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Can handheld dynamometry predict rotator cuff tear size? A study in 2100 consecutive patients

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Background: This study aimed to determine whether handheld dynamometry measurements could predict rotator cuff tear size in patients who required surgical treatment of their shoulder pathology.

Methods: Handheld dynamometer readings were collected prior to surgery and analyzed retrospectively for 2100 consecutive patients. Post hoc, the cohort was divided into patients with rotator cuff tears (n = 1747) and those without rotator cuff tears (n = 353). The tear group was stratified into partial- vs. full-thickness tears and into 4 groups based on tear size area.

Results: Patients with partial-thickness tears had greater internal rotation ($P = .03$), external rotation ($P < .001$), and supraspinatus ($P < .001$) strength than patients with full-thickness tears. Patients with tears had lower supraspinatus strength than patients without tears ($r = -0.82$, $P < .001$). Patients with a larger tear size had lower values of external rotation ($r = -1.46$, $P < .001$) and supraspinatus ($r = -1.18$, $P < .001$) strength. A model involving internal rotation and supraspinatus strength could predict the presence of a tear with a sensitivity of 82% and specificity of 29%. The correct prediction rate was 73% overall (82% in tear group and 29% in no-tear group). The following formula was found to predict rotator cuff tear size, showing modest correlation with our raw data ($r = 0.25$, $P < .001$): Tear size = 482.8 + (3.9 × Internal rotation strength) + (1.6 × Adduction strength) – (7.2 × External rotation strength) – (2.0 × Supraspinatus strength).

Conclusions: Handheld dynamometer readings could not reliably predict rotator cuff tear size, showing only modest correlation with our raw data. Handheld dynamometry readings could predict the presence of a tear, although tears in the intact cohort were overestimated (a specificity of 29% and negative predictive value of 25%).

Level of evidence: Level III; Diagnostic Study

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Keywords: Handheld dynamometry; rotator cuff tear; supraspinatus tear; rotator cuff tear size; supraspinatus tear size; arthroscopic rotator cuff repair

Rotator cuff tears are a common source of shoulder pain. Rotator cuff tears may be partial or full thickness and often present with pain and difficulty with overhead movements.[15] The supraspinatus is the most commonly implicated tendon in rotator cuff tears.

Rotator cuff tears are often repaired surgically. The repair method of choice often varies based on the size and

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thickness of the tear. Some partial-thickness tears may heal spontaneously.[11] Full-thickness tears amenable to repair can be directly repaired to the tuberosity, and some massive tears may require the use of interposition patches.[14] Therefore, it is important for the clinician to anticipate the size of a tear to guide treatment and appropriately counsel the patient regarding expectations and treatment options.

Strength testing has been shown to be useful in detecting rotator cuff pathology,[10,13] particularly for determining the presence of full-thickness rotator cuff tears. Manual muscle testing has been shown to exhibit low interexaminer reliability.[4,5] The subjectivity and lack of numerical scaling of manual muscle testing also make it difficult to develop criteria to predict the presence, absence, or size of a rotator cuff tear.[12] Handheld dynamometry has been proved to have high intrarater reliability and inter-rater reliability.[2,17] Therefore, individual clinicians can maintain consistency between recurrent readings, and dynamometry readings are reliable between different clinicians. Dynamometry values in supraspinatus abduction, external rotation, and internal rotation have been shown to be within 10 of 20 N of each other for an individual patient. Liftoff strength is usually much lower.[17] Strength values obtained by dynamometry have been predictive in determining the presence of rotator cuff tears[13] and in identifying full-thickness rotator cuff tears.[8,10] However, no study has determined whether handheld dynamometry can predict rotator cuff tear size. Therefore, this study aimed to determine whether handheld dynamometry readings are predictive of rotator cuff tear size.

Methods

This was a retrospective study from 2484 consecutive patients aiming to determine whether handheld dynamometry measurements were able to distinguish between rotator cuff tear sizes. All patients in this study who attended the senior author's clinic, had shoulder pathology considered sufficiently significant to warrant surgery, and subsequently underwent surgery were included. Patients were excluded if they did not have preoperative dynamometry data or if their operative record did not contain information regarding rotator cuff tear size.

All patients included in this study had strength of the affected shoulder measured by a handheld dynamometer (HFG 110; Transducer Techniques, Temecula, CA, USA). The measurements were all performed and recorded by an assistant to the senior author prior to surgery. All measurements were taken prior to imaging modalities such as ultrasound and radiography and before surgical treatment was offered.

Shoulder strength examination

The handheld dynamometer, pictured in Figure 1, *A*, was composed of a sensitive force-detecting plate (bottom of figure) attached to a computerized mechanism with a digital display and a hand strap for the examiner. Measurements were obtained by first asking the patient to generate a maximal voluntary contraction for 2 seconds and then maintain this contraction against the resistance of the dynamometer for 5 seconds. The dynamometer recorded the maximal load applied, expressing a digital reading in newtons. Internal rotation was assessed with the patient's arm by the side, the elbow flexed at 90°, and the forearm neutral in rotation. The patient directed the force medially while the examiner statically opposed this force with the dynamometer at the distal volar forearm (Fig. 1, *B*). Internal rotation strength measured the collective strength of the subscapularis, teres major, pectoralis major and minor, and latissimus dorsi. External rotation measurement was performed similarly to internal rotation, but the dynamometer was placed on the distal dorsal forearm and the patient applied a lateral rotational force while the examiner stabilized the elbow to remove any abducting forces (Fig. 1, *C*). External rotation was used to measure infraspinatus strength. The liftoff test was designed to assess the functional integrity of the subscapularis tendon. The arm was internally rotated and placed behind the back with the dorsum against the patient's back and palm facing the wall. The patient was asked to "push against the wall" with the dynamometer placed on the volar distal forearm (Fig. 1, *D*). Abduction in the scapular plane was a test specifically designed to assess the supraspinatus. It required positioning of the arm in 90° of abduction and directed 30° anteriorly from the coronal plane, essentially aligning the arm with the supraspinatus fossa, with the dynamometer placed on the dorsal mid forearm (Fig. 1, *E*). The patient was asked to oppose the downward force of the examiner to maintain the arm parallel to the floor. The final test, which measured adduction, was performed with the patient's arm in 30° of abduction, the dynamometer on the volar aspect of the distal forearm, and the patient instructed to adduct the arm (Fig. 1, *F*). Adduction does not involve the infraspinatus and supraspinatus and is therefore typically used as a control for rotator cuff pathology.[13]

The presence and characteristics of rotator cuff tears were measured intraoperatively via an arthroscopic probe and recorded intraoperatively by the senior author on a specifically designed form (Supplementary Appendix S1). Anteroposterior and mediolateral dimensions of tears were recorded (in millimeters) and multiplied to give the tear size as an area. Tear thickness was estimated to the nearest 10%. Partial-thickness tears were assessed as tears that had not completely separated the supraspinatus tendon from its footprint on the greater tubercle of the humerus.

Statistical analyses

Data were assessed using the Spearman correlation coefficient (r) comparing dynamometry measurements with the presence of a tear. Two-tailed Student t tests, with statistical significance set at $P < .05$, were used to determine whether dynamometry could distinguish between a partial- and full-thickness tear. Spearman correlation was performed between tear size and dynamometry measurements. A logistic regression analysis was performed for dynamometry relating to the presence of a tear. Backward stepwise regression analysis was used to identify combinations of tests that could predict rotator cuff tear size.

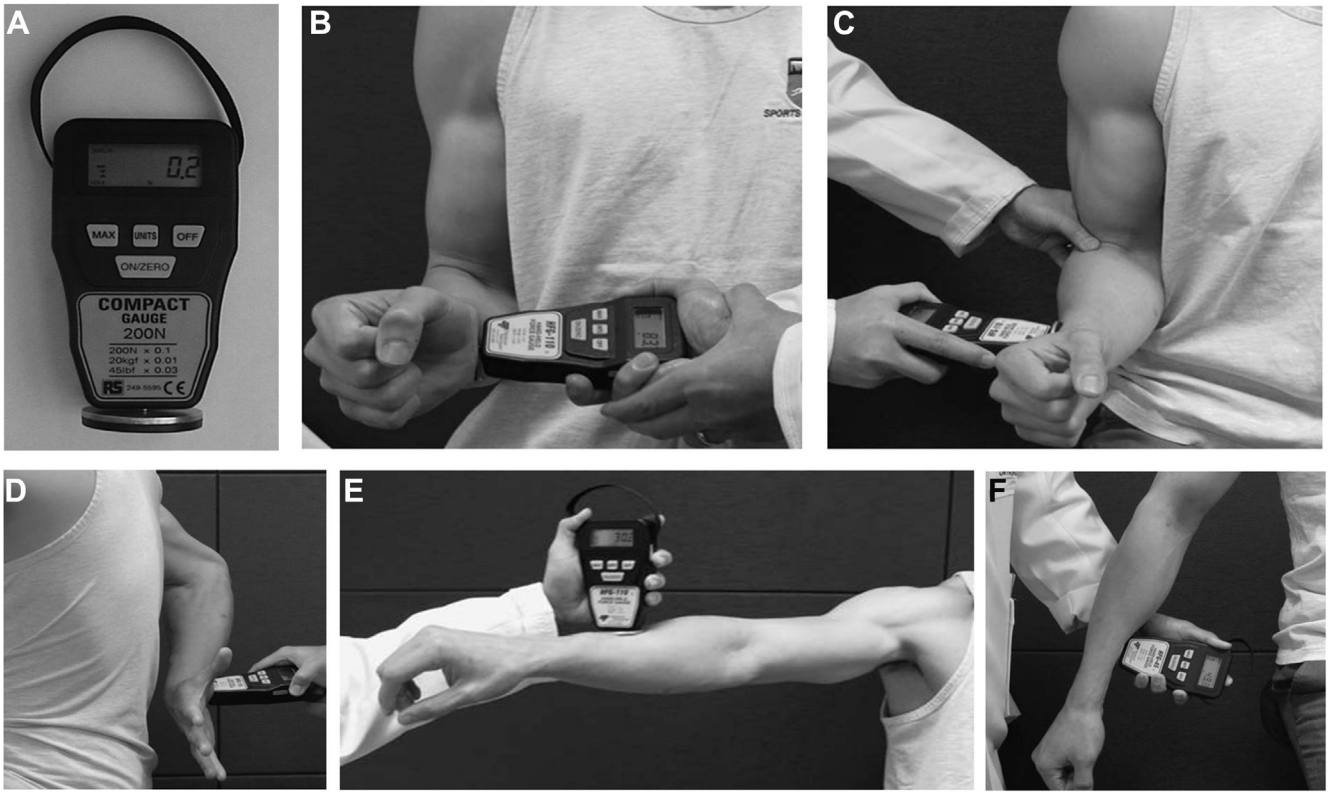

Figure 1 **(A)** Handheld dynamometer. **(B)** Internal rotation. **(C)** External rotation. **(D)** Liftoff test. **(E)** Abduction for supraspinatus strength. **(F)** Adduction. Figures used with permission.[15]

Results

Between February 3, 2004, and December 15, 2015, a total of 2484 patients (1295 male and 1189 female patients) underwent surgery with the senior author. We excluded 384 patients (196 male and 188 female patients) on the basis of incomplete preoperative dynamometry data. The remaining 2100 patients were divided into 2 groups according to their diagnosis at arthroscopy. The groups comprised 1747 patients in whom a rotator cuff tear was diagnosed (tear group) and 353 with no tear (no-tear group) at arthroscopy. The tear group was first divided based on the presence of a partial- vs. full-thickness tear. The groups consisted of 721 patients in whom a partial tear was diagnosed (partial tear group) and 1026 patients in whom a full-thickness tear was diagnosed (full-thickness tear group). The initial tear group was later divided based on the tear size area, defined as the product of the anteroposterior and mediolateral tear lengths, into 4 groups (Fig. 2). A summary of pathology in the group without tears is presented in Table I. Group demographic characteristics are summarized in Table II.

Handheld dynamometry

Presence of tear

Patients without rotator cuff tears had higher supraspinatus strength (mean [standard deviation]) than patients with tears (47 N [34 N] vs. 40 N [29 N], $P < .001$). No significant differences were found between the tear group and the no-tear group for external rotation strength (54 N [33 N] vs. 51 N [20 N], $P = .12$), liftoff strength (35 N [27 N] vs. 34 N [25 N], $P = .38$), internal rotation strength (64 N [34 N] vs. 63 N [35 N], $P = .82$), and adduction strength (70 N [40 N] vs. 68 N [37 N], $P = .3$) (Table III). Patients with lower supraspinatus strength were more likely to have a rotator cuff tear than patients with higher supraspinatus strength ($r = -0.82$, $P = .001$) (Fig. 3).

Logistic regression analysis

Multiple logistic regression analyses revealed the dynamometry readings with the greatest independent prediction of whether a tear was present to be the internal rotation and supraspinatus strength tests. The independent factors could be incorporated to produce an equation for predicting the presence of a rotator cuff tear based on preoperative dynamometry readings (measured in newtons) as follows:

$$\text{logit P} = 1.579 + (0.0117 \times \text{Internal Rotation}) - (0.0165 \times \text{Supraspinatus})$$

We used "Logit P" to determine the percentage chance of a patient having a rotator cuff tear (Fig. 4, *B*). We chose the clinical confidence cutoff point as 80%. On the basis of this cutoff, the logistic regression equation had an 82%

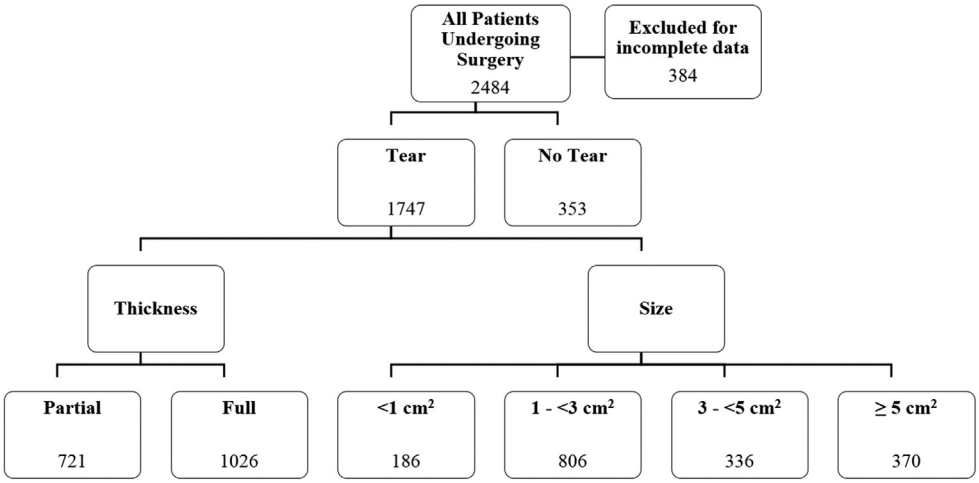

Figure 2 Diagram of study structure with patient totals.

Table I Distribution of shoulder pathology in no-tear group

	Patients
Diagnosis, % of total	
Adhesive capsulitis	23
SLAP lesion	19
Glenohumeral instability	18
Reverse total shoulder arthroscopy	9
Total shoulder arthroscopy	9
Acromial impingement	5
Calcific tendinitis	5
Hemiarthroplasty	3
Bankart lesion	2.8
Rotator cuff repair	2.5
Diagnostic procedure	<1
Humeral fracture	<1
Total, n	353

SLAP, superior labrum anterior-posterior.

Table II Group demographic characteristics

Group	Age, yr		Sex, male/female, n
	Mean (SD)	Range	
No tear	46 (18)	15-91	205/148
Tear	59 (12)	15-91	894/853
Partial thickness	55 (12)	18-86	402/319
Full thickness	62 (11)	15-91	577/449

SD, standard deviation.

sensitivity, 29% specificity, 85% positive predictive value, and 25% negative predictive value for predicting the presence of a rotator cuff tear. It was correct in determining the presence of a tear or no tear in 73% of patients across both groups. The model was able to correctly predict tears in 82% of patients with tears and correctly predict no tears in 29% of patients with no tears.

Thickness of tear

Dynamometry strength readings were compared between the no-tear group, partial-thickness tear group, and full-thickness tear group (Table IV, Fig. 5). Patients with partial-thickness tears had significantly higher internal rotation strength than patients with full-thickness tears (67 N vs. 63 N, $P = .025$). Significantly higher strength readings were found in the no-tear group compared with the full-thickness tear group for external rotation ($P < .001$), supraspinatus ($P < .001$) and liftoff ($P = .02$) strength. Significantly higher readings were noted in the partial tear group compared with the full-thickness tear group in internal rotation ($P = .03$), external rotation ($P < .001$), and supraspinatus ($P < .001$) strength. Patients with partial-thickness tears had greater adduction strength than those with no tears ($P = .03$).

Patients with adhesive capsulitis in the no-tear group had a lower adduction score (mean, 47 N) than patients with other shoulder pathologies in the no-tear group (mean, 74 N; $P < .001$). When the adhesive capsulitis patients were excluded and the no-tear group was again compared with the partial tear group, both groups had mean values of 74 N for adduction strength, with no significant difference between them ($P = .9$).

Patients with partial-thickness tears had greater strength values than patients with full-thickness tears for internal rotation ($r = -0.49$, $P < .001$), external rotation ($r = -0.156$, $P < .001$), supraspinatus ($r = -0.137$, $P < .001$), and adduction ($r = -0.49$, $P < .05$) strength. Therefore, patients with lower dynamometry readings for internal rotation, external rotation, supraspinatus, and adduction strength were more likely to have full-thickness tears than patients with higher values.

Table III Preoperative dynamometry readings for patients with and without rotator cuff tears

Presence of tear	Handheld dynamometry strength reading, mean (SD), N				
	Internal rotation	External rotation	Supraspinatus	Liftoff	Adduction
No tear	63 (35)	54 (33)	47 (34)	35 (27)	68 (37)
Tear	64 (34)	51 (29)	40 (29)	34 (25)	70 (40)
P value	.814	.119	<.001	.377	.303

SD, standard deviation.

Tear size

Patients were grouped based on tear size as follows: group I, less than 1 cm^2; group II, 1 to less than 3 cm^2; group III, 3 to less than 5 cm^2; and group IV, 5 cm^2 or greater (Table V). Patients with the largest tear size (group IV, $\geq$5 cm^2) were weaker in external rotation strength compared with all other groups (group I, $P < .01$; group II, $P < .001$, and group III, $P < .001$). Patients in group IV ($\geq$5 cm^2) were also weaker than all other groups in supraspinatus strength (group I, $P < .05$; group II, $P < .001$; and group III, $P < .05$). Patients in group II (1 to <3 cm^2) were stronger in adduction strength than patients in group I (<1 cm^2) (Fig. 6).

Multiple linear regression analysis

Tear size was independently correlated with external rotation power ($r = -1.46$, $P < .001$) and supraspinatus power ($r = -1.18$, $P < .001$). A linear regression model was then created using significant variables of handheld dynamometry to predict tear size. The independently predictive variables were the internal rotation ($P < .001$), adduction ($P = .02$), external rotation ($P < .001$), and supraspinatus ($P < .01$) strength tests, which were combined to produce the following formula:

$$\begin{aligned}\text{Tear size} = 482.793 &+ (3.870 \times \text{Internal Rotation})\\ &+ (1.579 \times \text{Adduction})\\ &- (7.165 \times \text{External Rotation})\\ &- (2.020 \times \text{Supraspinatus})\end{aligned}$$

This model had a modest correlation with the raw data in this study cohort ($r = 0.249$, $P < .001$) (Fig. 7).

Discussion

This study aimed to determine whether quantitative strength measurements obtained by handheld dynamometry readings could predict the size of rotator cuff tears. To our knowledge, this is the first study evaluating the quantitative strength of

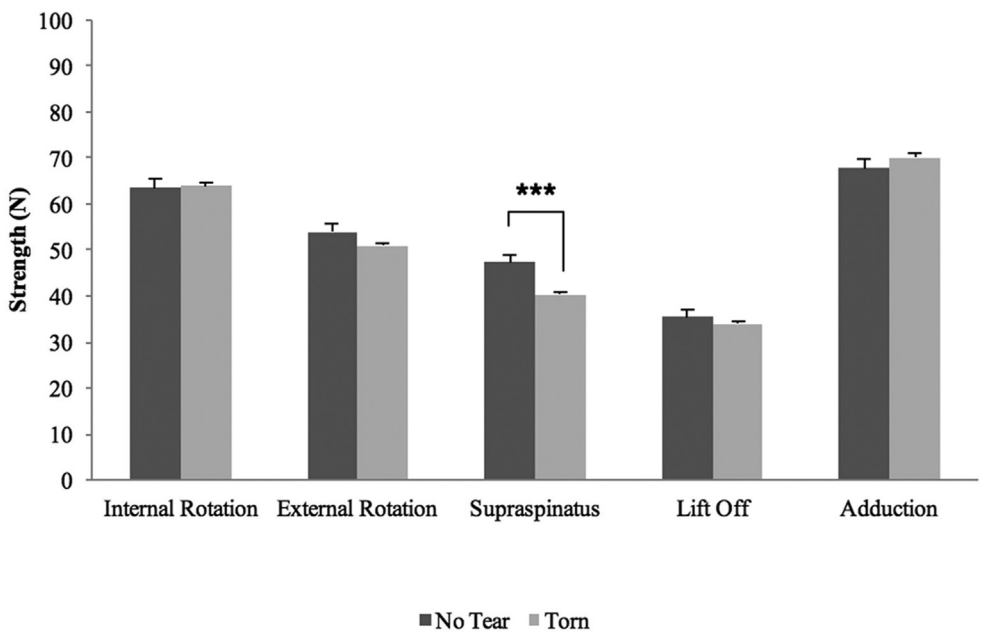

Figure 3 Handheld dynamometry measurements for patients with tears and no tears. ***$P < .001$.

A

	Tear (*n*)	No Tear (*n*)	
Test Positive	1330	240	$PPV = \frac{1330}{1330+98}$
Test Negative	288	98	$NPV = \frac{288}{288+240}$
	$Sensitivity = \frac{1330}{1330+288}$	$Specificity = \frac{98}{240+98}$	

B

Logit P $= log_e(\frac{p}{1-p})$ = 1.579 + (0.0117 x Internal Rotation) - (0.0165 x Supraspinatus)

The probability of tear is p. Now, presume that the result of the equation (Logit P) is equal to "x" after substituting strength values for internal rotation and supraspinatus.

i.e. Logit P = $log_e\left(\frac{p}{1-p}\right) = x$

$$e^x = \frac{p}{1-p}$$

$$e^x(1-p) = p$$

$$e^x - e^x p = p$$

$$e^x = e^x p + p$$

$$e^x = p(e^x + 1)$$

$$\frac{e^x}{e^x + 1} = p$$

Probability of tear $= \frac{e^x}{1+e^x} = \frac{e^{(\text{Logit P})}}{1+e^{(\text{Logit P})}}$

Figure 4 **(A)** Calculations of sensitivity, specificity, positive predictive value *(PPV)*, and negative predictive value *(NPV)* for logistic regression analysis. **(B)** Mathematical manipulation of regression equation to find percentage likelihood of patient having rotator cuff tear.

Table IV Preoperative dynamometry readings for patients with partial, full, and no tears

Type of tear	Handheld dynamometry strength reading, mean (SD), N				
	Internal rotation	External rotation	Supraspinatus	Liftoff	Adduction
No tear	64 (35)	54 (32)	49 (33)	40 (25)	68 (37)
Partial	67 (35)	57 (30)	46 (31)	38 (25)	74 (41)
Full	63 (32)	48 (26)	38 (26)	36 (22)	70 (38)

SD, standard deviation.

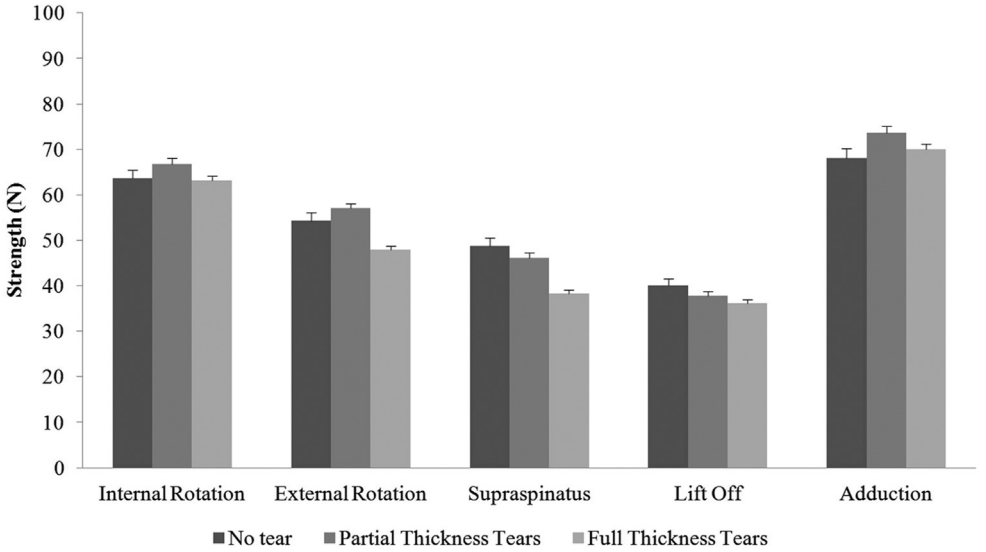

Figure 5 Handheld dynamometry measurements for patients with no tears, partial-thickness tears, and full-thickness tears.

patients with differing rotator cuff tear size areas. The results showed that rotator cuff tear size increases as external rotation and supraspinatus strength readings decrease. A model was developed to predict rotator cuff tear size area by incorporating dynamometry readings from internal rotation, adduction, external rotation, and supraspinatus strength tests. However, this equation showed only a modest correlation with our raw data. Quantitative strength measurements obtained by handheld dynamometry were not able to accurately predict rotator cuff tear size. In addition, statistical analysis found a functional index for diagnosing the presence of a rotator cuff tear with a high sensitivity and positive predictive value but a low specificity and negative predictive value. Therefore, although dynamometry identified patients with rotator cuff tears, it was less useful in ruling out other shoulder pathology. The equation, therefore, is valuable as a screening tool but is not specific enough to be used as a diagnostic tool.

Patients without rotator cuff tears had significantly higher supraspinatus strength than those with tears. A significant inverse correlation was found between supraspinatus strength and the presence of a tear, indicating that as supraspinatus strength increases, the probability of a rotator cuff tear decreases. Average strength readings were higher in intact cuffs than in torn cuffs across all strength tests, although no significant difference was found between the tear and no-tear groups for internal rotation, external rotation, liftoff, and adduction strength.

This study aimed to use these significant strength measurements in a logistic regression analysis to predict the presence of a rotator cuff tear. We built on a previous study of 200 patients by Osbahr and Murrell[13] (2006) that aimed to determine whether dynamometry values alone could predict the presence of a rotator cuff tear. Their study found that a functional index involving the supraspinatus and adduction could predict the presence of a rotator cuff tear with a sensitivity of 83%, specificity of 79%, positive predictive value of 80%, and negative predictive value of 82%. Our study of over 2000 patients found internal rotation and supraspinatus strength readings to be independently predictive of the presence of a rotator cuff tear. Multiple logistic regression analysis combined these 2 strength parameters to produce an equation to predict rotator cuff tears. On the basis of a clinical confidence cutoff point of 0.8, the model predicted tears with a sensitivity of 82% and positive predictive value of 85%. However, the

Table V Preoperative dynamometry readings for patients with various tear size areas

Group	Handheld dynamometry strength reading, mean (SD), N					
	Tear size, cm^2	Internal rotation	External rotation	Supraspinatus	Liftoff	Adduction
I	<1	63 (36)	53 (29)	44 (31)	35 (25)	67 (39)
II	1 to <3	65 (34)	55 (29)	45 (30)	37 (25)	72 (41)
III	3 to <5	68 (34)	53 (27)	43 (28)	39 (22)	76 (41)
IV	≥5	61 (30)	42 (24)	33 (21)	35 (22)	68 (34)

SD, standard deviation.

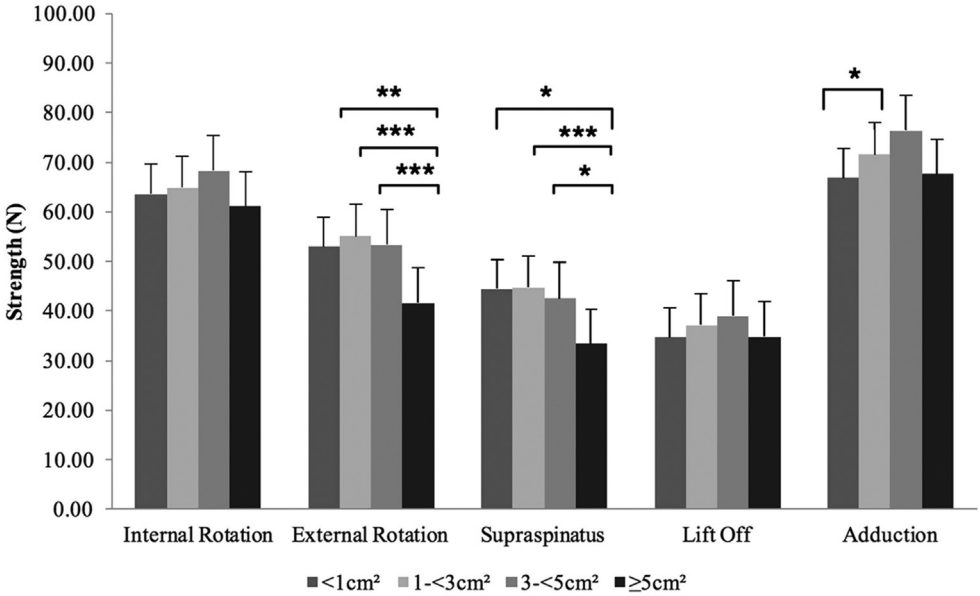

Figure 6 Handheld dynamometry measurements for patients with differing tear size areas. ***$P < .001$, **$P < .01$, and *$P < .05$, performed using 1-way analysis of variance.

equation exhibited a poor specificity of 29% and negative predictive value of 25% because of an overestimation of tears in the no-tear group. The equation had an overall correct prediction rate of 73%. The equation may, therefore, be clinically useful in screening patients for further diagnostic testing, but may not be specific enough to act as a standalone diagnostic measure.

Our study built on a previous study by Millican and Murrell[10] (2011) that aimed to determine a functional index for diagnosing partial-thickness tears in patients. Their study failed to find a significant difference in dynamometer measurements between patients with partial-thickness tears and patients without tears. Our study found significantly higher adduction strength in patients with partially torn

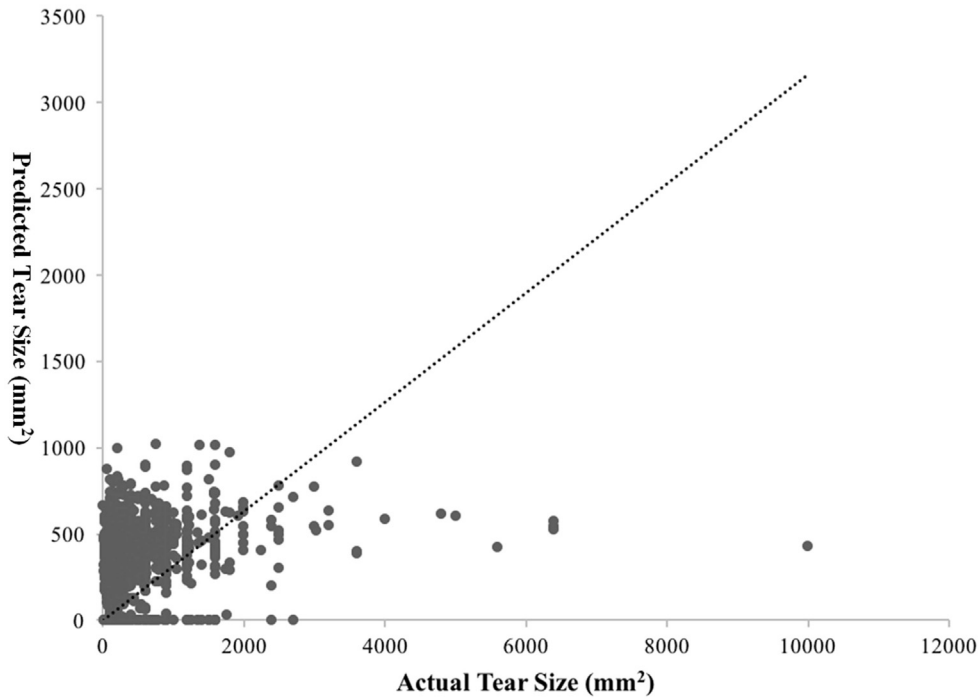

Figure 7 Scatter plot of actual tear size vs. predicted tear size.

cuffs than in those with intact cuffs. Adduction is typically considered a negative control for rotator cuff pathology as it involves force against the directions of force in the supraspinatus and infraspinatus muscles.[13] Reduced adduction strength is usually an indicator of diffuse shoulder pain. However, this should have manifested with no significant difference between the groups rather than a significant difference showing higher strength in the partial tear group. It has been proven that adhesive capsulitis, also known as "frozen shoulder," manifests with reduced shoulder strength owing to pain and impaired range of motion.[7] Adduction strength was significantly lower in patients with adhesive capsulitis and no rotator cuff tears compared with patients without adhesive capsulitis and without rotator cuff tears. After excluding adhesive capsulitis patients, we found no significant difference in adduction strength between patients without rotator cuff tears and those with partial-thickness tears. Hence, we confirmed that the initial adduction difference found between the groups was largely a result of patients with adhesive capsulitis.[10]

Our study was able to confirm higher strength values for external rotation and the supraspinatus in patients without rotator cuff tears compared with those with full-thickness tears, replicating the findings by Millican and Murrell[10] (2011). We also found a significantly lower liftoff strength reading for patients with full-thickness tears compared with patients without tears. Patients with full-thickness tears had significantly reduced internal rotation, external rotation, and supraspinatus strength compared with those with partial-thickness tears, which aligns with previous findings.[10]

This study incorporated quantitative strength measurements to predict the size of rotator cuff tears. Osbahr and Murrell[13] (2006) used a regression analysis to construct an equation for predicting tear size that included supraspinatus and adduction strength parameters, with modest correlation in their cohort of 200 patients. Our study was also able to find significant differences between dynamometry measurements for differing tear size areas. We found significantly higher strength in the smaller–tear size groups compared with the larger–tear size group for external rotation and supraspinatus strength. This finding confirms the gradual reduction in strength as tear size increases. Most rotator cuff tears are defects of the supraspinatus. Supraspinatus testing measures the strength of the supraspinatus muscle, whereas external rotation assesses the infraspinatus muscle. Therefore, the reduced external rotation strength in rotator cuff tears is thought to be due to the supraspinatus and infraspinatus sharing a common footprint on the superior facet of the greater tubercle of the humerus. A linear regression analysis revealed internal rotation, external rotation, adduction, and supraspinatus strength as significant variables in predicting rotator cuff tear size area. However, this model had only a modest correlation with our raw data in predicting the tear size of patients. The equation, which uses purely preoperative data, provides an anticipatory tear size for orthopedic surgeons, allowing preparation for various surgical techniques based on the size of the rotator cuff tear. Le et al[9] (2014) showed anteroposterior tear length, tear size area, and mediolateral tear length to be the highest independently predictive factors of rotator cuff retears after rotator cuff repair surgery. Therefore, the prediction of tear size provides the orthopedic surgeon insight into the likelihood of a patient undergoing a retear postoperatively.[9]

In analyzing the results of this study, several limitations must also be considered. The handheld dynamometry measurements were obtained by multiple observers, increasing the likelihood of varying results. However, the reliability of handheld dynamometry has been tested and proved in both healthy and pathologic shoulders.[1-3,5,6,16] Another limitation is that the control cohort did not match the experimental cohort in age. However, the incorporation of internal rotation, adduction, supraspinatus, and external rotation strength into the equation effectively eliminates the impact of age-related global strength reduction. Finally, there was a potential for observer and verification bias as the orthopedic surgeon had access to diagnostic tests prior to the procedure.

The study has several strengths that contribute to its reliability. This is a large study of 2100 patients who were operated on by a single surgeon. The intraoperative measurements of tear size and thickness were performed by the same surgeon, therefore providing reliability across measurements. The same handheld dynamometer model was used across measurements, and a standardized form and teaching protocol were put in place to train clinical assistants in obtaining strength measurements to maximize inter-rater reliability.

Conclusion

The results of this study indicate that handheld dynamometry is useful in identifying patients with rotator cuff tears. However, our results showed an overestimation of rotator cuff tears in patients who had no tears, particularly patients with frozen shoulder. Dynamometry is useful for screening, but further imaging in the form of ultrasound and magnetic resonance imaging is required prior to surgery.

Disclaimer

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other 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.

Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jse.2019.07.028.

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