pain, and impairment measures. Resting pain ratings were measured on a 0 to 10 scale and served as the dependent variable in our regression model. Stepwise regression was used to explain resting pain at 48 and 96 hours after induction of DOMS. The explanatory variables for this model were passive ROM in internal rotation and external rotation and active ROM in flexion and abduction, as well as self-reported evoked-pain intensity with abduction. With stepwise regression, there is always the potential for predictor variables to be included in a model based on chance association. Despite this potential weakness, we felt stepwise regression was appropriate for this analysis because we had no a priori hypotheses about the order of entry of variables into the model. The criterion for entry into the regression model was $P \leq .05$, and the criterion for removal from the regression model was $P > .10$.

RESULTS

Descriptive statistics for the demographic data are summarized in Table 1. Our model used stepwise regression to explain current resting pain intensity at 48 ($R^2 = 0.392$) and 96 hours ($R^2 = 0.164$) after exercise-induced DOMS. Abduction and internal-rotation ROM of the injured arm and evoked pain with abduction were all unique predictors at 48 hours after injury ($P < .001$). Evoked pain with arm abduction had the strongest association with current resting pain at this time ($\beta = .542$, $R^2 = 0.315$). Although passive internal rotation and active abduction were significantly associated at this time ($R^2 = 0.041$ and $R^2 = 0.036$, respectively), they did not contribute as much as evoked pain with abduction. At 96 hours after injury, evoked pain with abduction of the injured arm was the only significant contributor to the resting pain experienced at 96 hours ($P < .001$; Table 3). Means and standard deviations for all variables at 48 and 96 hours are provided in Table 4.

DISCUSSION

This study investigated the ability of selected shoulder-impairment measures to explain resting-pain intensity and recovery after an exercise-induced DOMS protocol. We used an exercise-induced DOMS protocol to mimic the muscle pain, inflammation, and loss of ROM that are associated with shoulder injury. This exercise-induced DOMS protocol is clinically relevant as an injury model for studying the pain associated with shoulder injury and the subsequent evaluation of recovery.[8] Other pain-induction protocols exist (eg, thermal, electrical, and chemical), but these protocols do not produce the functional impairments necessary to study the predictability of the measures we were interested in evaluating. We assessed resting-pain and impairment measures each day for 96 hours after induction of DOMS. This timeline for follow-up assessment is appropriate because the pain and impairment associated with this type of injury protocol have usually dissipated or resolved by 96 hours.

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Table 3. Impairment Measures That Predicted Clinical Shoulder Pain at 48 and 96 h After Delayed-Onset Muscle Soreness

Final Model	Variables	β	Standard Error	*P* Value
48 h: $R^2 = 0.392$	Abduction, °	.189	0.010	.014
	Internal rotation, °	.211	0.012	.007
	Evoked pain with abduction, 0–100 scale	.542	0.010	<.001
96 h: $R^2 = 0.164$	Evoked pain with abduction, 0–100 scale	.405	0.013	<.001

Our data suggest that peak resting pain occurred at 48 hours after exercise-induced DOMS in the shoulder. Resting pain at this time was associated with active abduction and passive internal rotation of the GH joint, as well as pain evoked with active abduction of the arm. Our model also suggests that evoked pain with active abduction of the GH joint is most closely associated with resting pain at 96 hours after induction of DOMS. This result implies that self-reported evoked pain with movement provides the greatest explanation for resting pain when compared with our other outcome measures. Evoked pain with movement and its relation to resting pain is important in possibly explaining the disability and discomfort that result from contraction of the involved musculature. The significant contribution of evoked pain with abduction also suggests the need for additional self-reported pain measures for muscular contraction in various ROMs. We believe these results are novel because the ability of these impairment measures to explain recovery after induced DOMS in the shoulder has not been reported previously. Our findings allow us to identify impairment measures that best predict recovery and may provide insight into the importance of assessing ROM and pain clinically.

Previous investigators[13] have focused on diagnostic testing such as magnetic resonance imaging, ultrasonography, radiographs, and computed tomography scans. Not only are these diagnostic tests expensive and inconvenient, they may not provide direct information as to how long an athlete will take to recover from an injury. Although targeting recovery can be difficult, the use of questionnaires to track the progression of resting pain and disability after shoulder injury has been a current focus of research. Some of the most commonly used questionnaires identified in the literature are the Oxford Shoulder Score; Disabilities of the Arm, Shoulder, and Hand; and Shoulder Pain and Disability Index.[37] These questionnaires provide clinicians with subjective outcome measures that allow them to evaluate the symptomatic relief and results of treatment as athletes recover from acute injury. These questionnaires are convenient to use, but they are not applicable to all shoulder injuries.[37] In addition, because the questionnaire answers are subjective, clinicians may not always be willing to rely solely on their athletes' self-reports. Therefore, we need to evaluate more objective outcome measures to better understand the progressive recovery process that occurs after an acute shoulder injury.

We are the first to directly examine whether impairment measures can predict clinical shoulder pain. Traditionally clinicians have relied on a variety of impairment measures, including orthopaedic special tests and ROM, to diagnose musculoskeletal conditions. However, past authors have not evaluated the association between these measures and recovery from pain. We evaluated resting pain for 96 hours after DOMS induction and its associations with ROM of the shoulder joint. Evaluation of these outcome measures elicited positive associations between resting pain and active abduction, passive internal rotation, and self-reported evoked pain with abduction at 48 hours postinjury. In addition, the evoked pain reported with abduction of the involved shoulder had the strongest association with resting pain at 48 hours postinjury and was a significant contributor to resting pain at 96 hours. Thus, these results provide valuable insight into measures that may allow clinicians to predict recovery from shoulder injury.

Although we cannot base direct clinical implications on these findings, we can provide suggestions for critically analyzing specific functional outcome measures as recovery from shoulder injury progresses. Specifically, evoked pain with abduction and limitations in abduction and internal rotation were the strongest predictors of resting pain and therefore warrant attention. However, preinjury baseline testing is needed for comparison with postinjury changes. This may not be practical in every clinical setting, but preseason baseline assessment would be simple, convenient, and valuable in an athletic setting.

LIMITATIONS

This study had several limitations that preclude direct translation of these results into a clinical setting. Despite the advantage of our exercise-induced injury protocol, the direct clinical implications of this study are limited. Upper extremity DOMS can be considered a clinically relevant pain model because participants experienced increasing levels of pain, loss of joint ROM, and self-reported limitations with activities of daily living.[8,38] We appreciate that an exercise-induced DOMS model is not an exact replica of clinical injury, mainly because the signs and symptoms are experimentally induced and usually resolve in a shorter time period. In addition, we studied healthy participants; the induction of DOMS does not mimic clinical pain because it does not occur in degenerative

Table 4. Descriptive Statistics for Each Measurement at 48 and 96 h After Delayed-Onset Muscle Soreness

	Time After Delayed-Onset Muscle Soreness, (Mean ± SD)	
Measure	48 h	96 h
Resting pain, 0–10 scale	1.97 ± 1.92	0.59 ± 0.90
Internal rotation, °	51.08 ± 12.32	57.49 ± 10.71
Abduction, °	164.41 ± 14.02	166.70 ± 11.93
Evoked pain with abduction, 0–100 scale	14.33 ± 15.33	3.58 ± 6.20

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tissue, as observed in pathologic conditions such as acute ligament sprains and muscle strains. The model produces symptoms that are relatively shorter in duration than what athletes would experience after an acute shoulder injury and are self-resolving. It is possible that the impairment measures we studied would have different associations with impairment measures from longer-duration shoulder pain. We only assessed pain with 1 movement measure: abduction. As a result, we are confident that this measure is associated with resting pain, but we are unsure whether this is the only movement associated with pain. Furthermore, this protocol was induced in young, healthy individuals who were not likely to have degenerative, structural, or anatomic changes common to acute injury. Future authors should focus on the validity of these impairment measures in an athletic population experiencing acute injury. The findings from this study should be translated into the clinical setting with caution.

CONCLUSIONS

Functional ROM in abduction and internal rotation and pain evoked by abduction of the injured arm predicted resting pain at 48 hours after induction of DOMS. At 96 hours after exercise-induced DOMS, only evoked pain with abduction of the injured arm predicted resting pain. This model suggests that peak resting pain after experimentally induced DOMS occurs at 48 hours and that ROM is highly associated with this clinical pain outcome. Controlling pain initially while restoring ROM in these directions may promote a more prompt recovery process. Therefore, it may be of value for clinicians to follow these impairment measures more closely during the rehabilitation process.

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