Acta Orthopaedica et Traumatologica Turcica 52 (2018) 109–114

Contents lists available at ScienceDirect

Acta Orthopaedica et Traumatologica Turcica

journal homepage: https://www.elsevier.com/locate/aott

Do subscapularis tears really result in superior humeral migration?

Mehmet Cetinkaya [a, *], Muhammet Baybars Ataoglu [b], Mustafa Ozer [c], Tacettin Ayanoglu [d], Ali Yusuf Oner [e], Ulunay Kanatli [b]

[a] Erzincan University, Mengucek Gazi Training and Research Hospital, Department of Orthopaedics & Traumatology, Erzincan, Turkey
[b] Gazi University, School of Medicine, Department of Orthopaedics & Traumatology, Ankara, Turkey
[c] Necmettin Erbakan University, Meram Medical School, Department of Orthopaedics & Traumatology, Konya, Turkey
[d] Yozgat State Hospital, Department of Orthopaedics & Traumatology, Yozgat, Turkey
[e] Gazi University School of Medicine, Department of Radiology, Ankara, Turkey

ARTICLE INFO

Article history:
Received 4 July 2017
Received in revised form
2 October 2017
Accepted 23 January 2018
Available online 13 February 2018

Keywords:
Arthroscopy
Shoulder
Subscapularis
Supraspinatus
Humeral migration
Humeral excursion

ABSTRACT

Objectives: The aim of this study was to analyse the effect of subscapularis tear on superior humeral excursion (SHE) and acromiohumeral distance (AHD). The hypothesis was that subscapularis tears do not result in superior humeral excursion.
Methods: Patients who underwent shoulder arthroscopy between August of 2011 and 2015 were reevaluated. Those with isolated Bankart lesion were used as control group and included in the Group 1, isolated full-thickness supraspinatus tear in the Group 2, isolated subscapularis tear in the Group 3, and combined subscapularis and supraspinatus tear in the Group 4. The mean SHE and AHD measurements on magnetic resonance imaging of these groups were compared to reveal any difference in superior humeral migration (SHM).
Results: There were 30 patients in each group. The mean age of Group 1 (26.44 ± 8.34) was younger than the other 3 groups. The mean AHD and SHE were higher in Group 1 and 3 (Mean AHD: 12.89 ± 2.24 and 12.28 ± 1.9, respectively. Mean SHE: -3.2 ± 0.99 and -2.78 ± 0.64, respectively) than Group 2 and 4 (Mean AHD: 6.2 ± 1.78 and 6.16 ± 1.52, respectively. Mean SHE: 0.72 ± 0.65 and 1.24 ± 0.63, respectively). The AHD and SHE were strongly correlated with each other (Pearson correlation coefficient = 0.184). The inter-observer and intra-observer correlation of the measurements of SHE on MRI were excellent with intraclass correlation coefficient of 0.95 and 0.94, respectively.
Conclusion: Subscapularis tears do not lead to SHM and subacromial impingement. However, superior rotator cuff tears can still lead to SHM and subacromial impingement even when subscapularis tendon is intact.
Level of evidence: Level III, diagnostic study.
© 2018 Turkish Association of Orthopaedics and Traumatology. Publishing services by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

Introduction

The superior migration of the humeral head following rotator cuff tear was first described by Golding in 1962 and emphasised by Weiner and Macnab in 1972.[1,2] They pronounced the correlation of humeral migration and acromiohumeral narrowing secondary to rotator cuff tears. The function of rotator cuff during the scaption is thought to be stabilization of the shoulder by compressing the humeral head into the glenoid cavity, thus providing concentric rotational motion of the joint and preventing the superior migration of the humeral head.[3–5] However, the individual contribution of the rotator cuff components has no consensus among the authors investigating the superior excursion of the humeral head. There are various opinions and findings in the literature, and the vast majority of the studies support the opinion that the subscapularis and superior rotator cuff, especially the infraspinatus, have functions in superior-inferior stability of the glenohumeral joint.[6–8]

In this study, the authors sought to understand the effect of subscapularis tear on superior humeral migration and

Institutional review board approval was provided for this retrospective study. IRB Number: 33216249–33216604.01.02-E.24142 (23/05/2017-7/04).

* Corresponding author. Erzincan University, Mengucek Gazi Training and Research Hospital, Department of Orthopaedics & Traumatology, 24030, Erzincan, Turkey. Tel: +90 532 7969887. Fax: +90 312 2129008.
E-mail address: drcetink@gmail.com (M. Cetinkaya).

Peer review under responsibility of Turkish Association of Orthopaedics and Traumatology.

https://doi.org/10.1016/j.aott.2018.01.007
1017-995X/© 2018 Turkish Association of Orthopaedics and Traumatology. Publishing services by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

acromiohumeral distance. The hypothesis of the study was that subscapularis tears do not result in substantial superior humeral excursion when measured on magnetic resonance imaging (MRI) sections.

Materials and methods

The shoulder arthroscopy database of the institute was retrieved to reevaluate surgery videos and MRI files of patients who underwent shoulder arthroscopy between August of 2011 and 2015. Only the patients with MRI findings congruent with arthroscopic findings were selected for the study, and those operated after a month later than the time of MRI procedure were not included to prevent misinterpretation. Patients with isolated Bankart lesion were used as control group and included in the Group 1, those with isolated full-thickness supraspinatus tear in the Group 2, those with isolated subscapularis tear in the Group 3, and those with both subscapularis and supraspinatus tears in the Group 4. In a previous study, the response within each subject group was normally distributed with the standard deviation of 1.3 and the difference between experimental and control means of 0.95. It is needed to study 29 experimental subjects and 29 control subjects to be able to reject the null hypothesis that the population means of the experimental and control groups are equal with probability (power) of 0.8. The Type I error probability associated with this test of this null hypothesis is 0.05. The groups were arranged with 30 patients in each which enabled to use parametric tests in statistical analyses. When evaluated whether distributed normally and homogenously, AHD and SHE were appropriate as continuous variables to analyse with parametric tests. The patients constituting the groups were chosen randomly by the help of an online software named *Research Randomizer Version 4.0* (2015, by Geoffrey C. Urbaniak and Scott Plous). The mean age, gender, and the involved shoulder of the patients were recorded.

Patients with a history of prior surgery or symptoms started acutely right after a trauma in the vicinity of involved shoulders (including fractures, dislocations, and falling down); patients with osteoarthritis, inflammatory joint disease, haemophilic arthritis, and pyrophosphate disease were not included in this study. There was no patient with biceps tendon dislocation or rupture in Group 1, but when there is in other groups, those patients were excluded from the study because of causing additional superior-inferior instability in the shoulder. Superior labrum anterior posterior (SLAP) lesions were not excluded from the study, except the Group 1, because of accompanying almost always to subscapularis tears. The superior cuff tears including infraspinatus and subscapularis tears classified as Type 1 according to the Lafosse classification were also excluded.[9] The institutional review board approval was provided for this retrospective investigation.

Arthroscopic procedure

All of the procedures and the classification of the subscapularis tears were performed by the senior surgeon, who had 15 years of experience in shoulder arthroscopy, and two assistants at the same institute under general anaesthesia with or without inter-scalene block or a single inter-scalene block. The operations were performed in semi-lateral position in which patients were allowed to rotate 20–30° posteriorly, thus placing the glenoid fossa parallel to the floor. The arm was in 45-degree abduction and 15-degree forward flexion under 10 lb longitudinal traction. Following the sterilisation with iodine solution and sterile draping, the standard posterior portal was constituted for the initial examination of intraarticular pathologies through a 30° rigid arthroscope. Additional portals were constituted according to the required interventions decided following the examination of shoulders by an arthroscopic probe through the anterior portal.

MRI procedure and the measurements on MRI

MRI examinations were performed with a dedicated shoulder coil on a 1.5 T system (Signa, HiSpeed, General Electric Medical Systems, Milwaukee, Wisconsin) in the supine position of patients as the arm lying beside the body in neutral rotation. The imaging protocol included oblique coronal T1-weighted (TR/TE:600/16) and fat-suppressed intermediate (T2-weighted) (TR/TE:3000/56), oblique coronal T1-weighted [TR/TE:500/16] and fat-suppressed intermediate (TR/TE:3000/56), and T2-weighted axial (TR/TE:500/15, flip angle:30) images. The field of view was 18 cm, the matrix was 192–384 × 256, and slice thickness/inter-slice gap was 3–4/0–1 mm in all sequences.

A focal discontinuity in the supraspinatus tendon extending from the articular to the bursal surface was assumed to be a full thickness rotator cuff tear on coronal oblique images and appears as fluid signal intensity on T2W.[10] An increased intermediate or fluid-like signal within the substance of the tendon, tendon margin irregularity, defect within the tendon, and/or retraction of the tendon were the criteria of subscapularis tear.[11] The involvement of the signal change within the substance of the tendon determined the size of the tear as full-thickness (tear extending from the articular surface to the bursal surface) or partial tear (only a portion of the tendon).

MRI scanning evaluation and measurements were made by two authors of this study, but not the senior surgeon who performed the procedures, according to the guidance of a radiologist with the degree of Professor and dedicated to musculoskeletal imaging. These two independent observers were blinded to the clinical and arthroscopic data of the patients. One of those measured the SHE once more a month after the first measurement and was blinded to his first measurement results. The inter-observer and intra-observer correlation of the measurements of the SHE were calculated. The SHE measurements were adapted for MRI from a previous description on radiographs.[12,13] In this method, a circle tangential to the borders of the humeral head was drawn, and the center of the humeral head (COHH) was determined by the tools of the DICOM (digital imaging and communications in medicine) viewer on T1-weighted coronal oblique sections of MRI. Then, glenoid fossa was determined by the line drawn between the superior and inferior most edges of the glenoid, and then the center of the glenoid fossa (COGF) was marked on this line. A second line was drawn from the COHH perpendicular to the glenoid fossa line, and the intersection point was marked. The distance between the intersection point and the COGF was recorded as the SHE (Fig. 1). If the COGF was inferior to the intersection point, the SHE was recorded as a negative value, and if it was superior, then the SHE took a positive value.

The acromiohumeral distance (AHD) was measured on T1-weighted coronal oblique sections. The narrowest distance found on those sections between the superior aspect of the humeral head and the inferior aspect of the acromion was recorded as AHD (Fig. 2).[14]

Statistical analysis

The groups were compared to each other with the Independent Samples T-Test and Kruskal–Wallis tests to assess the SHE, AHD, and age in the groups. The dichotomous variables were assessed by Crosstabs and Pearson's Chi-square test. The correlation of AHD and SHE was assessed with Pearson correlation coefficient. The reliability tests were evaluated with the Cronbach's alpha coefficient. The statistical significance was set at $P < .05$ level (2-tailed).

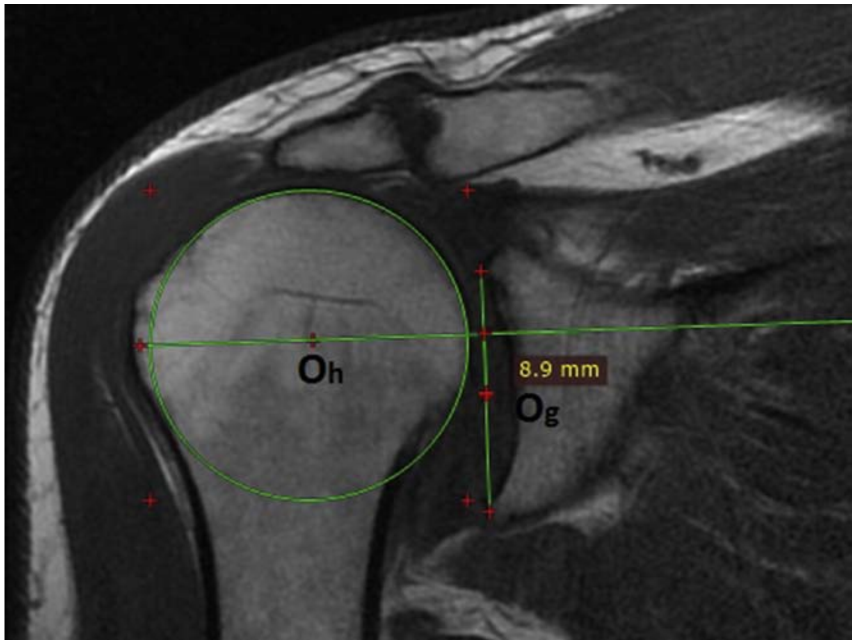

Fig. 1. Measurement of superior humeral excursion.

Statistical analyses were made with the Statistical Package for Social Sciences (SPSS) software (Version 21.0; SPSS Inc, Chicago, IL).

Results

The demographic data of the groups are given in Table 1. The mean age of Group 2 was statistically similar with Group 3 and 4 ($P > .05$) while that of Group 3 was statistically less than Group 4 ($P = .001$). The mean ages of Group 2, 3, and 4 were significantly more than Group 1 ($P = .000$). The involved shoulder was similar between Groups 1 and 3 and also in Group 2 and 4 ($P > .05$). However, it was different in Group 1 and 3 when compared to Group 2 and 4 with the Pearson's Chi-square Test ($P = .024$ and 0.014, respectively). The mean age was younger in Group 1, as expected ($P = .012$). However, there was no significant difference in terms of age between Group 2, 3, and 4 ($P > .05$).

The mean AHD and SHE were significantly different between these four groups when assessed with Oneway ANOVA test and are given in Table 2. The Post Hoc Tests revealed that the Group 2 and 4 were significantly different from Group 1 and 3 ($P = .000$ for both) while there was no significant difference between the Group 1 and 3 and the Group 2 and 4. The mean AHD was higher in Group 1 and 3 while the SHE was higher in Group 2 and 4 ($P = .000$). When the subscapularis tears were evaluated in terms of Lafosse classification, there were 17 type 2 and 13 type 3 in the Group 3 and 15 Type 2, 12 type 3, and 3 type 4 in the Group 4. The difference in mean AHD and SHE were not statistically significant between Lafosse subgroups among each Group 3 and 4 ($P > .05$). The correlation of

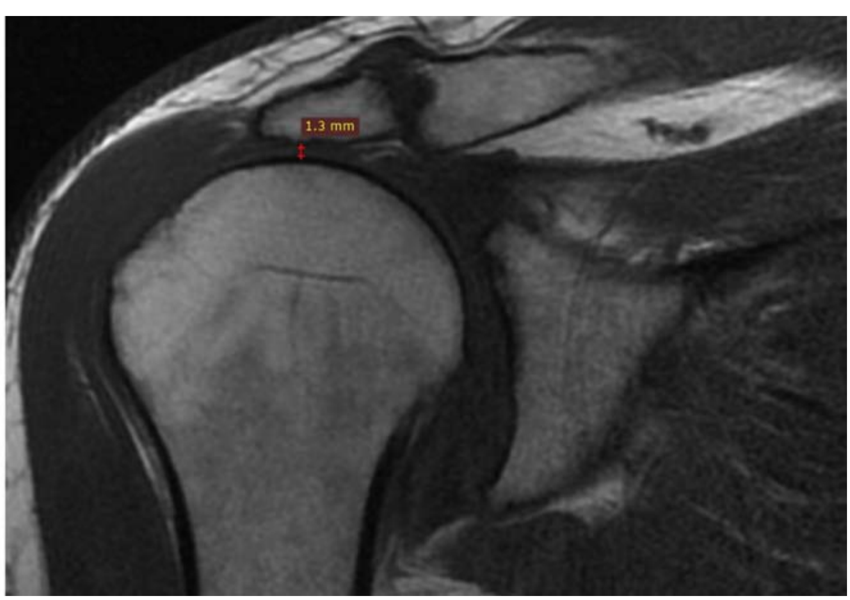

Fig. 2. Measurement of acromiohumeral distance.

Table 1
The demographic data of the groups including the mean age, gender, involved shoulder, and the related P values (F:Female, M:Male, L:Left, R:Right).

	Group 1	Group 2	Group 3	Group 4	P Value
Mean age±SD	26.44 ± 8.34	55.9 ± 8.41	52.23 ± 10.82	61.86 ± 10.06	<0.001
Sex	2 F (6.7%)	19 F (63.3%)	22 F (72.3%)	18 F (60%)	<0.001
	28 M (93.3%)	11 M (36.7%)	8 M (26.7%)	12 M (40%)	
Involved shoulder	19 L (63.3%)	5 L (16.7%)	19 L (63.3%)	7 L (23.3%)	0,008
	11 R (36.7%)	25 R (83.3%)	11 R (36.7%)	23 R (76.7%)	

Table 2
The mean SHE and AHD measurements, and the related P values of the groups.

	Group 1	Group 2	Group 3	Group 4	P Value
Mean SHE±SD	−3.2 ± 0.99	0.72 ± 0.65	−2.78 ± 0.64	1.24 ± 0.63	<0.001
Mean AHD±SD	12.89 ± 2.24	6.2 ± 1.78	12.28 ± 1.91	6.16 ± 1.52	<0.001

the AHD and SHE was evaluated by the Pearson correlation coefficient and found to be −0.184 which indicated a strong correlation. The inter-observer and intra-observer correlation of the measurements of SHE on MRI sections were excellent with intraclass correlation coefficient of 0.95 and 0.94, respectively. The same evaluation was not performed for the AHD measurements since there are numerous examples evaluating it in the literature.

Discussion

According to the current study, subscapularis tears have no significant additional contribution to the superior-inferior stability of the humeral head in the face of glenoid fossa, even though the arm was in neutral rotation while the patient lying in supine position eliminating the gravity pulling the humeral head inferiorly. The main stabiliser depressing the head inferiorly and towards the fossa glenoidalis was the superior rotator cuff. In cases with torn supraspinatus, the adding of subscapularis tear on SHE was very slight and statistically insignificant. The grade of the subscapularis tear according to the Lafosse classification system also had no effect on SHE.

In a previous study by Saupe and coworkers, AHD was measured on conventional radiographs and magnetic resonance images, and three groups were constituted regarding the AHD measurement as <8 mm, 8−10 mm, and >10 mm.[15] Although the rate of subscapularis tear in low-AHD group, 43%, was greater than it was in the others, which were 19% and 29%, respectively, and the rate of subscapularis tear in high-AHD group was greater than the intermediate one, they stated that there was no influence of location of rotator cuff tear on AHD. Moreover, the rate of supraspinatus tear in low-AHD group was 90% while it was 38% in the high-AHD group, and the rate of infraspinatus tear in those two groups were 67% and 5%, respectively. They were missing the higher rate of subscapularis tear in high-AHD group than the intermediate one. Actually, the results of their study were supporting the suggestion that the subscapularis tears do not significantly alter the superior-inferior stability of the humeral head in the face of glenoid fossa.

The individual contribution of the structures functioning in shoulder stability was investigated by several studies. Sharkey and Marder reported that all of the rotator cuff components were influencing the glenohumeral stability.[6] Harder et al reported that depression of the humeral head was achieved more effectively by infraspinatus and subscapularis than the supraspinatus, and the supraspinatus was of less importance in superior humeral stability.[7] Beer et al reported that supraspinatus and infraspinatus had no effect on superior-inferior glenohumeral stability, but the subscapularis was the major component of the rotator cuff withstanding the superior humeral excursion.

In the study of Keener and coworkers made with radiographs of patients diagnosed with ultrasonographic findings revealed that asymptomatic patients with no rotator cuff tear had a mean SHE of −0.68 ± 1.3, and symptomatic patients with full-thickness superior rotator cuff tears had a mean SHE of 0.27 ± 1.6. In the current study, the mean superior humeral migration was −3.25 ± 0.99 mm in patients with isolated Bankart lesion (Group 1, control group) and 0.72 ± 0.65 mm in those with isolated full-thickness supraspinatus tear. The difference may be due to the different imaging modalities (radiographs versus MRI), to the position of the patient during the imaging procedure (upright versus lying in supine position), and also to the position of the humeral head during the MRI procedure (neutral rotation at 30-degree of active scapular plane elevation versus neutral rotation lying beside the body at 0-degree of elevation). There are other examples of papers in the literature using radiographs of cadavers or patients with rotator cuff tear taken in upright position.[8,16,17] This study is unique which reports outcomes of superior humeral migration by using MRI of patients with rotator cuff tears confirmed arthroscopically.

It was previously reported that including only the supraspinatus muscle may not necessarily generate glenohumeral instability and that the other rotator cuff components (infraspinatus, teres minor, and subscapularis) can maintain the stability of the humeral head.[13,18] If the subscapularis tears initiated superior humeral migration and, thus, subacromial impingement syndrome, patients would present with subacromial impingement symptoms, since they, in their daily life, mostly do overhead actions rather than the combination of movements including flexion, adduction, and internal rotation which provoke pain with subscapularis tear. On the other hand, if the subscapularis tendon prevented superior humeral migration, patients with superior rotator cuff tear would not be presenting with subacromial impingement symptoms, especially over 90-degree of abduction which is described as the painful arc of the shoulder by Neer.[19]

The subscapularis muscle is thought to be active in shoulder abduction by compressing the humeral head into the glenoid cavity, especially in the abducted arm in which the most superior tendon of subscapularis force vector locates superiorly than the center of rotation moment of the humeral head.[20] This may explain why the humeral head migrates inferiorly to a more central position beyond 90-degree of abduction following the initial superior migration.[12,21,22] However, the literature has no data whether inferior humeral migration with hyperabduction diminishes or whether acromiohumeral impingement occurs with abduction over 90-degree in patients suffering from subscapularis tear.

Previous studies mostly evaluated the humeral excursion with the varying positions of humeral head in the face of glenoid.[22–25] These studies are very informative to further understand the contribution of rotator cuff components to the glenohumeral stabilization. However, these data are of no benefit in the daily practise to evaluate the shoulder. In the current study, the superior excursion of the humeral head was assessed with an imaging modality being used in the everyday practise of an orthopaedic surgeon.

In the current study, the position of humeral head in the face of glenoid fossa was only assessed in the supine position of the humeral head, which is neutral rotation and lying nearby the body. In this position, the effect of the gravity opposing the tone of the deltoid muscle is eliminated, thus provoking any potential superior humeral migration.[13,18,26] Actually, this position is important because the most annoying complaint of the patients is pain at nights.[25] However, most of the previous studies evaluated the radiographs of the patients taken standing in upright position,[2,8,17,22,23,25,27,28] but rarely in lying position.[15] In the current study, although the measurements were made on MRI sections taken when the gravity force opposing the tone of the deltoid muscle was eliminated, subscapularis tears had still no effect on superior-inferior instability of the humeral head. The measurements made on MRI sections have some advantages over those made on radiographs. The AHD is measured on the MRI section on which this distance is narrowest. That section can provide to the investigator only the humeral head and the corresponding inferior aspect of the acromion. However, all the humeral head and glenoid bone from the most posterior aspect to the most anterior aspect is included on radiographs which corrupts proper measurement of the subacromial distance, and also the humeral migration. Any change in the angle of a shoulder during the radiographic imaging may also disrupt standardisation. The AHD measurement outcomes were found to be consistent with the SHE outcomes and inversely correlated as expected.

The grade of subscapularis tears are mostly higher when combined with supraspinatus tears.[29] Supporting this data, there were no full-thickness tear in the isolated subscapularis tear group in this study while the combined subscapularis and supraspinatus tear group (group 4) had 3 (10%) full-thickness tear. However, it was somewhat lower than the rates given in the literature. Zwaag et al reported this incidence as 23.8%, Maqdes et al as 15.1%, and Heikenfeld et al as 15.1%.[30–32] The reason for a lower rate of full-thickness subscapularis tear can be the short period of time passed between the MRI and the shoulder arthroscopy procedures.

Limitations

The most important limitation of this study was the lack of MRI comparisons in different active scapular plan elevation angles. The quantity of humeral migration may change with active abduction. The lack of radiological data on the opposite shoulder is also an important limitation which makes it difficult to comment on the results by comparing to the normal side. The time period lasted between the initial symptoms and the surgery is not recorded in this study. Longer time interval may affect on the SHE measurements. An additional study group including patients with isolated superior labrum anterior posterior lesions may also be involved in the study. The preoperative symptoms and examination findings of the patients and correlation of those with the arthroscopic findings would provide additional data to the readers. Anyway, the goal of the current study was just to find out whether the subscapularis tears cause superior humeral migration or reduction in acromiohumeral distance. Another limitation of the study was the low rate of the full-thickness subscapularis tears in the group 4. This may affect the SHE outcomes of the patients. However, there was no significant difference in SHE between the patients when evaluated in terms of Lafosse subgroups of the subscapularis tears. The MR slice thickness was 3/4 mm. Three mm slices do provide enough data for measurements while 4 mm slices may decrease the efficiency of measurement technique. This may also have affected the outcomes of the measurements.

Conclusions

Subscapularis tears do not lead to superior humeral migration and subacromial impingement, but superior rotator cuff tears, and, therefore, intact subscapularis tendon does not prevent superior humeral migration and subacromial impingement caused by superior rotator cuff tear. When a superior rotator cuff tear causes superior humeral migration and subacromial impingement, any additional subscapularis tear does not increase those outcomes significantly.

References

1. Golding FC. The shoulder—the forgotten joint. *Br J Radiol*. 1962;35:149–158.
2. Weiner DS, Macnab I. Superior migration of the humeral head. A radiological aid in the diagnosis of tears of the rotator cuff. *J Bone Joint Surg Br*. 1970;52: 524–527.
3. Burkhart SS. Arthroscopic treatment of massive rotator cuff tears. Clinical results and biomechanical rationale. *Clin Orthop Relat Res*. 1991;267:45–56.
4. Lippitt S, Matsen F. Mechanisms of glenohumeral joint stability. *Clin Orthop Relat Res*. 1993;291:20–28.
5. Inman VT, Saunders JB, Abbott LC. Observations of the function of the shoulder joint. *Clin Orthop Relat Res*. 1996;330:3–12.
6. Sharkey NA, Marder RA. The rotator cuff opposes superior translation of the humeral head. *Am J Sports Med*. 1995;23:270–275.
7. Halder AM, Zhao KD, Odriscoll SW, Morrey BF, An KN. Dynamic contributions to superior shoulder stability. *J Orthop Res*. 2001;19:206–212.
8. Bezer M, Yildirim Y, Akgun U, Erol B, Guven O. Superior excursion of the humeral head: a diagnostic tool in rotator cuff tear surgery. *J Shoulder Elbow Surg*. 2005;14:375–379.
9. Lafosse L, Jost B, Reiland Y, Audebert S, Toussaint B, Gobezie R. Structural integrity and clinical outcomes after arthroscopic repair of isolated subscapularis tears. *J Bone Joint Surg Am*. 2007;89:1184–1193.
10. Sharma G, Bhandary S, Khandige G, Kabra U. MR imaging of rotator cuff tears: correlation with arthroscopy. *J Clin Diagn Res*. 2017;11:TC24–TC27.
11. Gyftopoulos S, OD J, Shah NP, Goss J, Babb J, Recht MP. Correlation of MRI with arthroscopy for the evaluation of the subscapularis tendon: a musculoskeletal division's experience. *Skeletal Radiol*. 2013;42:1269–1275.
12. Poppen NK, Walker PS. Normal and abnormal motion of the shoulder. *J Bone Joint Surg Am*. 1976;58:195–201.
13. Keener JD, Wei AS, Kim HM, Steger-May K, Yamaguchi K. Proximal humeral migration in shoulders with symptomatic and asymptomatic rotator cuff tears. *J Bone Joint Surg Am*. 2009;91:1405–1413.
14. Leschinger T, Wallraff C, Muller D, Hackenbroch M, Bovenschulte H, Siewe J. In vivo analysis of coracoid and subacromial shoulder impingement mechanism during clinical examination. *Eur J Orthop Surg Traumatol*. 2017;27:367–372.
15. Saupe N, Pfirrmann CW, Schmid MR, Jost B, Werner CM, Zanetti M. Association between rotator cuff abnormalities and reduced acromiohumeral distance. *AJR Am J Roentgenol*. 2006;187:376–382.
16. Mura N, O'Driscoll SW, Zobitz ME, et al. The effect of infraspinatus disruption on glenohumeral torque and superior migration of the humeral head: a biomechanical study. *J Shoulder Elbow Surg*. 2003;12:179–184.
17. Royer PJ, Kane EJ, Parks KE, et al. Fluoroscopic assessment of rotator cuff fatigue on glenohumeral arthrokinematics in shoulder impingement syndrome. *J Shoulder Elbow Surg*. 2009;18:968–975.
18. Steenbrink F, de Groot JH, Veeger HE, van der Helm FC, Rozing PM. Glenohumeral stability in simulated rotator cuff tears. *J Biomech*. 2009;42:1740–1745.
19. Neer 2nd CS. Anterior acromioplasty for the chronic impingement syndrome in the shoulder: a preliminary report. *J Bone Joint Surg Am*. 1972;54:41–50.
20. Escamilla RF, Yamashiro K, Paulos L, Andrews JR. Shoulder muscle activity and function in common shoulder rehabilitation exercises. *Sports Med*. 2009;39: 663–685.
21. Graichen H, Stammberger T, Bonel H, Karl-Hans E, Reiser M, Eckstein F. Glenohumeral translation during active and passive elevation of the shoulder - a 3D open-MRI study. *J Biomech*. 2000;33:609–613.
22. Chopp JN, O'Neill JM, Hurley K, Dickerson CR. Superior humeral head migration occurs after a protocol designed to fatigue the rotator cuff: a radiographic analysis. *J Shoulder Elbow Surg*. 2010;19:1137–1144.
23. Teyhen DS, Christ TR, Ballas ER, et al. Digital fluoroscopic video assessment of glenohumeral migration: static vs. Dynamic conditions. *J Biomech*. 2010;43: 1380–1385.
24. Chopp JN, Dickerson CR. Resolving the contributions of fatigue-induced migration and scapular reorientation on the subacromial space: an orthopaedic geometric simulation analysis. *Hum Mov Sci*. 2012;31:448–460.
25. Millett PJ, Giphart JE, Wilson KJ, Kagnes K, Greenspoon JA. Alterations in glenohumeral kinematics in patients with rotator cuff tears measured with Biplane fluoroscopy. *Arthroscopy*. 2016;32:446–451.

26. Buss DD, Freehill MQ, Marra G. Typical and atypical shoulder impingement syndrome: diagnosis, treatment, and pitfalls. *Instr Course Lect*. 2009;58:447–457.
27. Deutsch A, Altchek DW, Schwartz E, Otis JC, Warren RF. Radiologic measurement of superior displacement of the humeral head in the impingement syndrome. *J Shoulder Elbow Surg*. 1996;5:186–193.
28. Nishinaka N, Tsutsui H, Mihara K, et al. Determination of in vivo glenohumeral translation using fluoroscopy and shape-matching techniques. *J Shoulder Elbow Surg*. 2008;17:319–322.
29. Flury MP, John M, Goldhahn J, Schwyzer HK, Simmen BR. Rupture of the subscapularis tendon (isolated or in combination with supraspinatus tear): when is a repair indicated? *J Shoulder Elbow Surg*. 2006;15:659–664.
30. Heikenfeld R, Gigis I, Chytas A, Listringhaus R, Godolias G. Arthroscopic reconstruction of isolated subscapularis tears: clinical results and structural integrity after 24 months. *Arthroscopy*. 2012;28:1805–1811.
31. van der Zwaal P, Schuller L, Urlings TA, Coerkamp EG, van Arkel ER, van der List MP. Clinical outcome and structural integrity of all-arthroscopic repair of degenerative subscapularis tendon tears. *Knee Surg Sports Traumatol Arthrosc*. 2013;21:1620–1625.
32. Maqdes A, Abarca J, Moraiti C, et al. Does preoperative subscapularis fatty muscle infiltration really matter in anterosuperior rotator cuff tears repair outcomes? A prospective multicentric study. *Orthop Traumatol Surg Res*. 2014;100:485–488.