The effect of obesity on fatty infiltration of the rotator cuff musculature in patients without rotator cuff tears

Andrew P. Matson¹, Christopher Kim¹, Swara Bajpai²,
Cynthia L. Green³, Thomas W. Hash⁴ and Grant E. Garrigues¹

Abstract

Background: The modified Goutallier classification system describes the fatty infiltration of rotator cuff musculature (RCM) seen on magnetic resonance imaging (MRI) to assist with surgical decision-making for patients with rotator cuff tears (RCT). We describe the relationship between body mass index (BMI) and fatty infiltration in patients without RCT.

Methods: Twenty-five patients from each of four different BMI ranges ($< 25 \text{ kg/m}^2$; 25 kg/m^2 to 30 kg/m^2 ; 30 kg/m^2 to 35 kg/m^2 ; $> 35 \text{ kg/m}^2$) were randomly selected from 1088 consecutive shoulder MRI scans (T1 parasagittal series). Four physician-readers evaluated MRI scans and assigned modified Goutallier grades (0 to 4) in each of the four rotator cuff muscles, as well as two adjacent muscles.

Results: Grade distributions varied significantly based on BMI category for infraspinatus ($p = 0.001$), teres minor ($p < 0.001$), subscapularis ($p = 0.025$), teres major ($p < 0.001$) and deltoid ($p < 0.001$). Higher grades were evident with a diagnosis of diabetes mellitus in three of six muscles ($p < 0.05$), hyperlipidaemia in one muscle ($p = 0.021$) and greater patient age in three muscles ($p < 0.05$).

Conclusions: Obese and severely obese patients without RCT have more fatty infiltration seen on MRI. Patient factors (older age and diagnosis of diabetes mellitus) can be predictive of fatty infiltration in RCM. Fatty infiltration of RCM is not solely attributable to the presence of a RCT.

Keywords

fatty infiltration, Goutallier classification, magnetic resonance imaging, obesity, rotator cuff, shoulder

Date received: 22nd May 2017; accepted: 17th September 2017

Introduction

Fatty infiltration of rotator cuff musculature (RCM) is considered to be an irreversible process of architectural rearrangement related to mechanical unloading or denervation.^{1–5} It has been demonstrated that greater initial fatty infiltration of RCM is associated with inferior outcomes following rotator cuff repair.^{6–10} Thus, surgeons may quantify the extent of fatty infiltration to assist with surgical decision-making.^{11,12}

Goutallier introduced a system to classify the degree fatty infiltration of RCM seen on a computed tomography (CT) scan,^{12,13} which was later modified by Fuchs et al.¹³ to apply to magnetic resonance imaging (MRI) scan interpretation (stage 0, no fatty infiltration; stage 1, some fatty streaks; stage 2, less fat than muscle;

stage 3, as much fat as muscle; stage 4, more fat than muscle).¹³ Despite the wide acceptance of this MRI classification system for changes in RCM following a rotator cuff tear (RCT), little is known about variation in fatty infiltration of RCM among patients without

¹Department of Orthopaedic Surgery, Duke University Medical Center, USA

²School of Medicine, Duke University Medical Center, USA

³Department of Biostatistics and Bioinformatics, Duke University Medical Center, USA

⁴Department of Radiology, Duke University Medical Center, USA

Corresponding author:

Andrew P. Matson, Box 3000, Department of Orthopaedic Surgery, Duke University Medical Center, Durham, NC 27710, USA.

Email: andrew.matson@duke.edu

RCT. With greater than one-third of American adults meeting criteria for obesity and an increasing prevalence worldwide,¹⁴ it is important to understand how obesity and other patient-related variables may impact our interpretation of shoulder MRI scans.

We considered that a baseline measurement of fatty infiltration in the absence of these pathologies would help guide future studies with respect to classification and, potentially, clinical decision making. The purpose of this investigation was to describe the relationship between BMI and fatty infiltration of RCM as graded by the modification by Fuchs et al.¹³ of the Goutallier classification system in patients without RCT. We hypothesized that patients with a higher BMI would have higher Goutallier grades despite not having a RCT. We further hypothesized that additional patient factors beyond RCT chronicity and neurogenic atrophy [diabetes mellitus (DM), hyperlipidaemia (HL), smoking] might affect the fatty infiltration of the RCM. The negative implications of fatty infiltration as a result of a RCT or neurogenic atrophy are known and irreversible.^{1–5} There is conflicting evidence regarding the effect of obesity on rotator cuff repair outcomes, with some studies showing that obesity is associated with worse outcomes^{6,15–17} and one study demonstrating no difference from non-obese cohorts.¹⁸ To the best of our knowledge, no previous study has investigated the role of obesity in fatty infiltration of the rotator cuff. Future research will be needed to determine whether any potential fatty infiltration as a result of obesity has this same poor prognosis as that related to RCT or neurological pathology.

Materials and methods

Patients

Using records of Current Procedural Terminology (CPT) and International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM) codes, 1088 consecutive shoulder MRI scans obtained at a single tertiary referral institution between January 2014 to June 2015 on patients without a diagnosis of RCT were identified. CPT codes for shoulder MRI included 73 221 (without contrast), 73 222 (with contrast) and 73 223 (with and without contrast). ICD-9-CM codes used for exclusion were 727.61 (non-traumatic rupture of rotator cuff) and 726.13 (incomplete tear or rupture of the rotator cuff), as well as several rotator cuff procedure codes (23410, 23412, 23420, 24341 and 29727). Medical records and MRI reports (all by musculoskeletal-fellowship trained radiologists) were reviewed to determine which patients

qualified for the study group. Exclusion criteria included the following: ipsilateral partial or full-thickness RCT noted in MRI report, history of ipsilateral shoulder surgery, avascular necrosis, cervical spondylitis, radiculopathy or neuromuscular disease. Once the exclusion criteria were applied to the group of 1088 patients, 565 remained eligible for inclusion. Patient demographic data are shown in Table 1.

BMI (kg/m^2) groups were defined as follows: I, < 25 ; II, ≥ 25 and < 30 ; III, ≥ 30 and < 35 ; and IV, ≥ 35 , which correspond to previously defined normal weight, overweight, obese and severely obese groups, respectively.¹⁷ Obesity was defined as BMI ≥ 30 based on the definition reported by the World Health Organization.¹⁹ Twenty-five patients from each group (I to IV) were randomly selected for inclusion in the study group. Fifteen of the 100 patients were randomly selected for repeat measurements to allow for calculation of intra-observer reliability.

Data collection

Patient demographics and comorbidities were obtained from medical chart reviews performed by two researchers who were not involved with the clinical care of the patients. Height and weight values were recorded from the most proximate clinical visit to the date of the MRI.

The four physician observers included an orthopaedic surgery resident, an orthopaedic sports medicine and shoulder surgery fellow, an orthopaedic surgeon fellowship-trained in shoulder and elbow surgery, and a radiologist fellowship-trained in musculoskeletal radiology. Overall percentages reported and Kappa scores include data from all four observers. The attending orthopaedic surgeon was chosen as the primary observer because his interpretations would most accurately mimic the real-world scenario where a surgeon makes a clinical judgment regarding the degree of atrophy and its implications for the patient. The musculoskeletal radiologist was chosen for inter-observer comparison with the orthopaedic surgeon given the comparable, greater shoulder MRI scan interpretation experience level of these two observers relative to the remaining two observers.

All observers were blinded from any patient information and given the same instructions for the interpretation and grading of the 100 MRI scans that made up the study group. They were instructed to find the most lateral T1 parasagittal MRI scan on which the scapular spine is in contact with the scapular body, and to perform all measurements and grading on this image. The four rotator cuff muscles (supraspinatus, infraspinatus, subscapularis, teres minor) and three

Table 1. Patient demographics by body mass index category.

Variable	Normal	Overweight	Obese	Severely obese	Overall
Population	169	192	124	80	565
Age, mean (SD)	55.9 (9.8)	56.9 (10.4)	56.3 (10.9)	55.1 (10.7)	56.2 (10.4)
Sex, male, <i>n</i> (%)	54 (32.0)	113 (58.9)	66 (53.2)	33 (41.2)	266 (47.1)
Diabetes mellitus, <i>n</i> (%)	8 (4.7)	27 (14.1)	21 (16.9)	34 (42.5)	90 (15.9)
Hyperlipidaemia, <i>n</i> (%)	40 (23.7)	67 (34.9)	48 (38.7)	32 (40.0)	187 (33.1)
Smoking, <i>n</i> (%)	45 (26.7)	47 (24.5)	29 (23.4)	30 (37.5)	151 (26.7)
Study sample	25	25	25	25	100
Age, mean (SD)	55.2 (9.4)	55.5 (9.8)	55.4 (10.1)	55.8 (12.6)	55.5 (10.4)
Sex, male, <i>n</i> (%)	11 (44.0)	16 (64.0)	14 (56.0)	9 (36.0)	49 (49.0)
Diabetes mellitus, <i>n</i> (%)	1 (4.0)	2 (8.0)	5 (20.0)	11 (44.0)	19 (19.0)
Hyperlipidaemia, <i>n</i> (%)	6 (24.0)	10 (40.0)	11 (44.0)	8 (32.0)	35 (35.0)
Smoking, <i>n</i> (%)	6 (24.0)	3 (12.0)	4 (16.0)	9 (36.0)	22 (22.0)

Figure 1. T1 parasagittal magnetic resonance image showing the seven muscles evaluated on the most lateral view in which the scapular spine is in contact with the scapular body. Muscles: 1, supraspinatus; 2, infraspinatus; 3, teres minor; 4, subscapularis; 5, deltoid; 6, teres major; 7, trapezius.

surrounding muscles (deltoid, trapezius, and teres major) were identified (Fig. 1). Grading was performed as described by Fuchs et al.¹³ in his modification of the Goutallier classification system,²⁰ where 0=no fatty

infiltration; 1=some fatty streaks; 2=less fat than muscle; 3=as much fat as muscle; and 4=more fat than muscle (Fig. 2).

Visualization of the thin trapezius muscle at this level near its insertion was inconsistent and often incomplete and therefore this muscle was omitted from further analysis. Additionally, four MRI scans were classified as 'not gradable' as a result of either MRI cuts not going medial sufficiently (*n*=2), poor resolution (*n*=1) or invasive neoplasm obscuring musculature (*n*=1) and these were excluded from the analysis.

Statistical analysis

Data were summarized using routine descriptive statistics for both continuous (median and range as a result of non-normally distributed data) and categorical (counts with percentages) variables. Correlations of Goutallier grade (0 to 4) for each of six muscles to categorical baseline descriptors (BMI group, DM, HL and tobacco use) were performed using Fisher's exact test as a result of expected cell counts less than five, whereas correlations with continuous variables (age and BMI) was accomplished using the Kruskal–Wallis test or Pearson's correlation coefficient (*r*). Inter- and intra-observer reliability across all four physicians was assessed using the interclass correlation coefficient (ICC) with 95% confidence intervals for continuous

Figure 2. T1 parasagittal magnetic resonance images. 2a = Goutallier Grade 0; 2b = Grade 1, 2c = Grade 2.

variables and kappa scores for categorical variables. $p < 0.05$ was considered statistically significant. All analyses were performed using SAS, version 9.4 (SAS Institute Inc., Cary, NC, USA).

Results

Overall, significant fatty infiltration of rotator cuff and surrounding musculature was seen infrequently by the four observers (2287 total grades), with most grades being 0 (62%) or 1 (32%) and few grades being 2 (5%), 3 (< 1%) or 4 (< 1%). Obese patients received a score of 0 less frequently than did non-obese patients (51% versus 74%, $p < 0.001$).

Distributions for the Goutallier grades were significantly higher on average ($p < 0.05$) in larger BMI categories for four out of six of the muscles evaluated by the attending orthopaedic surgeon (Table 2). A Goutallier grade of 2 or higher was assigned in 15.4% (45/293) of muscles for obese patients (BMI III, IV) compared to 2.1% (6/281) of muscles for non-obese patients ($p < 0.001$).

Table 3 shows the distribution of Goutallier grades for the various muscles by the three comorbidities. Higher Goutallier grades were recorded for DM patients in three of six muscles, including three of four rotator cuff muscles ($p < 0.05$). In the same three muscles, patients with higher Goutallier grades were older based on the median age ($p < 0.05$). A diagnosis of HL was associated with higher Goutallier grades for the subscapularis muscle ($p = 0.021$) and tobacco use was not associated with Goutallier grades for any muscle (Table 3).

Discussion

Greater fatty infiltration of RCM has been linked to inferior outcomes following rotator cuff repair^{7–10,21,22}

and surgeons may use their assessment of RCM fatty infiltration to guide surgical decision-making.^{11,12} Goutallier's classification system^{20,23} and its subsequent modification by Fuchs et al.,¹³ serve to provide a standardized system through which the extent of fatty infiltration can be graded. We show that patient factors beyond RCT chronicity and neurogenic atrophy can also affect fatty infiltration of the RCM; specifically, obesity, DM and HL all were shown to be associated with differential grading of fatty infiltration.

It remains undetermined whether fatty infiltration associated with obesity, DM or HL carries the same poor prognosis as that as a result of chronic RCT or neurogenic atrophy. Namdari et al.¹⁸ demonstrated that early outcomes following repair of RCT were equivalent between 57 obese and 97 non-obese patients. Several recent systematic reviews or meta-analyses, however, have indicated that obesity may be a negative prognostic factor for recovery following surgery for RCT.^{6,15,16} Thus, it is important to distinguish, and it also remains to be seen, whether the inferior outcomes in obese patients are related to fatty infiltration of RCM versus other factors related to obesity outside of muscular pathophysiology, such as more difficult surgery or rehabilitation.

In the present study, we report significant variability in fatty infiltration based on BMI category in five of six muscles evaluated in patients without RCT. Additionally, associations were seen between fatty infiltration and both diabetes and patient age for the supraspinatus, infraspinatus and subscapularis muscles. To our knowledge, variation in fatty infiltration of RCM seen among patients without RCT has not been reported previously. Our data indicated that HL was associated with greater fatty infiltration in only one of six muscles (subscapularis). In an animal model of rotator cuff tears, it has been demonstrated that

Table 2. Distribution of Goutallier muscle grade by muscle and body mass index (BMI) category.

Muscle	BMI category	Sample size	Goutallier muscle grade (count)				p-value
			0	1	2	3	
Supraspinatus	I	23	16	7	0	0	0.090
	II	24	18	6	0	0	
	III	25	12	11	2	0	
	IV	24	11	13	0	0	
Infraspinatus	I	23	13	9	1	0	0.001
	II	24	13	9	2	0	
	III	25	6	15	2	2	
	IV	24	3	12	9	0	
Teres minor	I	23	18	5	0	0	0.070
	II	24	21	1	2	0	
	III	25	16	5	3	1	
	IV	24	13	8	3	0	
Subscapularis	I	23	15	8	0	0	0.025
	II	24	15	9	0	0	
	III	24	13	6	3	2	
	IV	24	7	11	5	1	
Deltoid	I	23	21	2	0	0	< 0.001
	II	23	18	5	0	0	
	III	25	19	15	1	0	
	IV	24	11	12	1	0	
Teres major	I	23	12	11	0	0	< 0.001
	II	24	18	5	1	0	
	III	25	4	14	7	0	
	IV	24	12	9	3	0	

Categorical BMI (kg/m^2) and Goutallier muscle grade. BMI categories: I, < 25; II, ≥ 25 and < 30; III, ≥ 30 and < 35; IV, ≥ 35 . p-values calculated by Fisher's exact test with significance level set at $p < 0.05$.

hypercholesterolaemia was associated with more RCM fatty infiltration following RCT and subsequent repair.²⁴ Because the present study excluded patients with RCT, we postulate that HL may become more relevant to fatty infiltration in the setting of injury-induced atrophy, as opposed to that of a healthy muscle-tendon unit.

In studies aiming to explore the effects of aging on RCM, Raz et al.^{25,26} reported that fatty infiltration increased significantly with increasing age for patients both with and without RCT. Our finding of significantly higher average age in the higher Goutallier grade categories for supraspinatus, infraspinatus and subscapularis is consistent with this result. Teres

Table 3. Distribution of Goutallier muscle grade by muscle and comorbid diagnoses.

Muscle	Variable	Category	Sample size	Goutallier muscle grade (count)				p-value
				0	1	2	3	
Supraspinatus	DM	No	76	51	24	1	0	0.013
		Yes	19	6	12	1	0	
	Tobacco	No	72	45	25	2	0	0.768
		Yes	21	12	9	0	0	
	HL	No	61	38	23	0	0	0.210
		Yes	34	19	13	2	0	
Infraspinatus	DM	No	76	33	35	7	1	0.005
		Yes	19	2	10	6	1	
	Tobacco	No	72	28	36	6	2	0.145
		Yes	21	7	8	6	0	
	HL	No	61	25	28	8	0	0.238
		Yes	34	10	17	5	2	
Teres minor	DM	No	76	54	16	6	0	0.221
		Yes	19	14	2	2	1	
	Tobacco	No	72	52	14	5	1	0.935
		Yes	21	15	4	2	0	
	HL	No	61	43	13	5	0	0.584
		Yes	34	25	5	3	1	
Subscapularis	DM	No	75	45	23	5	2	0.034
		Yes	19	5	11	2	1	
	Tobacco	No	72	40	26	4	2	0.374
		Yes	20	9	7	3	1	
	HL	No	60	35	17	7	1	0.021
		Yes	34	15	17	0	2	
Deltoid	DM	No	76	51	24	1	0	0.102
		Yes	18	8	9	1	0	
	Tobacco	No	71	49	21	1	0	0.073
		Yes	21	9	11	1	0	
	HL	No	61	37	23	1	0	0.693
		Yes	33	22	10	1	0	

(continued)

Table 3. Continued

Muscle	Variable	Category	Sample size	Goutallier muscle grade (count)				p-value
				0	1	2	3	
Teres major	DM	No	76	38	31	7	0	0.661
		Yes	19	8	8	3	0	
	Tobacco	No	72	36	27	9	0	0.236
		Yes	21	8	12	1	0	
	HL	No	61	31	23	7	0	0.666
		Yes	34	15	16	3	0	

Patient variables and Goutallier muscle grade. DM, diabetes mellitus; HL, hyperlipidaemia. p-values calculated by Fisher's exact test with significance level set at $p < 0.05$.

minor, which, in the present study, did not exhibit a pattern of fatty infiltration associated with age, was also noted by Raz et al.^{25,26} to be most resistant to aging based on histological analysis.

On a molecular level, important signalling pathways involved with rotator cuff muscle homeostasis include protein kinase B (Akt) and mammalian target of rapamycin (mTOR).²⁷ Alterations of these pathways result in activation of genes that enhance protein breakdown and activate adipogenic changes mediated by sterol regulating element-binding protein 1 (SREBP1) and fibrotic changes mediated by transforming growth factor beta (TGF- β).²⁸ This in turn propagates the differentiation of pre-adipocytes into adipocytes,²⁹ mainly through the action of peroxisome proliferator-activated receptor gamma (PPAR γ).³⁰ PPAR γ has a well-established link to obesity and obesity-related disorders;^{31,32} thus it is possible that both fatty infiltration from chronic RCT and obesity without RCT may act through the same pathway. If true, this would imply a poor prognosis for all patients with fatty atrophy and a RCT, even if the fatty atrophy is secondary to obesity and not tear chronicity or neurogenic change.

Although the Goutallier classification system was initially designed for the interpretation of CT imaging,^{20,23} it has been shown to offer more consistent interpretation among observers for use with MRI scan interpretation.^{13,33} We report excellent intra- and interobserver agreement as measured by ICC values of 0.98 and 0.78, respectively, between our orthopaedic shoulder surgeon and musculoskeletal radiologist. Oh et al.³³ reported ICC values for inter- and intraobserver agreement of 0.60 to 0.72 and 0.29 to 0.80, respectively among five observers for Goutallier grades in magnetic resonance arthrography of patients with RCT. Our

high level of agreement may be related to our attempt to provide specific, uniform instructions for Goutallier grading among our observers, as well as our inclusion of only those observers (2/4) who had completed their specialty training to realistically simulate a diagnostic clinical scenario. Also, in contrast to Oh et al.,³³ our study group consisted of only patients without RCT which may introduce less baseline variability in the data compared to a group with chronic, full-thickness tears.

Kappa values ranged from 0.41 to 0.61, indicating moderate to substantial agreement among the four observers in the present study.³⁴ Fuchs et al.¹³ reported kappa values of 0.82 to 0.93 for inter-observer agreement of MRI Goutallier classification between two readers. However, Slabaugh et al.³⁵ reported kappa values of 0.43 and 0.56 for inter- and intra-observer agreement, respectively, in a group of 30 experienced shoulder surgeons. Schiefer et al.³⁶ demonstrated that inter-observer agreement was higher among three orthopaedic surgeons (kappa scores 0.72 to 0.82) than among three radiologists (kappa scores 0.61 to 0.66). Our inclusion of the attending orthopaedic surgeon as the primary observer for statistical calculations on Goutallier grades was based on maximizing clinical relevance and also represents the most reproducible observations based on the previous literature.³⁶

The present study has several limitations that should be considered when interpreting the results. First, no patients included in the study group had evidence of RCT. Given that the Goutallier classification is used exclusively in the evaluation of RCM in patients with RCT, this may raise concern about the external validity of the present study. We consider it important to establish an understanding of the degree of fatty infiltration present at baseline in the absence of RCT and thus it

was our primary goal to investigate this variability as it relates to BMI. Second, inherent to the retrospective design of this study is the possibility for differential misclassification and selection bias. To limit the effect of bias on our results, we created a standardized method of assessing a patient's qualification for the study group, then randomly selected patients for inclusion in each of the four BMI categories and, finally, blinded observers to all patient information. Third, with approximately 95% of grades assigned being either 0 or 1, the small degree of variability seen in the present study may fall short of the variability seen in RCM of patients with RCT. However, from the significant differences seen among narrow distributions of Goutallier grades in patients without RCT, we propose that these trends can be extrapolated to patients with RCT and higher Goutallier grade variability. We see no reason to assume that patients with fatty infiltration secondary to obesity who develop a RCT would then have reversal of this infiltration; the present study was conducted on patients with intact RCM to isolate this effect. Therefore, we hypothesize that obese patients with RCT will have some element of their fatty infiltration secondary to their obesity. Finally, we did not incorporate any element of physical examination into our analysis even though clinical evaluation of RCT normally includes both physical examination, as well as interpretation of MRI. Although it is possible that variation in fatty infiltration seen in the present study may have no association with strength, previous research has demonstrated that strength is inversely related with fatty infiltration in the setting of RCT.⁴

Conclusions

The findings of the present study suggest that fatty infiltration of RCM should not be solely attributed to RCT pathology. Among patients without RCT, obese patients have greater fatty muscle infiltration seen on MRI. Additionally, other patient factors, including older age and DM, can be predictive of higher Goutallier grades. Whether fatty infiltration based on high BMI has the same dire prognostic implications as fatty infiltration based on rotator cuff tear chronicity or neurogenic atrophy remains to be seen, although this association may have implications for grading for both clinical treatment and research because the modified Goutallier classification cannot be applied in the same way to obese patients.

Acknowledgements

We would like to acknowledge Donald T. Kirkendall, ELS, a contracted medical editor, for his assistance in preparing the manuscript submitted for publication. This project was

presented at the North Carolina Orthopaedic Association Annual meeting in Pinehurst, NC, on 8 October 2016.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

Ethical review and patient consent

This study protocol was approved by the Duke University Institutional Review Board under Protocol Number Pro00066068 prior to beginning the data collection.

References

1. Beeler S, Ek ET and Gerber C. A comparative analysis of fatty infiltration and muscle atrophy in patients with chronic rotator cuff tears and suprascapular neuropathy. *J Shoulder Elbow Surg* 2013; 22: 1537–1546.
2. Fuchs B, Gilbert MK, Hodler J and Gerber C. Clinical and structural results of open repair of an isolated one-tendon tear of the rotator cuff. *J Bone Joint Surg Am* 2006; 88: 309–316.
3. Gerber C, Fuchs B and Hodler J. The results of repair of massive tears of the rotator cuff. *J Bone Joint Surg Am* 2000; 82: 505–515.
4. Gerber C, Schneeberger AG, Hoppeler H and Meyer DC. Correlation of atrophy and fatty infiltration on strength and integrity of rotator cuff repairs: a study in thirteen patients. *J Shoulder Elbow Surg* 2007; 16: 691–696.
5. Meyer DC, Hoppeler H, von Rechenberg B and Gerber C. A pathomechanical concept explains muscle loss and fatty muscular changes following surgical tendon release. *J Orthop Res* 2004; 22: 1004–1007.
6. Fermont AJ, Wolterbeek N, Wessel RN, Baeyens JP and de Bie RA. Prognostic factors for recovery after arthroscopic rotator cuff repair: a prognostic study. *J Shoulder Elbow Surg* 2015; 24: 1249–1256.
7. Gasbarro G, Ye J, Newsome H, et al. Morphologic risk factors in predicting symptomatic structural failure of arthroscopic rotator cuff repairs: tear size, location, and atrophy matter. *Arthroscopy* 2016; 32: 1947–1952.
8. Gladstone JN, Bishop JY, Lo IK and Flatow EL. Fatty infiltration and atrophy of the rotator cuff do not improve after rotator cuff repair and correlate with poor functional outcome. *Am J Sports Med* 2007; 35: 719–728.
9. Goutallier D, Postel JM, Gleyze P, Leguilloux P and Van Driessche S. Influence of cuff muscle fatty degeneration on anatomic and functional outcomes after simple suture of full-thickness tears. *J Shoulder Elbow Surg* 2003; 12: 550–554.
10. Warner JJ, Higgins L, Parsons IM and Dowdy P. Diagnosis and treatment of anterosuperior rotator cuff tears. *J Shoulder Elbow Surg* 2001; 10: 37–46.

11. Melis B, DeFranco MJ, Chuinard C and Walch G. Natural history of fatty infiltration and atrophy of the supraspinatus muscle in rotator cuff tears. *Clin Orthop Relat Res* 2010; 468: 1498–1505.
12. Melis B, Wall B and Walch G. Natural history of infraspinatus fatty infiltration in rotator cuff tears. *J Shoulder Elbow Surg* 2010; 19: 757–763.
13. Fuchs B, Weishaupt D, Zanetti M, Hodler J and Gerber C. Fatty degeneration of the muscles of the rotator cuff: assessment by computed tomography versus magnetic resonance imaging. *J Shoulder Elbow Surg* 1999; 8: 599–605.
14. Ogden CL, Carroll MD and Flegal KM. Prevalence of obesity in the United States. *JAMA* 2014; 312: 189–190.
15. Fermont AJ, Wolterbeek N, Wessel RN, Baeyens JP and de Bie RA. Prognostic factors for successful recovery after arthroscopic rotator cuff repair: a systematic literature review. *J Orthop Sports Phys Ther* 2014; 44: 153–163.
16. Kluczynski MA, Bisson LJ and Marzo JM. Does body mass index affect outcomes of ambulatory knee and shoulder surgery? *Arthroscopy* 2014; 30: 856–865.
17. Warrender WJ, Brown OL and Abboud JA. Outcomes of arthroscopic rotator cuff repairs in obese patients. *J Shoulder Elbow Surg* 2011; 20: 961–967.
18. Namdari S, Baldwin K, Glaser D and Green A. Does obesity affect early outcome of rotator cuff repair? *J Shoulder Elbow Surg* 2010; 19: 1250–1255.
19. World Health Organization. Obesity and overweight fact sheet 2015. <http://www.who.int/mediacentre/factsheets/fs311/en> (accessed 18 August 2016).
20. Goutallier D, Postel JM, Bernageau J, Lavau L and Voisin MC. Fatty muscle degeneration in cuff ruptures. Pre- and postoperative evaluation by CT scan. *Clin Orthop Relat Res* 1994; 304: 78–83.
21. Goutallier D, Postel JM, Lavau L and Bernageau J. [Impact of fatty degeneration of the supraspinatus and infraspinatus muscles on the prognosis of surgical repair of the rotator cuff]. *Rev Chir Orthop Reparatrice Appar Mot* 1999; 85: 668–676.
22. Williams MD, Ladermann A, Melis B, Barthelemy R and Walch G. Fatty infiltration of the supraspinatus: a reliability study. *J Shoulder Elbow Surg* 2009; 18: 581–587.
23. Goutallier D, Bernageau J, Patte D. Assessment of the trophicity of the muscles of the ruptured rotator cuff by CT scan. In: Post M, Morrey BF and Hawkins RJ, eds. *Surgery of the shoulder*. St Louis, Missouri: Mosby, 1990:11–13.
24. Chung SW, Park H, Kwon J, Choe GY, Kim SH and Oh JH. Effect of hypercholesterolemia on fatty infiltration and quality of tendon-to-bone healing in a rabbit model of a chronic rotator cuff tear: electrophysiological, biomechanical, and histological analyses. *Am J Sports Med* 2016; 44: 1153–1164.
25. Raz Y, Henseler JF, Kolk A, et al. Patterns of age-associated degeneration differ in shoulder muscles. *Front Aging Neurosci* 2015; doi:10.3389/fnagi.2015.00236).
26. Raz Y, Henseler JF, Kolk A, et al. Molecular signatures of age-associated chronic degeneration of shoulder muscles. *Oncotarget* 2016; 7: 8513–8523.
27. Thankam FG, Dilisio MF and Agrawal DK. Immunobiological factors aggravating the fatty infiltration on tendons and muscles in rotator cuff lesions. *Mol Cell Biochem* 2016; 417: 17–33.
28. Luan T, Liu X, Easley JT, Ravishankar B, Puttlitz C and Feeley BT. Muscle atrophy and fatty infiltration after an acute rotator cuff repair in a sheep model. *Muscles Ligaments Tendons J* 2015; 5: 106–112.
29. Liu X, Joshi SK, Samagh SP, et al. Evaluation of Akt/mTOR activity in muscle atrophy after rotator cuff tears in a rat model. *J Orthop Res* 2012; 30: 1440–1446.
30. Joshi SK, Liu X, Samagh SP, et al. mTOR regulates fatty infiltration through SREBP-1 and PPARgamma after a combined massive rotator cuff tear and suprascapular nerve injury in rats. *J Orthop Res* 2013; 31: 724–730.
31. Evans RM, Barish GD and Wang YX. PPARs and the complex journey to obesity. *Nat Med* 2004; 10: 355–361.
32. Vidal-Puig A, Jimenez-Linan M, Lowell BB, et al. Regulation of PPAR gamma gene expression by nutrition and obesity in rodents. *J Clin Invest* 1996; 97: 2553–2561.
33. Oh JH, Kim SH, Choi JA, Kim Y and Oh CH. Reliability of the grading system for fatty degeneration of rotator cuff muscles. *Clin Orthop Relat Res* 2010; 468: 1558–1564.
34. Landis JR and Koch GG. An application of hierarchical kappa-type statistics in the assessment of majority agreement among multiple observers. *Biometrics* 1977; 33: 363–374.
35. Slabaugh MA, Friel NA, Karas V, Romeo AA, Verma NN and Cole BJ. Interobserver and intraobserver reliability of the Goutallier classification using magnetic resonance imaging: proposal of a simplified classification system to increase reliability. *Am J Sports Med* 2012; 40: 1728–1734.
36. Schiefer M, Mendonca R, Magnanini MM, et al. Intraobserver and interobserver agreement of Goutallier classification applied to magnetic resonance images. *J Shoulder Elbow Surg* 2015; 24: 1314–1321.