J Shoulder Elbow Surg (2020) 29, 2213–2220

ELSEVIER

Journal of Shoulder and Elbow Surgery

www.elsevier.com/locate/ymse

The new dynamic isotonic manipulation examination (DIME) is a highly sensitive secondary screening tool for supraspinatus full-thickness tears

Paul F. Abraham, BS[a,*], Mark R. Nazal, MD, MPH[a], Nathan H. Varady, SB[a], Stephen M. Gillinov, AB[a], Noah J. Quinlan, MD[b], Kyle Alpaugh, MD[c], Scott D. Martin, MD[a]

[a]*Department of Orthopaedic Surgery, Sports Medicine Center, Massachusetts General Hospital, Boston, MA, USA*
[b]*Department of Orthopaedic Surgery, University of Utah, Salt Lake City, UT, USA*
[c]*Department of Orthopaedic Surgery, University of Massachusetts, Worcester, MA, USA*

Background: Traditional shoulder physical examination (PE) tests have suboptimal sensitivity for detection of supraspinatus full-thickness tears (FTTs). Therefore, clinicians may continue to suspect FTTs in some patients with negative rotator cuff PE tests and turn to magnetic resonance imaging (MRI) for definitive diagnosis. Consequently, there is a need for a secondary screening test that can accurately rule out FTTs in these patients to better inform clinicians which patients should undergo MRI. The purpose of this study was to assess the ability of 2 new dynamic PE tests to detect supraspinatus pathology in patients for whom traditional static PE tests failed to detect pathology.

Methods: We prospectively enrolled 171 patients with suspected rotator cuff pathology with negative findings on traditional rotator cuff PE, who underwent 2 new dynamic PE tests: first, measurement of angle at which the patient first reports pain on unopposed active abduction and, second, the dynamic isotonic manipulation examination (DIME). Patients then underwent shoulder magnetic resonance arthrogram. Data from the new PE maneuvers were compared with outcomes collected from magnetic resonance arthrogram reports.

Results: Pain during DIME testing had a sensitivity of 96.3% and 92.6% and a negative predictive value of 96.2% and 94.9% in the coronal and scapular planes, respectively. DIME strength $\leq$86.0 N had a sensitivity of 100% and 96.3% and a negative predictive value of 100% and 95.7% in the coronal and scapular planes, respectively. Pain at $\leq 90^{\circ}$ on unopposed active abduction in the coronal plane had a specificity of 100% and a positive predictive value of 100% for supraspinatus pathology of any kind (ie, tendinopathy, "fraying," or tearing).

Conclusion: DIME is highly sensitive for supraspinatus FTTs in patients with negative traditional rotator cuff PE tests for whom there is still high clinical suspicion of FTTs. Thus, this test is an excellent *secondary* screening tool for supraspinatus FTTs in patients for whom clinicians suspect rotator cuff pathology despite negative traditional static PE tests. Given its high sensitivity, a negative DIME test rules out supraspinatus FTT well in these patients, and can therefore better inform clinicians which patients should undergo MRI. In addition, the angle at which patients first report pain on unopposed active shoulder abduction is highly specific for supraspinatus pathology.

This investigation was performed at Department of Sports Medicine, Massachusetts General Hospital and Department of Sports Medicine, Brigham and Women's Hospital.
Institutional review board approval was received from Partners HealthCare (protocol #2014P000801).

*Reprint requests: Paul F. Abraham, BS, Massachusetts General Hospital, 175 Cambridge Street, Suite 400, Boston, MA 02118, USA.
E-mail address: paulabraham93@gmail.com (P.F. Abraham).

https://doi.org/10.1016/j.jse.2020.06.029

Level of evidence: Level II; Diagnosis Study

Keywords: Rotator cuff; supraspinatus; full-thickness tear; diagnostic; shoulder physical examination; magnetic resonance imaging

Shoulder pain is the third most common musculoskeletal complaint to primary care providers, accounting for over 11 million office visits in 2010.[11] Rotator cuff pathology is the most common etiology of shoulder pain and presents a particular clinical challenge.[2,7,41] The supraspinatus tendon is the most commonly torn rotator cuff tendon because of its course through the narrow subacromial space, its propensity for impingement, and its exposure to high friction forces.[17,23,30] Operative and nonoperative management of rotator cuff full-thickness tears (FTTs) are estimated to incur average societal costs of $19,366 and $40,457, respectively, and lifetime quality-adjusted life years are higher for those treated operatively than nonoperatively.[26,39] FTTs usually have excellent operative outcomes,[9,20] even in patients with massive tears, high-grade fatty infiltration, or advanced age.[5,34,38] In contrast, partial thickness tears (PTTs) often do not require operative management and show good improvement with conservative measures.[24,37] Consequently, prompt and accurate diagnosis of FTTs is of significant clinical importance.

Unfortunately, no single physical examination (PE) maneuver is able to reliably diagnose supraspinatus FTTs.[3,27,43] Although the external rotation lag sign and drop arm test have excellent specificity for supraspinatus FTT,[3,6,14-16,27] these and other existing tests lack sufficient sensitivity to confidently rule out FTTs.[14,15,21] Weakness on the empty can test, for example, is 53%-60%[22,31] sensitive for supraspinatus FTTs and becomes only marginally more sensitive when pain and/or weakness on examination is considered a positive test.[3,21,22,43] Therefore, clinicians may continue to harbor strong clinical suspicion for FTTs in some patients with negative empty can tests and turn to magnetic resonance imaging (MRI)—the gold standard for diagnosing rotator cuff pathology[4,30,35]—for definitive diagnosis of supraspinatus FTTs.

Although MRI is useful for diagnosis of FTTs and subsequent surgical planning, the vast majority of rotator cuff injuries do not require surgery. In a recent prospective value-based care analysis of MRI use for suspected rotator cuff tendinopathy, Cortes et al[10] found that 90.2% of the MRIs ordered did not affect management, as only 5 of 51 patients underwent rotator cuff repair, resulting in $181,619 of unnecessary advanced imaging charges. Because PTTs and small isolated FTTs do not rapidly progress in size,[12,37] the authors proposed that patients with minimal or no strength deficits on PE may only need MRI after failing conservative management.[10] However, given that delaying surgery for patients with medium- and large-sized FTTs can result in tear progression and worse functional outcomes,[28,42] there is a need for a PE maneuver with improved sensitivity for supraspinatus FTTs to better inform clinicians when to order MRI.

Previous studies have demonstrated the inability of many static PE maneuvers to reliably isolate the rotator cuff,[8,25,32] but the ability of dynamic positioning to detect tearing of these muscles is unknown. Therefore, the purpose of this study was to assess the ability of 2 new dynamic PE maneuvers designed by the senior author to detect rotator cuff pathology. We hypothesized that these PE maneuvers would detect supraspinatus FTTs that were previously missed by traditional, static rotator cuff examination.

Materials and methods

This is a prospective assessment of 2 new dynamic PE maneuvers designed by the senior author to detect rotator cuff pathology in a consecutive series of patients, using MRI as a "gold standard." The senior author suspected rotator cuff disease, despite *negative* traditional rotator cuff examination, in 240 patients presenting to his clinic with a chief concern of shoulder pain during the study period. All 240 patients were screened for study eligibility. The inclusion criteria were as follows: clinical suspicion of rotator cuff disease (ie, shoulder pain worsened with overhead activities; nighttime pain), *negative* traditional rotator cuff examination (no pain or weakness on full can or empty can tests, no weakness or inability to lift hand from the sacrum on the lift-off test, and no pain or weakness on external or internal rotation strength tests), ability to tolerate shoulder PE, and willingness to participate in the study. The exclusion criteria were as follows: radiographically apparent glenohumeral osteoarthritis, previously diagnosed rotator cuff tear of the affected shoulder, MRI before PE, willingness to undergo magnetic resonance arthrography (MRA) after participation in the study, prior ipsilateral shoulder surgery, injury to the ipsilateral hand or wrist, limited abduction range of motion (ROM), and history or radiographic evidence of anterior or posterior shoulder dislocation. Critically, patients with positive traditional rotator cuff testing were *not* included in this cohort; thus, any supraspinatus tears in this cohort were previously *missed* by traditional, static PE tests.

For all 171 patients who met study criteria, the senior author performed 2 new PE maneuvers after routine PE. First, unopposed active abduction ROM was measured, and second, the new dynamic isotonic manipulation examination (DIME) was performed. A handheld dynamometer/inclinometer (Hoggan microFET 3; Hoggan Scientific, LLC, Salt Lake City UT, USA) was used to provide additional objective data for this study. All patients underwent MRA of the affected shoulder that was read by a fellowship-trained musculoskeletal radiologist affiliated with the study. Previous studies validating new shoulder examinations had

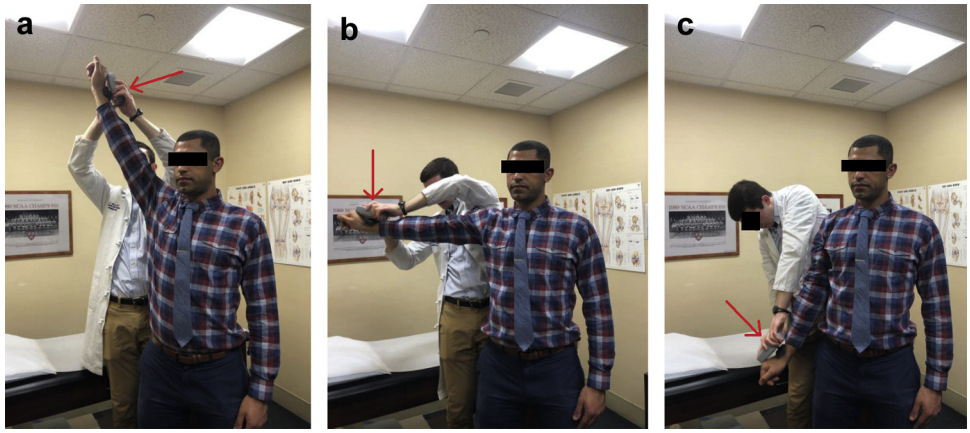

Figure 1 DIME performed in the coronal plane. To perform the DIME test, the patient's arm is placed in maximal abduction with the palm facing down. The examiner places the dynamometer on the dorsal aspect of the wrist and applies a constant force perpendicular to the arm. The patient is instructed to maximally resist this force while the examiner forces the arm into adduction over a smooth, 5-second arc. The 3 panes represent the (**a**) start, (**b**) midpoint, and (**c**) end of the DIME test. Red arrows represent the direction force is applied throughout the arc. *DIME*, dynamic isotonic manipulation examination.

similar numbers of subjects and positive examination findings as ours.[29,36]

Two new PE maneuvers

Test 1: unopposed active abduction test

For this test, the patient is asked to stand with his or her arm at the side and to abduct slowly in the coronal plane with the palm facing down. The patient is asked if he or she feels pain at any point throughout the abduction arc. If the patient indicates pain, the angle at which pain is first reported is noted. This is then repeated in the scapular plane, or 30° of forward flexion from the coronal plane. To ensure accurate angle measurement for the purpose of this study, active abduction ROM was measured using the inclinometer functionality of the dynamometer.

Test 2: dynamic isotonic manipulation examination

With the patient's arm placed in maximal abduction with the palm facing down, the examiner applies a constant force to the dorsal aspect of the wrist, perpendicular to the arm. The patient is instructed to maximally resist this force, whereas the examiner forces the arm into adduction over a smooth, 5-second arc (Fig. 1). To provide additional objective data for this study, a dynamometer was placed on the dorsal side of the wrist to measure the applied force and length of time during which the force was applied; we ensured reproducibility of the applied force by only recording measurements that were applied over a smooth, 5-second arc ± 0.5 seconds. This is performed in both the coronal and scapular planes, first on the asymptomatic arm and then on the symptomatic arm. The symptomatic-to-asymptomatic arm (S/A) DIME strength ratio is then calculated. All patients were included when analyzing absolute strength measurements on DIME testing; patients who had a history or clinical evidence of contralateral shoulder pathology were excluded from the analyses of S/A DIME strength ratios. On completion of DIME strength measurement, patients are asked if they felt pain at any point along the arc.

Table I Pain during DIME in coronal and scapular planes as a predictor of supraspinatus FTT on MRA

Pain during DIME examination?	Supraspinatus FTT on MRA?		
	Yes	No	Total
Coronal plane			
Yes	26	119	145
No	1	25	26
Total	27	144	171
Scapular plane			
Yes	25	106	131
No	2	37	39
Total	27	143	170*

DIME, dynamic isotonic manipulation examination; *FTT*, full-thickness tear; *MRA*, magnetic resonance arthrogram.
* One patient with a focal FTT of the supraspinatus did not undergo DIME pain testing in the scapular plane.

Statistical methods

Data from these new PE maneuvers were compared with outcomes collected from gold standard postvisit MRA. The primary outcome was the ability of the PE maneuvers to discriminate supraspinatus FTT vs. no FTT. Secondary analyses included discriminating any supraspinatus tear vs. no tear and any supraspinatus pathology vs. no pathology. Categorical variables were analyzed with χ^2 or Fisher's exact tests, as appropriate, and continuous variables were compared with Student's *t*-tests. Post hoc inter-rater reliability metrics were collected on a subset of 8 patients undergoing DIME by 2 independent examiners (SDM and PFA) and calculated using intraclass correlation coefficient. Pain on DIME and strength $\leq$86.0 N on DIME were considered positive tests for the DIME pain and DIME strength tests, respectively.

Table II DIME strength measurements in patients with and without supraspinatus FTT

MRA finding	Absolute strength (newton)			Symptomatic-to-asymptomatic (S/A) strength ratio		
	n	Coronal plane	Scapular plane	n	Coronal plane	Scapular plane
Full-thickness tear	27	44.2 (36.6-51.9)	48.7 (39.0-58.4)	21	65% (57%-73%)	71% (58%-85%)
No full-thickness tear	144*	52.7 (48.6-56.7)	57.4 (53.0-61.8)	119*	76% (70%-81%)	83% (78%-87%)
P value		.0921†	.1189		.0350‡	.0781†

DIME, dynamic isotonic manipulation examination; *FTT*, full-thickness tear; *MRA*, magnetic resonance arthrogram.
Data reported as mean (95% confidence interval). Statistical significance notation: ‡ $P \leq .05$; † $.10 \geq P > .05$.
Patients with a history of contralateral shoulder pain were excluded from S/A strength ratio analysis.
* One patient with supraspinatus tendinopathy did not undergo DIME strength testing in the coronal plane. This patient had a history of contralateral shoulder pain and was excluded from S/A strength ratio analysis. Another patient with a focal FTT of the supraspinatus did not undergo DIME strength testing in the scapular plane. This patient did not have a history of contralateral shoulder pain and was included in S/A strength ratio analysis.

Table III DIME strength as a predictor of supraspinatus FTT on MRA

DIME strength ≤86.0 N?	Supraspinatus FTT on MRA?		
	Yes	No	Total
Coronal plane			
Yes	27	127	154
No	0	16	16
Total	27	143	170*
Scapular plane			
Yes	26	121	147
No	1	22	23
Total	27	143	170*

DIME, dynamic isotonic manipulation examination; *FTT*, full-thickness tear; *MRA*, magnetic resonance arthrogram.
* One patient with supraspinatus tendinopathy did not undergo DIME strength testing in the coronal plane and another patient with a focal FTT of the supraspinatus did not undergo DIME strength testing in the scapular plane.

Patients were classified as having supraspinatus pathology if the MRA reported on supraspinatus tendinopathy, a "frayed" tendon, PTT, high-grade PTT, focal FTT, full-thickness perforation, or FTT. Patients were classified as having a supraspinatus tear if the MRA reported on PTT, high-grade PTT, focal FTT, full-thickness perforation, or FTT.

Statistical analysis was performed using SAS v9.4 (SAS Institute, Cary, NC, USA), and $P \leq .05$ was considered significant (significance level .05). Patients with partially completed examinations were only included in analyses for completed variables.

Results

The study cohort consisted of 171 patients (102 [60%] males, 69 [40%] females). The mean patient age (±95% confidence interval) was 52.0 ± 1.9 years. The mean symptom duration (±95% confidence interval) was 10.8 ± 2.9 months. MRA revealed 27 (15.8%) FTTs, 12 (7.0%) focal FTTs/full-thickness perforations, 13 (7.6%) high-grade PTTs, 39 (22.8%) PTTs, 17 (9.9%) "frayed" tendons, 37 (21.6%) instances of tendinopathy, and 26 (15.2%) instances of no supraspinatus pathology. Of the 27 FTTs, 5 (18.5%) were small, 20 (74.1%) were medium, 1 (3.7 %) was large, and 1 (3.7 %) was massive. Because the cohort consisted solely of patients without positive findings on static rotator cuff tests, traditional rotator cuff examination missed 27 FTTs in this cohort.

DIME

A total of 145 (84.8%) patients had pain during DIME testing in the coronal plane. Of them, 26 had FTTs, whereas only 1 of 26 patients without pain during DIME testing had an FTT. Thus, the presence of pain during DIME testing in the coronal plane had a sensitivity of 96.3%, a specificity of 17.4%, and a negative predictive value (NPV) of 96.2% for detection of supraspinatus FTTs (Table I). Of the 145 patients with pain on this test, 127 (87.6%) had supraspinatus pathology, 62 (42.8%) had infraspinatus pathology, 122 (84.1%) had acromioclavicular joint arthropathy, and 101 (69.7%) had labral pathology.

A total of 131 (77.1%) patients had pain on DIME testing in the scapular plane. Of them, 25 had FTTs, whereas only 2 of 39 patients without pain during DIME testing had FTTs. Thus, the presence of pain during DIME testing in the scapular plane had a sensitivity of 92.6%, a specificity of 25.9%, and an NPV of 94.9% for detection of supraspinatus FTTs (Table I).

In the coronal plane, patients with FTTs were significantly weaker than those without FTTs (S/A ratio: 65 ± 8% vs. 76 ± 6%, $P = .035$, Table II). In addition, none of the 16 patients who had a DIME strength >86.0 N had an FTT. Thus, a DIME strength of ≤86.0 N in the coronal plane had a sensitivity of 100%, a specificity of 11.1%, and an NPV of 100% for detection of supraspinatus FTTs (Table III).

In the scapular plane, the strength of patients with and without FTTs was more similar (S/A ratio: 71 ± 13% vs. 83 ± 5%, $P = .078$, Table II). In addition, only 1 of the 23 patients who had a DIME strength >86.0 N had an FTT. Thus, a DIME strength of ≤86.0 N in the scapular plane

Table IV DIME strength measurements in patients with and without supraspinatus tears

MRA finding	Absolute strength (newton)			Symptomatic-to-asymptomatic (S/A) strength ratio		
	n	Coronal plane	Scapular plane	n	Coronal plane	Scapular plane
Supraspinatus tear	91*	49.7 (45.0-54.4)	55.4 (50.1-60.6)	73*	72% (66%-77%)	78% (73%-84%)
No supraspinatus tear	80*	53.2 (47.5-58.8)	56.7 (50.4-62.9)	67	77% (68%-86%)	84% (76%-91%)
P value		.3470	.7544		.2898	.2460

DIME, dynamic isotonic manipulation examination; *MRA*, magnetic resonance arthrogram.
Data reported as mean (95% confidence interval).
Patients with a history of contralateral shoulder pain were excluded from S/A strength ratio analysis.
* One patient with supraspinatus tendinopathy did not undergo DIME strength testing in the coronal plane. This patient had a history of contralateral shoulder pain and was excluded from S/A strength ratio analysis. Another patient with a focal FTT of the supraspinatus did not undergo DIME strength testing in the scapular plane. This patient did not have a history of contralateral shoulder pain and was included in S/A strength ratio analysis.

Table V Angle of pain during active, unopposed abduction in the coronal plane as a predictor of supraspinatus pathology on MRA

	Supraspinatus pathology on MRA?		
	Yes	No	Total
Angle of pain on unopposed ROM in the coronal plane			
≤90°	24	0	24
>90°	66	13	79
Total	90	13	103

MRA, magnetic resonance arthrogram; *ROM*, range of motion.

had a sensitivity of 96.3%, a specificity of 15.4%, and an NPV of 95.7% for detection of supraspinatus FTTs (Table III).

Patients with any supraspinatus tear (FTT or PTT) had similar mean S/A DIME strength ratios as those who did not in both the coronal (72 ± 6% vs. 77 ± 9%, $P = .290$, Table IV) and scapular (78 ± 6% vs. 84 ± 7%, $P = .246$, Table IV) planes.

Unopposed active abduction test

On unopposed active abduction in the coronal plane, 103 (56.7%) patients reported pain. The mean angle at which pain was first reported was 118.3° ± 7.6° (minimum, 35°) in those with supraspinatus pathology (n = 90) and 137.6° ± 17.9° (minimum, 96°) in those without supraspinatus pathology (n = 13). Of 103 patients with pain during ROM testing, 24 reported that the pain started at an angle ≤90°, and all 24 patients had supraspinatus pathology on MRA. Of those with pain that began at an angle >90°, 66 had supraspinatus pathology and 13 had no supraspinatus pathology. Thus, the angle of pain ≤90° during unopposed abduction in the coronal plane had a sensitivity of 26.7%, a specificity of 100%, and a positive predictive value of 100% for detection of supraspinatus pathology (Table V).

Inter-rater reliability

Both DIME pain and DIME strength tests had an intraclass correlation coefficient of 1.0 on a subset of 8 patients undergoing DIME by 2 independent examiners.

Discussion

In this study, we evaluated the ability of 2 new PE maneuvers to improve detection of supraspinatus pathology in patients with negative traditional, static PE maneuvers. The overlap in function between the supraspinatus and deltoid muscles makes it difficult for clinicians to isolate the supraspinatus during PE,[1,13] and electromyography studies have shown that static strength testing of the supraspinatus does not adequately isolate it.[1,8,25,32,33] For these and other reasons, empty can testing has a suboptimal sensitivity to reliably rule out all supraspinatus FTTs.[3,21,22,31,43] Although some studies suggest that other positions may better isolate the supraspinatus muscle,[8,32,33] a key aspect of isolating the supraspinatus may not be better positioning, but rather dynamic examination. The dynamic DIME test detected 27 FTTs in our cohort, thus supporting our hypothesis that DIME would detect supraspinatus FTTs missed by traditional, static rotator cuff examination. DIME's ability to stress the supraspinatus throughout its ROM potentially improves supraspinatus isolation as compared with empty and full can tests, and its use of dynamometry allows for more accurate and objective strength measurement. Both of these factors may play a role in its improved sensitivity over static PE maneuvers.

In our cohort, pain on DIME testing was extremely sensitive for supraspinatus FTTs (approximately 96%). Because negative results of highly sensitive tests effectively rule out disease, DIME is an ideal secondary screening tool in patients for whom clinicians have high clinical suspicion

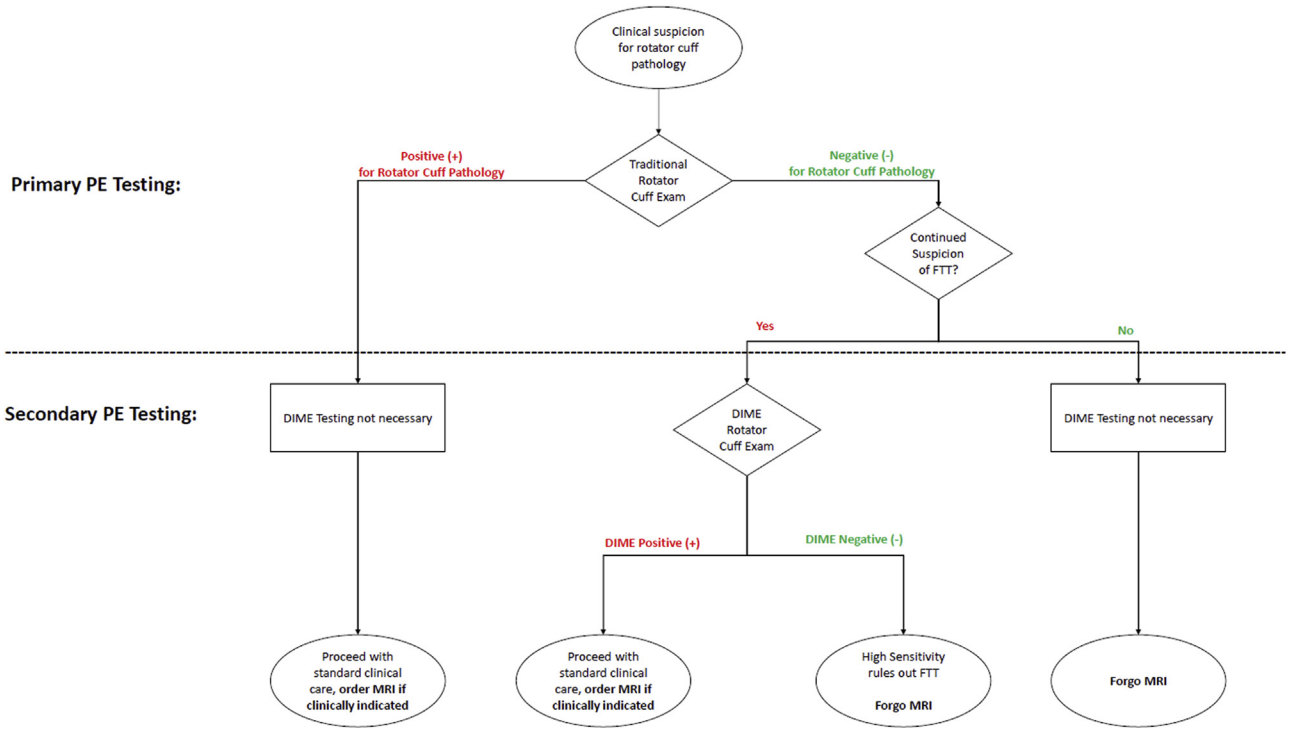

Figure 2 Flowchart to determine the appropriate use of DIME. DIME is designed to give clinicians one more tool in their armamentarium after traditional rotator cuff examination has failed to convincingly rule out FTT. If DIME is negative, FTT is adequately ruled out and the clinician can comfortably forego ordering an MRI. If DIME is positive, the clinician may decide to order an MRI to rule out FTT. *DIME*, dynamic isotonic manipulation examination; *FTT*, full-thickness tear; *MRI*, magnetic resonance imaging; *PE*, physical examination.

of supraspinatus FTT despite having negative traditional rotator cuff examinations. For example, a clinician may be concerned about an FTT in an athlete with negative empty and full can tests because of the athlete's ability to compensate for supraspinatus weakness with accessory muscles, including the deltoid. Such a scenario can be extended to a variety of contexts including patients with severe pain, histories, or other factors suggestive of FTT yet who do not have positive static rotator cuff testing. Rather than immediately ordering an MRI to rule out FTT in these patients, clinicians can now turn to the DIME test, which is able to better stress the rotator cuff specifically and overcome compensatory muscles given its dynamic nature. If the test is negative (as is the case approximately 20% of the time), the clinician can be relatively confident that the patient does not have a supraspinatus FTT and thus may save an unnecessary MRI. The average cost of a shoulder MRI is reported to be $4181, and the Medicare allowable amount is $612.[10] Thus, MRI costs in this cohort were $101,568 greater than they would have been had MRIs not been ordered for the 26 patients (2 with Medicare coverage) for whom DIME ruled out FTT. In a health care system that is becoming increasingly concerned with the value of care,[40] DIME can provide clinicians with an additional tool to help decide which patients should undergo MRI.

In short, DIME should be thought of as a way to extend the utility of the PE when traditional tests have failed to adequately rule out FTT. It is critical to note that although DIME's specificity appears low, these numbers represent the test's performance when every other test has failed to satisfactorily rule out FTT. The test is designed to give clinicians one more tool in their armamentarium after other tests have failed to convincingly rule out FTT, and as such, its performance is evaluated in this setting (ie, in patients for whom there is still suspicion of FTT despite negative static tests). Figure 2 illustrates a flowchart to help clinicians determine when it is appropriate to use DIME.

In addition to DIME pain testing, which can be performed without the need of any equipment, the DIME examination can be further supplemented with the use of a handheld dynamometer to obtain strength measurements. Patients with FTTs had significantly lower S/A strength ratios than those without FTTs in the coronal plane. Similarly, a DIME strength $\leq$86.0 N in each plane was very sensitive for supraspinatus FTTs. Importantly, however, pain during DIME testing was nearly as sensitive as DIME strength measurements (96.3% vs. 100%) for FTTs. Therefore, this test has great utility even for clinicians without dynamometers.

With respect to the second new PE maneuver—the unopposed active abduction test—pain at $\leq$90° on unopposed active abduction in the coronal plane was 100% specific for supraspinatus pathology of any kind (ie, tendinopathy, "fraying," or tearing). Thus, this test can help clinicians

confirm supraspinatus pathology in patients with negative static PE tests, a group of patients that clinicians may struggle to diagnose with confidence. These findings make sense, as biomechanical studies have found the supraspinatus to be the most prominent early abductor of the glenohumeral joint.[18] Furthermore, rotator cuff tears classically present as pain around 60° of abduction;[16] this test can, therefore, be considered a modified painful arc test that is very specific for supraspinatus pathology in patients with negative static PE tests. Lastly, clinicians are likely able to identify a 90° angle without the use of an inclinometer, making this test useful in the setting of virtual PE (eg, telehealth).

A particular strength of this study was its large, prospectively collected sample. Furthermore, including only subjects with negative traditional rotator cuff tests allowed for the assessment of a test that can improve detection of supraspinatus tears missed by traditional PE. Critically, DIME identified 27 FTTs that were first *missed* by traditional static PE tests. Most of these FTTs were medium-sized or larger, highlighting the importance of prompt diagnosis in this cohort, as these tears have high rates of tear progression.[28,42] Nonetheless, this study was subject to several limitations. First, because pain on DIME testing is a subjective finding, the outcome of the test can be different in 2 patients with identical shoulder pathology. However, measures were taken to make this test as objective as possible: (1) the examiner asked all patients whether they felt pain during DIME testing in a standardized way; (2) presence of pain was based on patient report and not open to the examiner's interpretation; and (3) the order of tests was standardized. Furthermore, we performed inter-rater reliability testing on a subset of 8 subjects with 100% agreement between 2 independent examiners for both DIME pain and DIME strength testing. Another limitation is that only 27 patients with FTTs were included in this study, resulting in a loss of power to detect significant differences in scapular plane DIME strength between patients with and without FTTs. Another limitation is that DIME is relatively nonspecific for supraspinatus FTTs; however, it is important to recognize that, as a secondary screening tool, this test prioritizes sensitivity over specificity in order to provide clinicians with one more PE maneuver to help rule out FTT and judiciously use MRI. Future studies should be conducted to determine whether externally rotating the shoulder during DIME testing (so that the palm faces upwards) decreases pain provocation and limits false-positive findings, as has been shown with static supraspinatus strength testing.[19]

Conclusion

The new DIME test can identify a significant number of FTTs missed by traditional static PE techniques. This test can be conducted with or without a dynamometer and is very sensitive for supraspinatus FTTs. Thus, this test is an ideal secondary screening tool for patients with suspected FTTs despite negative traditional rotator cuff PE and can help inform clinicians which of these patients should undergo MRI. In addition, the angle at which a patient reports pain on unopposed active shoulder abduction in the coronal plane is highly specific for supraspinatus pathology of any type, including tendinopathy, fraying, and tearing.

Disclaimer

This study was supported by the Conine Family Fund for Joint Research.

The authors, their immediate families, and any research foundations with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

References

1. Alpert SW, Pink MM, Jobe FW, McMahon PJ, Mathiyakom W. Electromyographic analysis of deltoid and rotator cuff function under varying loads and speeds. J Shoulder Elbow Surg 2000;9:47-58.
2. Aumiller WD, Kleuser TM. Diagnosis and treatment of cuff tear arthropathy. JAAPA 2015;28:33-8. https://doi.org/10.1097/01.JAA.0000469435.44701.ce
3. Bak K, Sorensen AK, Jorgensen U, Nygaard M, Krarup AL, Thune C, et al. The value of clinical tests in acute full-thickness tears of the supraspinatus tendon: does a subacromial lidocaine injection help in the clinical diagnosis? A prospective study. Arthroscopy 2010;26:734-42. https://doi.org/10.1016/j.arthro.2009.11.005
4. Blanchard TK, Bearcroft PW, Constant CR, Griffin DR, Dixon AK. Diagnostic and therapeutic impact of MRI and arthrography in the investigation of full-thickness rotator cuff tears. Eur Radiol 1999;9:638-42.
5. Burkhart SS, Barth JR, Richards DP, Zlatkin MB, Larsen M. Arthroscopic repair of massive rotator cuff tears with stage 3 and 4 fatty degeneration. Arthroscopy 2007;23:347-54. https://doi.org/10.1016/j.arthro.2006.12.012
6. Castoldi F, Blonna D, Hertel R. External rotation lag sign revisited: accuracy for diagnosis of full thickness supraspinatus tear. J Shoulder Elbow Surg 2009;18:529-34. https://doi.org/10.1016/j.jse.2008.11.007
7. Chakravarty K, Webley M. Shoulder joint movement and its relationship to disability in the elderly. J Rheumatol 1993;20:1359-61.
8. Chalmers PN, Cvetanovich GL, Kupfer N, Wimmer MA, Verma NN, Cole BJ, et al. The champagne toast position isolates the supraspinatus better than the Jobe test: an electromyographic study of shoulder physical examination tests. J Shoulder Elbow Surg 2016;25:322-9. https://doi.org/10.1016/j.jse.2015.07.031
9. Cho C-H, Song K-S, Hwang I, Warner JJP. Does rotator cuff repair improve psychologic status and quality of life in patients with rotator cuff tear? Clin Orthop Relat Res 2015;473:3494-500. https://doi.org/10.1007/s11999-015-4258-1
10. Cortes A, Quinlan NJ, Nazal MR, Upadhyaya S, Alpaugh K, Martin SD. A value-based care analysis of magnetic resonance

imaging in patients with suspected rotator cuff tendinopathy and the implicated role of conservative management. J Shoulder Elbow Surg 2019;28:2153-60. https://doi.org/10.1016/j.jse.2019.04.003
11. Department of Research & Scientific Affairs, American Academy of Orthopaedic Surgeons. Physician visits for musculoskeletal symptoms and complaints. 2013. https://www.aaos.org/articlelink/?id=6406. Accessed November 18, 2019.
12. Fucentese SF, von Roll AL, Pfirrmann CW, Gerber C, Jost B. Evolution of nonoperatively treated symptomatic isolated full-thickness supraspinatus tears. J Bone Joint Surg Am 2012;94:801-8. https://doi.org/10.2106/jbjs.I.01286
13. Hawkes DH, Alizadehkhaiyat O, Fisher AC, Kemp GJ, Roebuck MM, Frostick SP. Normal shoulder muscular activation and co-ordination during a shoulder elevation task based on activities of daily living: an electromyographic study. J Orthop Res 2012;30:53-60. https://doi.org/10.1002/jor.21482
14. Hegedus EJ, Goode A, Campbell S, Morin A, Tamaddoni M, Moorman CT III, et al. Physical examination tests of the shoulder: a systematic review with meta-analysis of individual tests. Br J Sports Med 2008;42:80-92 discussion: 92. https://doi.org/10.1136/bjsm.2007.038406
15. Hegedus EJ, Goode AP, Cook CE, Michener L, Myer CA, Myer DM, et al. Which physical examination tests provide clinicians with the most value when examining the shoulder? Update of a systematic review with meta-analysis of individual tests. Br J Sports Med 2012;46:964-78. https://doi.org/10.1136/bjsports-2012-091066
16. Hermans J, Luime JJ, Meuffels DE, Reijman M, Simel DL, Bierma-Zeinstra SM. Does this patient with shoulder pain have rotator cuff disease?: The Rational Clinical Examination systematic review. JAMA 2013;310:837-47. https://doi.org/10.1001/jama.2013.276187
17. Hijioka A, Suzuki K, Nakamura T, Hojo T. Degenerative change and rotator cuff tears. An anatomical study in 160 shoulders of 80 cadavers. Arch Orthop Trauma Surg 1993;112:61-4.
18. Hik F, Ackland DC. The moment arms of the muscles spanning the glenohumeral joint: a systematic review. J Anat 2019;234:1-15. https://doi.org/10.1111/joa.12903
19. Itoi E, Kido T, Sano A, Urayama M, Sato K. Which is more useful, the "full can test" or the "empty can test," in detecting the torn supraspinatus tendon? Am J Sports Med 1999;27:65-8.
20. Jain NB, Ayers GD, Fan R, Kuhn JE, Warner JJP, Baumgarten KM, et al. Comparative effectiveness of operative versus nonoperative treatment for rotator cuff tears: a propensity score analysis from the ROW cohort. Am J Sports Med 2019;47:3065-72. https://doi.org/10.1177/0363546519873840
21. Jain NB, Luz J, Higgins LD, Dong Y, Warner JJ, Matzkin E, et al. The diagnostic accuracy of special tests for rotator cuff tear: the ROW cohort study. Am J Phys Med Rehabil 2017;96:176-83. https://doi.org/10.1097/phm.0000000000000566
22. Kim E, Jeong HJ, Lee KW, Song JS. Interpreting positive signs of the supraspinatus test in screening for torn rotator cuff. Acta medica Okayama 2006;60:223-8. https://doi.org/10.18926/amo/30715
23. Kim HA, Kim SH, Seo YI. Ultrasonographic findings of painful shoulders and correlation between physical examination and ultrasonographic rotator cuff tear. Mod Rheumatol 2007;17:213-9. https://doi.org/10.1007/s10165-007-0577-8
24. Kuhn JE, Dunn WR, Sanders R, An Q, Baumgarten KM, Bishop JY, et al. Effectiveness of physical therapy in treating atraumatic full-thickness rotator cuff tears: a multicenter prospective cohort study. J Shoulder Elbow Surg 2013;22:1371-9. https://doi.org/10.1016/j.jse.2013.01.026
25. Malanga GA, Jenp YN, Growney ES, An KN. EMG analysis of shoulder positioning in testing and strengthening the supraspinatus. Med Sci Sports Exerc 1996;28:661-4.
26. Mather RC III, Koenig L, Acevedo D, Dall TM, Gallo P, Romeo A, et al. The societal and economic value of rotator cuff repair. J Bone Joint Surg Am 2013;95:1993-2000. https://doi.org/10.2106/jbjs.L.01495
27. Miller CA, Forrester GA, Lewis JS. The validity of the lag signs in diagnosing full-thickness tears of the rotator cuff: a preliminary investigation. Arch Phys Med Rehabil 2008;89:1162-8. https://doi.org/10.1016/j.apmr.2007.10.046
28. Moosmayer S, Gartner AV, Tariq R. The natural course of nonoperatively treated rotator cuff tears: an 8.8-year follow-up of tear anatomy and clinical outcome in 49 patients. J Shoulder Elbow Surg 2017;26:627-34. https://doi.org/10.1016/j.jse.2016.10.002
29. O'Brien SJ, Pagnani MJ, Fealy S, McGlynn SR, Wilson JB. The active compression test: a new and effective test for diagnosing labral tears and acromioclavicular joint abnormality. Am J Sports Med 1998;26:610-3.
30. Opsha O, Malik A, Baltazar R, Primakov D, Beltran S, Miller TT, et al. MRI of the rotator cuff and internal derangement. Eur J Radiol 2008;68:36-56. https://doi.org/10.1016/j.ejrad.2008.02.018
31. Park HB, Yokota A, Gill HS, El Rassi G, McFarland EG. Diagnostic accuracy of clinical tests for the different degrees of subacromial impingement syndrome. J Bone Joint Surg Am 2005;87:1446-55. https://doi.org/10.2106/jbjs.D.02335
32. Reddy AS, Mohr KJ, Pink MM, Jobe FW. Electromyographic analysis of the deltoid and rotator cuff muscles in persons with subacromial impingement. J Shoulder Elbow Surg 2000;9:519-23.
33. Ruckstuhl H, Krzycki J, Petrou N, Favre P, Horn T, Schmid S, et al. Shoulder abduction moment arms in three clinically important positions. J Shoulder Elbow Surg 2009;18:632-8. https://doi.org/10.1016/j.jse.2008.10.021
34. Sheean AJ, Hartzler RU, Denard PJ, Ladermann A, Sanders TG, Zlatkin MB, et al. Preoperative radiographic risk factors for incomplete arthroscopic supraspinatus tendon repair in massive rotator cuff tears. Arthroscopy 2018;34:1121-7. https://doi.org/10.1016/j.arthro.2017.09.046
35. Small KM, Adler RS, Shah SH, Roberts CC, Bencardino JT, Appel M, et al. ACR Appropriateness Criteria® shoulder pain-atraumatic. J Am Coll Radiol 2018;15:S388-402. https://doi.org/10.1016/j.jacr.2018.09.032
36. Speer KP, Hannafin JA, Altchek DW, Warren RF. An evaluation of the shoulder relocation test. Am J Sports Med 1994;22:177-83.
37. Tashjian RZ. Epidemiology, natural history, and indications for treatment of rotator cuff tears. Clin Sports Med 2012;31:589-604. https://doi.org/10.1016/j.csm.2012.07.001
38. Verma NN, Bhatia S, Baker CL III, Cole BJ, Boniquit N, Nicholson GP, et al. Outcomes of arthroscopic rotator cuff repair in patients aged 70 years or older. Arthroscopy 2010;26:1273-80. https://doi.org/10.1016/j.arthro.2010.01.031
39. Vitale MA, Vitale MG, Zivin JG, Braman JP, Bigliani LU, Flatow EL. Rotator cuff repair: an analysis of utility scores and cost-effectiveness. J Shoulder Elbow Surg 2007;16:181-7. https://doi.org/10.1016/j.jse.2006.06.013
40. Warner JJP, Higgins LD. Editorial commentary: volume and outcome: 100 years of perspective on value from E.A. Codman to M.E. Porter. Arthroscopy 2017;33:1282-5. https://doi.org/10.1016/j.arthro.2017.03.023
41. Yamaguchi K, Ditsios K, Middleton WD, Hildebolt CF, Galatz LM, Teefey SA. The demographic and morphological features of rotator cuff disease. A comparison of asymptomatic and symptomatic shoulders. J Bone Joint Surg Am 2006;88:1699-704. https://doi.org/10.2106/jbjs.E.00835
42. Yamamoto N, Mineta M, Kawakami J, Sano H, Itoi E. Risk factors for tear progression in symptomatic rotator cuff tears: a prospective study of 174 shoulders. Am J Sports Med 2017;45:2524-31. https://doi.org/10.1177/0363546517709780
43. Yuen CK, Mok KL, Kan PG. The validity of 9 physical tests for full-thickness rotator cuff tears after primary anterior shoulder dislocation in ED patients. Am J Emerg Med 2012;30:1522-9. https://doi.org/10.1016/j.ajem.2011.12.022