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CLINICAL RESEARCH

Does the Upward Migration Index Predict Function and Quality of Life in Arthroscopic Rotator Cuff Repair?

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Abstract
Background Although upward humeral head migration is a well-recognized phenomenon in patients with tears of the cuff, it is unclear whether it relates to patient function after cuff repair. The upward migration index (UMI) assesses proximal migration of the humeral head while controlling for patients' bony morphologic features.
Questions/purposes We asked whether functional and quality-of-life (QOL) improvement occurs longitudinally in patients with low, moderate, or high degrees of proximal humeral migration after arthroscopic cuff repair and whether differences occur between groups.
Patients and Methods We retrospectively reviewed 118 patients with full-thickness tears treated by arthroscopic cuff repair. Patients were divided into three groups depending on the severity of preoperative proximal humeral migration seen on MRI. We determined function using two functional scores and the Western Ontario Rotator Cuff Index (a QOL index). Evaluations were performed preoperatively and 6 and 12 months postoperatively. A general linear model analysis controlled for patient characteristics, including the UMI, to determine their effects on functional and QOL scores.
Results Function and QOL improved after surgery in all three groups. The UMI did not correlate with final functional or QOL scores. Six-month functional and QOL scores correlated with final scores. The best predictor of final strength was initial strength.
Conclusions Preoperative UMI did not correlate with functional or QOL improvements after surgery. The data suggest substantial proximal migration of the humeral head, as measured by the UMI, should not be considered a contraindication to arthroscopic rotator cuff repair.
Level of Evidence Level II, prognostic study. See Guidelines for Authors for a complete description of levels of evidence.

Each author certifies that he or she has no commercial associations (eg, consultancies, stock ownership, equity interest, patent/licensing arrangements, etc) that might pose a conflict of interest in connection with the submitted article.
Each author certifies that his or her institution approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participation in the study was obtained.
This work was performed at Ottawa Hospital.

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Introduction

In 1962, measurement of the acromiohumeral interval (AHI) on plain radiographs was identified as a useful method of assessing disorders of the rotator cuff [17]. Several studies have shown a distance less than 7 mm between the lowest point on the acromion and the highest point on the humeral head on radiographs correlates with the presence of a tear of the rotator cuff [17, 24, 38], but the presence of a rotator cuff tear does not always lead to a decrease in the AHI: in a necropsy study, Cotton and Rideout [9] observed, although the normal AHI was 6 to 14 mm, this distance was not decreased in all specimens with a torn rotator cuff.

Ultrasound and MRI yield high sensitivities and specificities in making the diagnosis of rotator cuff tear

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[10, 32, 33]. However, superior migration of the humeral head, as an imaging sign, continues to have substantial clinical utility. A decrease in the AHI has been correlated with the presence of infraspinatus (ISP) tears, fatty infiltration of the rotator cuff, and the chronicity of symptoms [26, 30].

Several studies have examined the AHI for its utility as a prognostic indicator of functional outcome after repair of the rotator cuff [2, 12, 37]. A narrow AHI preoperatively reportedly correlated with poorer preoperative function, ROM, strength, and lower rates of satisfaction, after surgery [12]. Walch et al. [37] found an AHI less than 7 mm preoperatively correlated with lower postoperative Constant-Murley scores and less recovery of strength. Bellumore et al. [2] suggested greater proximal migration would lead to a poorer Constant-Murley score postoperatively.

Hirooka et al. [20] described an alternative method of measuring proximal humeral migration. By determining the distance between the lowest point on the acromion and the center of the humeral head and dividing this by the radius of the humeral head, the AHI can be expressed as a ratio termed the UMI [20]. This index controls for differences in patients' bony morphologic features. van de Sande and Rozing [34] confirmed the accuracy of measuring the UMI on plain radiographs by showing a high correlation between plain films and CT scans. Further, the UMI correlates with the amount of fatty infiltration in the rotator cuff musculature and with the presence of tears of the rotator cuff [35].

Our objectives were to (1) determine whether substantial improvement in functional and QOL indices occurs after arthroscopic cuff repair (ACR) in patients with varying degrees of upward migration of the humeral head; (2) determine whether functional or QOL indices differ after ACR in patients with low, moderate, or high degrees of upward migration of the humeral head; (3) identify possible prognostic factors, including the UMI, after ACR; and (4) determine which factors correlate with UMI, including tear size and fatty infiltration of the cuff musculature.

Patients and Methods

We retrospectively reviewed 118 prospectively followed patients (118 shoulders) who underwent rotator cuff repairs from 2005 to 2008 at our institution. During that time, we performed a total of 187 ACRs. The criteria for inclusion in the study were (1) the presence of a full-thickness rotator cuff tear as confirmed by intraoperative assessment; (2) confirmation of reparability of the tear (defined as a full and complete repair of the cuff with reapproximation of the tendon for full coverage of the footprint); and (3) preoperative assessment with MRI. The exclusion criteria were (1) the presence of associated shoulder disorders, including labral lesions, glenohumeral arthrosis, or shoulder sepsis; (2) repair of the rotator cuff with open technique; and (3) followup less than 1 year. Of the 187 patients, 125 had full-thickness tears and met the inclusion and exclusion criteria. Seven of these patients did not have MRI and were excluded from the analysis, thus leaving 118 patients, including 83 men and 35 women with a mean age at surgery of 56.1 years (95% confidence interval, 54.2–57.9 years) (Table 1). Seventy-five (63%) involved the right shoulder. All patients had a minimum of 6 months of nonoperative therapy before rotator cuff repair, including the use of NSAIDs, physiotherapy, and a maximum of three cortisone injections. The patients were grouped based on the degree of proximal migration as described by van de Sande et al. [35]: (1) UMI of 1.25 or less (Group 1, low UMI) (n = 29); (2) UMI of 1.25 to 1.35 (Group 2, medium UMI) (n = 46); and (3) UMI greater than 1.35 (Group 3, high UMI) (n = 43) (Table 1). Functional and QOL data were collected preoperatively and at 6- and 12-month followups. No patients were lost to followup. All data were

Table 1. Baseline demographic data

Variable	Low UMI group (1–1.25) (n = 29)	Medium UMI group (1.25–1.35) (n = 46)	High UMI group (> 1.35) (n = 43)	Total (n = 118)
Age (years)*	57 (52.8, 61.2)	54.8 (51.5, 58.1)	57.2 (54.4, 59.9)	56.1 (54.2, 57.9)
Gender				
Male	24 (82.8%)	33 (71.7%)	26 (60.5%)	83 (70.3%)
Female	5 (17.2%)	13 (28.3%)	17 (39.5%)	35 (29.7%)
Side				
Right	21 (72.4%)	27 (58.7%)	27 (62.8%)	75 (63.6%)
Left	8 (27.6%)	19 (41.3%)	16 (37.2%)	43 (36.4%)
Coronal tear (mm)*	35.6 (31.8, 39.4)	24.4 (21.1, 27.6)	18.3 (16.1, 20.4)	24.9 (22.9, 27.0)
Sagittal tear (mm)*	33.1 (28.5, 37.7)	18.7 (16.9, 20.5)	15.5 (12.5, 18.5)	21.2 (19.1, 23.3)

* Values are expressed as means, with 95% confidence intervals in parentheses; UMI = upward migration index.

obtained from the database; no patients were recalled specifically for this study. The protocol was approved by our institutional review board and all patients gave informed consent.

Eight biceps tenodeses were performed in the low UMI group (Group 1), six in the medium UMI group (Group 2), and four in the high UMI group (Group 3). There were no differences in age, gender, or side among patients in the three groups. For all patients, the mean coronal dimension of the cuff tears was 24.9 mm (SD, 11.3 mm) and the mean sagittal dimension was 21.2 mm (SD, 11.5 mm). The respective coronal and sagittal dimensions for the three groups were different (Table 1). The low UMI group was comprised of six supraspinatus (SSP) tears and 23 two-tendon tears (SSP and ISP). The medium UMI group was comprised of 38 SSP tears and eight two-tendon (SSP/ISP) tears, and the high UMI group included 41 SSP tears and two tears involving SSP with ISP delamination.

All rotator cuff repairs were performed by one surgeon (PL), using arthroscopic techniques and a standardized approach that did not change during the course of the investigation [4]. Surgery was performed with the patient in the lateral decubitus position with 10 pounds of continuous arm traction with the arm abducted. Hypotensive anesthesia was used to facilitate intraoperative observation when required. For the repair, three portals typically were used: an anteromedial portal for instrumentation, a lateral portal for instruments and anchor insertion, and a posterolateral portal for observation. The subacromial space was cleared of adhesions, bursal tissue, and reactive synovitis. Mobilization of the rotator cuff was achieved with a superior capsular release and a rotator interval-coracohumeral ligament release if required for a low-tension repair of the SSP tendon to the cuff footprint. After appropriate débridement and mobilization of the tendons to allow for a tension-free repair, decortication of the greater tuberosity was performed. No trough was created. A tension band repair was used for all repairs. Anchors were placed slightly distal (0.5–1 cm) to the lateral edge of the greater tuberosity with single-row technique. A suture hook was used, usually through the anteromedial portal, to pass inverted horizontal mattress stitches through the tendon medial to the tendon edge. Sliding-locking knots (Weston) allowed the tendon to be reduced to the footprint to allow for complete coverage; once the tendon was reduced completely but under minimal tension, the knots were locked and secured with three alternating half-hitches. All tendons were repaired with suture anchors (5.5-mm Super Revo® anchors; Linvatec, Largo, FL, USA). Subacromial decompressions were performed on four patients for purposes of observation. No distal clavicle excisions were performed. A biceps tenodesis was performed in 18 patients. This consisted of placing a suture anchor in the intertubercular groove and weaving a whipstitch through the tendon. The proximal portion of the biceps then was excised after the tenodesis. Postoperatively, the arm was protected in a sling, with only passive ROM exercises in the pain-free range permitted for the first 6 weeks.

All clinical evaluations were performed preoperatively and at 6- and 12-month followups by one independent investigator (KB) not associated with the surgery. Data were collected in the clinic setting after evaluation by the surgeon. Function was assessed using the nonweighted Constant-Murley score [8], a 100-point, validated outcome tool. The ROM for active forward elevation and external rotation was measured with the patient in the standing position using a goniometer. The internal rotation was noted according to the method of Constant and Murley [8]. Pain was measured using a visual analog scale ranging from 0 (unbearable pain) to 15 (no pain). Strength was measured with a dynamometer scaled in 0.5-kg increments attached to the patient's wrist. The dynamometer was secured such that the patient's arm was held at approximately the horizontal position. The patient was instructed to raise the arm using maximum force against resistance for 3 seconds. Other outcome measures included the American Shoulder and Elbow Surgeons (ASES) score [28] and the Western Ontario Rotator Cuff Index (WORC) [22], a validated, QOL outcome tool. All three outcome measures provide scores ranging from 0 to 100, with 100 being a perfect score.

An investigator (PCL) who was blinded to patient scores reviewed operative reports and MRI scans. All UMI measurements also were performed by a second investigator (EL) for the purpose of calculating interobserver variability (calculated kappa = 0.23 (fair) for UMI data). Preoperative standard radiographs (including a true AP view) and MRI scans were available for all patients. Radiographic analysis consisted of determination of the acromiohumeral space as measured on the MRI. As previously described [34], the coronal image, perpendicular to the glenohumeral joint, was used to measure the largest radius of the humeral head using a circle fit. The images were controlled in the sagittal plane parallel to the glenoid surface throughout the reconstructions. The smallest distance between the undersurface of the acromion and the most proximal part of the humeral head was determined and measured in the AP plane. The UMI was calculated by dividing the distance from the undersurface of the acromion to the center of the humeral head by the radius of the humeral head (Fig. 1).

In addition, rotator cuff tear status was determined by evaluation of the MRI. MRI was performed using a Symphony 1.5-T unit (Siemens Medical Systems, Iselin, NJ, USA) and its extremity coil. The rotator cuff was imaged with axial, coronal proton density (PD) weighted, coronal T2-fat-suppressed (FS), sagittal double oblique (OBL)

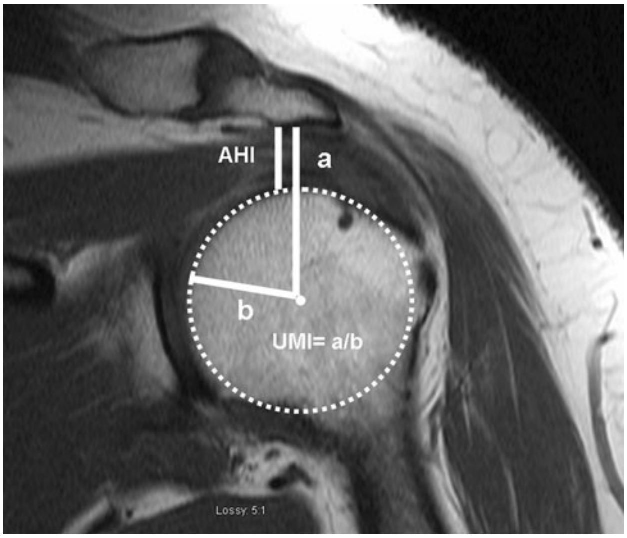

Fig. 1 The UMI is calculated on MRI of the shoulder by dividing the distance between the lowest point on the acromion to the center of the humeral head (a) with the radius of the humeral head (b).

turbo spin echo (TSE) FS, InPhase-OutPhase imaging at TE 2.4–4.8–6.2, and T2 quantitative. The global fatty infiltration index [16, 18, 19] of the cuff musculature also was recorded.

Data were expressed as mean with SD. Statistical analysis was performed using a mixed-effect model using a longitudinal analysis approach to consider within-group correlations for functional improvement in each cohort with time and ANOVA for comparison among the three groups in cross section. ANOVA was used as the data were normally distributed. We then created a general linear model that controlled for age, gender, and baseline and 6-month functional and QOL scores, strength, AHI, UMI, tear size, and the global fatty infiltration index [16, 18, 19]; the final ASES, Constant-Murley, and WORC scores were the dependent variables. A second regression model controlled for tear size and the global fatty infiltration index with UMI as the dependent variable. All analyses were conducted using SAS® 9. 1 (SAS Institute Inc, Cary, NC, USA).

Results

We observed incremental increases ($p < 0.001$) between baseline and 6 months and between 6 and 12 months for the ASES, WORC, and Constant-Murley scores and strength (Table 2).

Functional and QOL scores (Table 3) and Constant-Murley strength subscores among Groups 1, 2, and 3 were similar at all the times, except for the Constant-Murley score, which at 6 months, was lower ($p = 0.04$) in the high UMI group than in the low and medium groups. By 12 months, this difference was no longer significant ($p = 0.07$).

Table 2. Functional and quality-of-life outcomes

Outcome	Baseline	6 months	12 months	p Value
ASES score	47.4 (17.3)	77.3 (16.4)	83.4 (19.1)	< 0.0001
Constant-Murley score	57.0 (16.2)	72.2 (16.8)	79.2 (16.8)	< 0.0001
WORC score	31.4 (15.3)	68.7 (22.7)	74.4 (26.0)	< 0.0001
Strength	8.7 (6.4)		13.9 (7.5)	< 0.0001

Values are expressed as mean, with SD in parentheses; ASES = American Shoulder and Elbow Surgeons; WORC = Western Ontario Rotator Cuff Index.

With the 12-month ASES score as the dependent variable, (1) a one-unit increase in the ASES score at 6 months correlated ($R^2 = 0.4$; $p < 0.001$) with a 0.56-unit increase in final ASES score; with the 12-month Constant-Murley score as the dependent variable, a one-unit increase in the 6-month Constant-Murley score correlated with ($R^2 = 0.5$; $p < 0.0001$) a 0.58-unit increase in the final Constant-Murley score. With the 12-month WORC as the dependent variable, a one-unit increase in the 6-month WORC correlated with ($R^2 = 0.6$; $p < 0.0001$) a 0.7-unit increase in the final WORC score. With the 12-month Constant-Murley strength score as the dependent variable, a 1-year increase in age correlated ($R^2 = 0.42$; $p = 0.019$) with a 0.13-kg increase in final strength; male gender correlated with ($R^2 = 0.42$; $p = 0.0003$) a 5.2-kg increase in final strength; a 1-mm increase in AHI correlated with ($R^2 = 0.42$; $p = 0.0008$) a 2.67-kg increase in final strength; and a 1-kg increase in baseline strength correlated with ($R^2 = 0.42$; $p < 0.0001$) a 0.6-kg increase in final strength. We identified no other associations between AHI, UMI, or tear size and final ASES, WORC, or Constant-Murley scores.

With the UMI as the dependent variable, tear size correlated negatively ($p < 0.0001$) but fatty infiltration ($p = 0.44$) did not.

Discussion

The UMI provides a method of determining the degree of superior migration of the humeral head in rotator cuff disorders while controlling for differences in patients' bony morphologic features. We presumed relative to a well-centered humeral head, a high degree of proximal migration would yield poor ASES, Constant-Murley, and QOL (WORC) scores and thus would represent a relative contraindication to ACR. We therefore determined (1) whether substantial functional improvement occurs in patients with low, moderate, or high degrees of superior migration after

Table 3. Functional and quality-of-life outcome scores by group

Variable	Low UMI group (1–1.25) (n = 29)	Medium UMI group (1.25–1.35) (n = 46)	High UMI group (> 1.35) (n = 43)	Total (n = 118)	p Value
ASES score					
Baseline	51.0 ± 17.7	49.3 ± 15.5	43.2 ± 17.6	47.5 ± 17.0	0.08
6 months	73.8 ± 17.4	79.7 ± 16.1	76.2 ± 17.0	77.1 ± 16.7	0.35
12 months	82.8 ± 20.4	85.6 ± 19.7	80.8 ± 18.5	83.2 ± 19.4	0.44
Strength					
Baseline	8.2 ± 6.8	8.5 ± 5.6	9.8 ± 6.9	8.8 ± 6.4	0.48
12 months	12.7 ± 8.9	15.0 ± 7.6	13.4 ± 6.7	13.9 ± 7.6	0.31
Constant-Murley score					
Baseline	60.0 ± 18.8	55.6 ± 15.3	57.1 ± 15.4	57.2 ± 16.2	0.56
6 months	76.1 ± 12.9	75.3 ± 17.4	66.2 ± 17.5	72.0 ± 17.0	0.04
12 months	81.3 ± 19.4	80.2 ± 16.8	75.6 ± 15.3	78.8 ± 17.0	0.11
WORC score					
Baseline	34.6 ± 17.2	32.4 ± 13.9	29.4 ± 15.3	31.9 ± 15.3	0.27
6 months	71.3 ± 18.4	71.6 ± 22.1	63.7 ± 25.9	69.1 ± 22.9	0.40
12 months	77.9 ± 28.1	77.1 ± 24.5	70.9 ± 25.6	75.0 ± 25.7	0.44

Values are expressed as mean ± SD; UMI = upward migration index; ASES = American Shoulder and Elbow Surgeons; WORC = Western Ontario Rotator Cuff Index.

ACR; (2) whether any differences in ASES, Constant-Murley, or WORC scores occur between patients who have low, moderate, or high upward migration; and (3) whether the preoperative UMI has any prognostic value in predicting final ASES, Constant-Murley, or WORC scores after ACR while controlling for other patient variables.

We recognize several limitations of our study. First, MRI was used to assess the degree of upward migration in calculating the UMI and AHI. We chose MRI over plain radiographs as MRI allows for accurate assessment of distances between bony landmarks while eliminating the possible variable of patient positioning. Second, the radiographic landmark for determining the lower edge of the acromion is a sclerotic line tangent to its undersurface. As this line is not a fixed anatomic landmark, its position varies with changes in the direction of the xray beam. Third, MRI is obtained with the patient in the supine position whereas plain radiographs are performed with the patient sitting. Despite this, the two techniques reportedly [39] have an intermethod correlation coefficient for the AHI of r = 0.6 (moderately high). The correlation coefficient between the UMI as measured on plain radiographs versus CT was even greater (r = 0.86) when shoulder radiographs are taken in a controlled fashion [34]. The interobserver variability for measurement of the AHI on MRI or CT was reported as 0.8 by Werner et al. [39]. The interobserver variability for measurement of the UMI in our study was 0.23 (fair). Fourth, there are inherent limitations in accuracy in determining distances on digital imaging systems as there is reliance on algorithms to calculate distances on images that are magnified, and resolution may not always be optimal. Fifth, followup of the cohort in this study was relatively short at 12 months. However, previous studies [1, 6, 13, 25, 36] suggest functional status after 12 months tends to remain constant or improve slightly. As this is a study investigating prognosis, a 12-month followup was chosen on which to base our analysis, given that by this time healing is complete and the majority of patients have completed their rehabilitation. Finally, other variables may influence the final ASES, Constant-Murley, or WORC scores apart from patient factors, such as surgical technique, the rehabilitation program, and other factors that may not yet be understood.

We observed a correlation between the degree of humeral head upward migration and tear size in the coronal and sagittal dimensions. However, analysis of baseline functional and strength data indicated no differences existed among the three groups preoperatively. Interestingly, substantial functional improvement was observed in patients in all three groups from baseline to the 6-month followup and from 6- to 12-month followups. Thus, even patients with a high degree of superior migration showed substantial improvement in functional and QOL scores overall. Based on these data, it appears even patients with a high degree of superior migration may benefit from ACR. We conclude a lower UMI (and higher degree of proximal migration) should not represent an absolute contraindication to ACR, thus refuting our initial presumption. This finding is in contrast to results reported by Walch et al. [37] in which a narrow preoperative AHI correlated with poorer final Constant-Murley scores in patients after open cuff repair.

Others have reported substantial pain relief can occur after cuff repair, even in the presence of an unhealed rotator cuff; Jost et al. [21] reported on the Constant-Murley scores of 20 patients with nonhealed cuffs after repair at a mean 7.6-year followup. The adjusted Constant-Murley score was 88% and was similar to the score at 3.2 years. Nineteen of 20 patients remained satisfied with the surgical result despite structural failure of the repair [21]. Although we do not have imaging data to document postoperative healing status of the tendon in this series, healing rates likely would be lower in patients with more severe superior migration of the humeral head, given the larger tear sizes [3, 6, 14]. Despite this, the findings of our study have important implications for clinical practice. Contrary to previous reports [2, 12, 37], our data indicate that a high degree of proximal humeral migration preoperatively, as measured by the UMI, should not be considered a contraindication to arthroscopic rotator cuff repair. Functional outcome indices are highly clinically relevant. Therefore they are of greater value overall as a measure of surgical success than healing status alone.

Previous studies have suggested larger tear size correlates negatively with healing potential, ASES and Constant-Murley scores, active motion, and strength [3, 6, 14]. These previous studies measured tear size by various methods but did not attempt to determine a correlation between proximal migration and functional outcome. In our study, function, QOL, and strength did not differ among the three UMI groups on preoperative imaging. The only significant intergroup difference was the 6-month Constant-Murley score, which was lower in the high UMI group than in the low and medium groups. By 12 months, there no longer was a difference. It is not clear why this assessment proved different, but we speculate this may represent a Type I error.

The regression analysis of ASES, Constant-Murley, and WORC QOL scores showed most variables were not predictors. Of all variables studied, the 6-month ASES, Constant-Murley, and WORC QOL scores provided the strongest predictor of final outcome. This held true regardless of the outcome instrument used. This finding implies, as 6-month outcome is strongly correlated with 12-month outcome, the 6-month ASES, Constant-Murley, and WORC QOL scores potentially could be used as an important branch-point in a decision tree regarding whether a patient requires further workup or possibly repeat surgical intervention in the event the patient has not showed substantial improvement by 6 months. Additional study into incremental improvement with time after cuff repair is needed to answer this question definitively. With final strength as the dependent variable, we found four factors of prognostic value: age, gender, AHI, and initial strength. The AHI correlated with final strength whereas the UMI did not. It is possible the AHI can be measured more reliably than the UMI, which requires two separate measurements and is a relative value. The kappa statistic of 0.23 calculated in our study indicates only a fair level of correlation between observers, which may explain why the AHI correlated with final strength and the UMI did not. The strongest association with final strength, however, occurred with initial strength. Thus, patients with severe weakness initially are the least likely to recover strength after ACR, whereas patients with better initial strength are likely to see more substantial strength increases after repair. A recent study by Oh et al. [27] found older age and female gender correlated with the Simple Shoulder Test, and tear size correlated with the ASES score. Other studies have identified other factors as prognostic of functional outcome; age [4, 7, 11], gender [29], tendon status [4, 7], duration of symptoms [15], tear size [5, 23, 31], and fatty infiltration [16, 18, 19]. It is possible other variables exist that influence the outcome of cuff repair that are not yet known. A strength of our study is that a regression model was used to identify prognostic factors while controlling for the influence of other factors in the model.

Patients who underwent ACR showed substantial functional and QOL improvement after ACR even with large superior migration of the humeral head as determined by the UMI. When final ASES, Constant-Murley, and WORC QOL scores were compared in patient cohorts with differing degrees of superior migration, no differences were observed.

When studied for its utility as a prognostic factor, the UMI did not correlate with final ASES, Constant-Murley, and WORC QOL scores. We therefore conclude that substantial proximal migration of the humeral head, as measured by UMI, should not be considered a contraindication to arthroscopic rotator cuff repair. However, 6-month ASES, Constant-Murley, and WORC QOL scores were associated with final scores. The best predictor of final strength was initial strength, although age, gender, and the AHI also were useful predictors.

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