Functional implications of structural “anomalies” in shoulder pain

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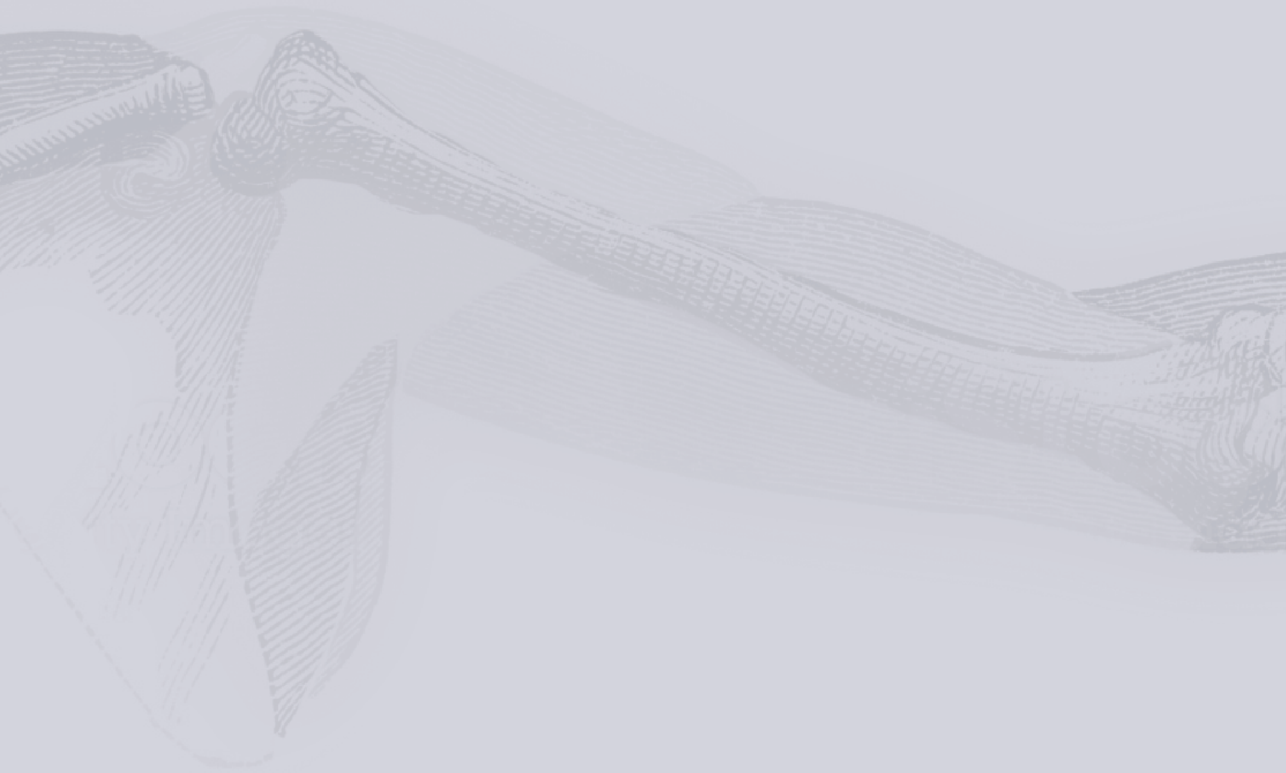

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The presence of a rotator cuff tear interferes with age-dependent muscle atrophy of intact shoulder muscles

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ABSTRACT

Background: Rotator cuff muscle atrophy is frequently studied, but it is unknown whether redistribution of mechanical load in the presence of a rotator cuff tear influence muscle atrophy that is observed in patients. We hypothesised that in the presence of a supraspinatus tear, redistribution of mechanical load towards teres minor and deltoid slows down atrophy of these muscles over time.

Methods: In this retrospective observational study of 129 patients, we measured the cross-sectional surface-areas on MRI of shoulder muscles in an intact rotator cuff (n=92) and in a supraspinatus-tear group (n=37) with a mean follow-up of 3 ± 1.8 years. Mixed models were applied to evaluate changes in surface-area of the rotator cuff and deltoid with adjustments for age, sex and follow-up time.

Results: In patients with an intact rotator cuff, the mean surface-area of the teres minor decreased 6mm^2/year (95% confidence interval 0.7 – 11.1, P = 0.026) and the mean deltoid surface-area decreased 75mm^2/year (95% confidence interval 24.5 – 124.8, P = 0.004). The presence of a rotator cuff tear was associated with less reduction of teres minor and deltoid surface-area in patients <50 years, with an effect of a tear of 22mm^2/year (95% confidence interval 1.7 – 41.7, P = 0.034) and 250mm^2/year (95% confidence interval 75.8 – 424.3, P = 0.006), respectively.

Conclusions: Whereas the surface-area of teres minor and deltoid decrease over time in patient with an intact rotator cuff, the decline in surface-area of these muscles was substantially less in the presence of a rotator cuff tear. Our findings indicate that atrophy may be reduced if an increase in mechanical load is exerted onto the muscle.

INTRODUCTION

Each year up to 30% of the population reports pain, functional deficits and deprived activities of daily living due to shoulder complaints.[25, 28] These complaints are predominantly attributed to conditions affecting rotator cuff (RC) function, including RC tears.[33, 35] Morphologic changes including shoulder muscle size and fatty infiltration have been demonstrated to be an important predictor for long-term shoulder dysfunction during activities of daily living of these patients, which highlights the need for further investigations in determinants affecting muscle size.[11, 29]

Shoulder muscles undergo a continuous decline in muscle mass (i.e. atrophy) as part of an ongoing ageing process throughout adulthood akin to other skeletal muscles.[1, 16, 23, 24, 37] An increase in mechanical loading has been shown to cause changes in muscle architecture and may attenuate this age-associated decline in muscle mass.[6, 9, 23, 27] For that matter, a redistribution of forces in the shoulder suffering from a supraspinatus-tear enlarges mechanical loads of the remaining muscles, which may reduce the usual age-associated decline in muscle mass. The mechanical compensatory increase in muscle activity has been demonstrated in the teres minor and deltoid muscles.[2, 4, 19, 22, 31] Therefore, we postulate that age-associated atrophy of these intact muscles is decelerated in the presence of an RC tear. Current knowledge about atrophic changes that occur in the teres minor and deltoid muscle in the intact RC is based on cross-sectional studies, whereas cohort studies exist for RC tear patients.[1, 17, 22, 24, 26, 37] Consequently, it is unknown whether teres minor or deltoid atrophy can really decelerate or even inverts to muscle hypertrophy in the presence of an RC tear compared to the intact RC, hence an observational cohort study is needed.

The aim of this longitudinal study was to quantify muscle atrophy in two groups of patients: 1) a group with an intact RC and 2) a group with a torn rotator cuff. Data were used to investigate whether atrophy of the teres minor and deltoid muscle in patients with a rotator cuff tear follow a different pattern compared to patients with an intact RC. In agreement with our biomechanical concept of redistribution of forces in RC tears, we hypothesised that the presence of an RC tear is associated with a lower reduction of teres minor and deltoid muscle CSA than in patients with an intact RC.

MATERIALS AND METHODS

Participants

In this retrospective observational cohort study, we evaluated all consecutive patients, who had magnetic resonance imaging (MRI) of the shoulder between January 1, 2005 and March 1, 2014 at the Haaglanden Medical Center, The Hague, the Netherlands. MRI was the principal diagnostic modality to evaluate the RC during the period. Patients with shoulder related complaints and/or functional limitations underwent MRI scanning when intra-articular pathologies (such as an RC tear, labral tear or ligamentous injury) was suspected after medical history and physical evaluation by an orthopaedic trainee or orthopaedic surgeon. Only patients with two MRI scans of the same shoulder with an interval of at least one year between both MRIs were included. Exclusion criteria were: age <30 years, surgical intervention of the RC, MRI artifacts that hampered quantification measurements of muscle size, full-thickness subscapularis tear, fracture, rheumatoid arthritis, muscle dystrophy, tumour and osteonecrosis (Figure 1). In this period, the shoulder of 200 patients had been scanned twice with MRI. Of this group, 129 patients qualified for this study, numbers and reasons for exclusion are presented in Figure 1. The medical ethical committee "Zuidwest Holland" approved this study (14-027) and provided a waiver of the requirement of informed consent.

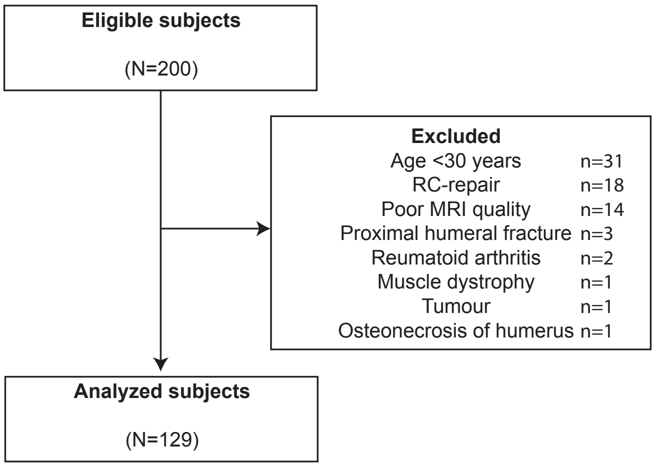

Figure 1. A total of 129 MRIs of the shoulder qualified for evaluation of changes in cross-sectional surface area and were analysed twice. Abbreviations: MRI, magnetic resonance imaging; N, number; RC, rotator cuff.

MR imaging procedure

MRI scans were performed with a dedicated shoulder coil and turbo spin-echo sequences on Avanto or Symphony 1.5T MRI units (Siemens AG, Erlangen, Germany). T1 weighted images (TR/TE 500-600ms /11-15ms, slice thickness 4mm, inter-slice gap 1mm, field of view of 15cm) or T2 weighted images with fat suppression (TR/TE 2240ms/90ms, slice thickness 4mm, inter-slice gap 0.4mm) were used for our systematic evaluation of muscle size [10, 17, 32, 37]. Images were visualized on a picture archiving and communication system and analysed with Sectra IDS5 (Sectra Medical Systems AB, Linköping, Sweden).

Muscle size of the RC and deltoid muscles were quantified by measuring the cross-sectional surface area (CSA) on the MRI of the first visit (baseline) and the second follow-up visit using pre-specified methodology.[10, 14, 17, 26, 32, 37] Good reliability of our methods has been described.[14] In brief, the CSA of supraspinatus, infraspinatus, teres minor and subscapularis were measured in the parasagittal plane on the most lateral slice where the anatomical glenoid neck and base of the coracoid process were present. The CSA of the deltoid muscle was measured in the transverse plane with the humeral head at its widest point. The widest radius of the humeral head was determined by fitting circles onto the humeral head at various slices to calculate its relative size with respect to the population average. Since differences in anthropometrics may exist, the use of normalised CSA (mm^2) has been suggested.[26] We also present the normalised CSA calculated by multiplying the patients' raw CSA and their relative humeral head size. Since the teres minor and deltoid are assumed to experience enlarged mechanical loads in the presence of an RC tear and generally do not tear, we focused on the changes in CSA of these muscles.[2, 4, 19, 22, 31]

Each RC muscle was scored as intact or as torn at both visits (i.e. baseline and follow-up). RC tear geometry was determined by measuring the size of the tear in the sagittal and coronal plane.[5, 14, 34] The maximal sagittal and coronal tear dimension were measured by drawing a straight line in the anterior-to-posterior configuration (i.e. tear width) and by drawing a straight line from the supraspinatus footprint to the medial edge of the tear (i.e. tear length). Using tear dimensions, a massive RC tear was defined as a long and wide tear (both >20mm).[5]

Statistical analyses

Patients were categorised into two groups for plotting our data: the first group (i.e. controls, n=92) had an intact RC at follow-up and the second group (n=37) had an RC tear limited to the supraspinatus or in combination with the infraspinatus tendon at both baseline and follow-up. To obtain sufficient numbers in all groups, we did not further categorise RC tear patients although tear dimension may act differently on shoulder biomechanics. Baseline characteristics were compared using an independent Student's t-test or Pearson chi-square test when appropriate.

A linear mixed model analysis was used to compare the change in normalised CSA between the intact RC and torn RC group per year for each shoulder muscle and its 95% confidence interval (CI). This mixed model analysis enables to deal with the development of an RC tear over time and the covariance of errors in study designs with repeated measurements. A random intercept in combination with an autoregressive structure of order one for the within patient residuals was used to model covariance. The dependent variable was the normalised CSA, measured at baseline and at follow-up. Presence of an RC tear on the MRI-scan (i.e. yes/no), baseline age, sex (male/female), follow-up time (years, interval between baseline and follow-up), and the interaction between the presence of an RC tear and follow-up time in years were included as fixed effects. The interaction term was used to describe the difference in morphologic structural changes over time between patients with and without an RC tear. Because both groups differed in mean age and changes in muscle mass could be different at various decades of life, we performed additional subgroup analyses in patients ≤50 years of age and patients aged >50 years. Subgroup division was arbitrarily set at 50 years to maintain sufficient numbers in each stratum. Statistical analyses were conducted using IBM SPSS statistics for Windows (version 20.0, IBM Corp, 2011, Armonk, New York, USA). A two-sided P value of <0.05 was considered statistically significant.

RESULTS

Demographics

Baseline characteristics of the 129 patients with a baseline and follow-up MRI are described in Table 1. At baseline, 105 patients had an intact RC [i.e. subacromial pain syndrome (n=67), acromioclavicular osteoarthritis (n=16), labral defect (n=15), or ligamentous injury (n=7)]. Twenty-four patients had an RC tear at baseline (i.e. 16 isolated supraspinatus tears and 8 massive posterosuperior RC tears). At follow-up, the RC was still intact in 92 out of 105 subjects (88%). Seven patients had developed an isolated supraspinatus tear, four patients with a supraspinatus tear developed a massive RC tear and six patients with an intact RC at baseline had developed a massive RC tear at follow-up. In total, 37 patients had an RC tear at follow-up (i.e. 19 isolated supraspinatus tears and 18 massive posterosuperior RC tears). Mean follow-up was 3 years in both groups. Mean age in the RC tear group was 11 years (95%CI 7.4 – 14.5, P < 0 .001) higher than the intact RC group.

Table 1. Baseline characteristics

	Intact RC	**RC tear**
	N = 92	N = 37
Age, mean ± SD, yrs	46 ± 9.5	57 ± 8.5
Follow-up, mean ± SD, yrs	3 ± 1.8	3 ± 1.9
Male sex, n (%)	48 (52%)	26 (70%)
Left side studied, n (%)	46 (50%)	16 (43%)
Coronal tear size, mean ± SD, mm	N/A	27 ± 13.1
Sagittal tear size, mean ± SD, mm	N/A	23 ± 12.6

Abbreviations: RC, rotator cuff; N, number; SD, standard deviation; yrs, years; mm, millimetre; N/A, not applicable.

Changes in cross-sectional surface area in the shoulder

Raw data with unadjusted mean CSA of each shoulder muscle is presented in Table 2. In the intact RC group, the mean decrease in size of the teres minor, subscapularis and deltoid was 23mm^2 (95%CI 0.4 – 46.2), 57mm^2 (95%CI 13.0 – 101.5) and 241mm^2 (95%CI 88.2 – 393.4), respectively (Supplement 1). Raw data are also provided for the RC tear group.

Table 2. Mean CSA for individual shoulder muscles

		n	**Intact RC**	*n*	**RC tears**
Supraspinatus CSA, mean ± SD, mm^2					
	Baseline	*92*	418 (102)	*36*	362 (117)
	Follow-up	*92*	414 (108)	*37*	322 (117)
Infraspinatus CSA, mean ± SD, mm^2					
	Baseline	*92*	700 (180)	*37*	659 (232)
	Follow-up	*92*	718 (209)	*37*	652 (247)
Teres minor CSA, mean ± SD, mm^2					
	Baseline	*92*	468 (123)	*37*	450 (139)
	Follow-up	*92*	444 (106)	*37*	462 (169)
Subscapularis CSA, mean ± SD, mm^2					
	Baseline	*92*	668 (243)	*37*	597 (262)
	Follow-up	*90*	608 (241)	*37*	602 (263)
Deltoid CSA, mean ± SD, mm^2					
	Baseline	*79*	3779 (979)	*31*	3995 (1058)
	Follow-up	*87*	3620 (964)	*34*	3864 (880)

Mean CSA on MRI for shoulder muscles at baseline and follow-up stratified on the absence (i.e. intact RC group) or presence (RC tear group) of an RC tear at follow-up at 3 years' follow-up. Abbreviations: RC, rotator cuff; CSA, cross-sectional surface area; mm, millimetre; SD, standard deviation.

Does cross-sectional surface area change differently in patient with a rotator cuff tear versus those with an intact RC?

When incorporating baseline age, sex, differences in interval between two consecutive MRIs and the development of an RC tear over time into our mixed model (i.e. adjusting for these fixed factors), the CSA of the teres minor decreased with 6 mm^2/year in the intact RC group (Table 3). A 10 mm^2/year increase in CSA of the teres minor was found in the RC tear group. The effect of an RC tear was a reduced decline of teres minor CSA with 15mm^2/year (95%CI 3.8 – 27.0, P = 0.010 or 3% of its baseline size), resulting in a net yearly growth. We did not find a significant association between an RC tear and the CSA of the deltoid muscle without age stratification. In the subscapularis muscle, the annual decline in CSA was decreased in the presence of an RC tear with 34 mm^2/year (6% of the baseline size) compared to the decline in the control group (Supplement 2).

Subgroup analyses with age stratification showed that in patients younger than 50 years (n=80) atrophy of the teres minor and deltoid follows a different pattern in the intact compared to the torn RC group (Table 3, Figure 2). While there was profound muscle atrophy of the teres minor and deltoid muscle in the young intact RC group, the decline in CSA in younger patients with an RC tear slowed down, with 22mm^2/year (95%CI 1.7 – 41.7, P = 0.034) and 250mm^2/year (95%CI 75.8 – 424.3, P = 0.006) on total CSA in the presence of an RC tear (Table 3).

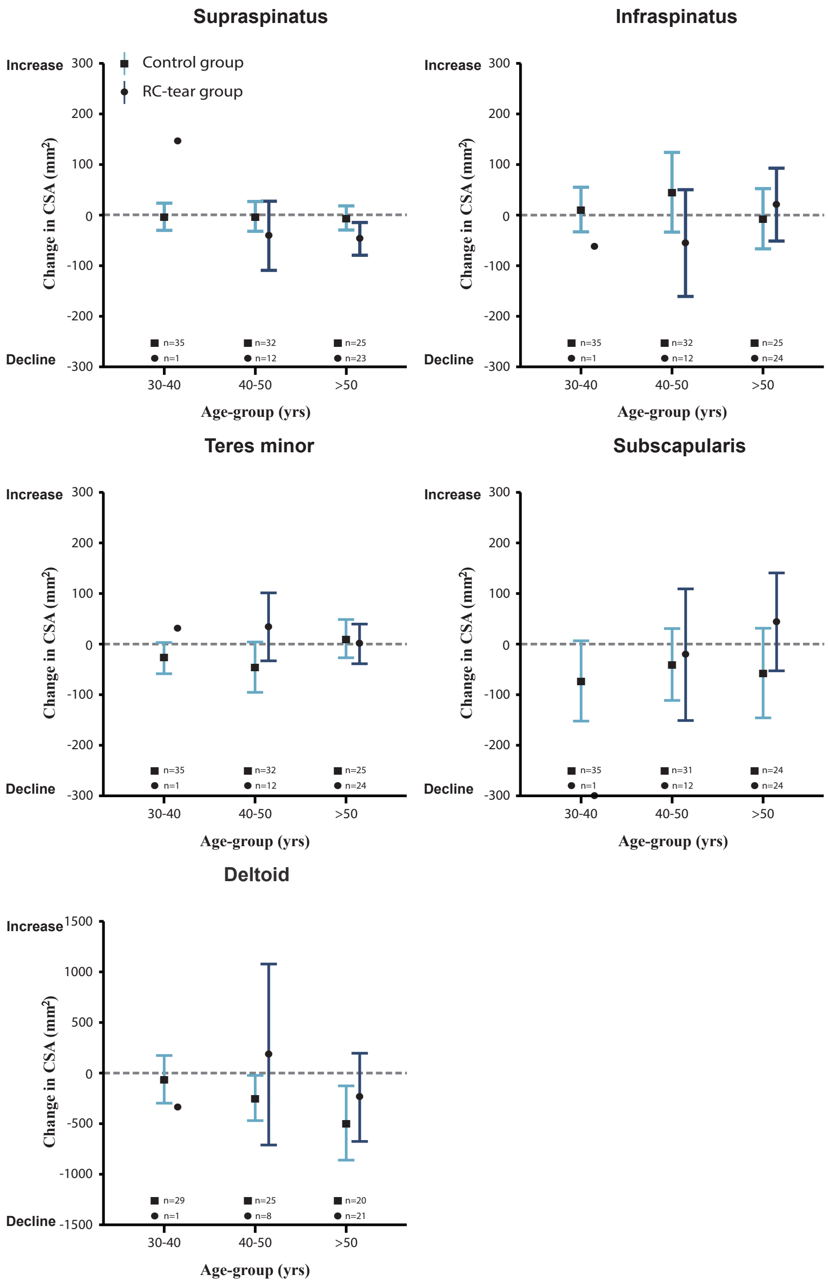

Figure 2. Change in cross-sectional muscle surface area per age category. Mean total change in CSA and 95% confidence interval between MRI measurements for patients with an intact RC (▪, n = 92) and a supraspinatus tear (●, n = 37) at three age categories. Controls and the RC tear group are categorised according to the diagnosis at follow-up. Numbers described the number of available data and may represent missing data. Abbreviations: RC, rotator cuff; CSA, Cross-section surface area; mm, millimetre; yrs., years.

Table 3. Changes in CSA per year of the teres minor and deltoid muscle

	Teres minor CSA (mm^2/yr)		Deltoid CSA (mm^2/yr)	
	Mean change (95% CI)	*p value*	Mean change (95% CI)	*p value*
≤ 50 years				
Model for intact RC[a]	-9 (-16.1 – -2.7)	0.007*	-49 (-104.5 – 6.1)	0.080
Model for RC tear[a]	12 (-6.4 – 31.1)	0.196	201 (36.0 – 365.7)	0.018*
Fixed effect: RC tear	22 (1.7 – 41.7)	0.034*	250 (75.8 – 424.3)	0.006*
> 50 years				
Model for intact RC[a]	1 (-6.5 – 9.4)	0.718	-123 (-214.9 – -23.0)	0.010*
Model for RC tear[a]	8 (-3.3 – 19.7)	0.159	-81 (-200.3 – 39.2)	0.184
Fixed effect: RC tear	7 (-7.5 – 21.0)	0.346	42 (-109.3 – 195.1)	0.575
All patients				
Model for intact RC[a]	-6 (-11.1 – -0.7)	0.026*	-75 (-124.8 – -24.5)	0.004*
Model for RC tear[a]	10 (-0.7 – 19.7)	0.068	-19 (-113.5 – 76.4)	0.700
Fixed effect: RC tear	15 (3.8 – 27.0)	0.010*	56 (-51.8 – 164.0)	0.306

A decline in CSA is indicated with a minus sign (-). Mixed model analysis enables to deal with the development of an RC tear over time and to adjust for age, sex and differences in interval between two consecutive MRIs. Abbreviations: CSA, cross-sectional surface area; mm^2/yr, square millimetre per year, year CI, confidence interval; RC, rotator cuff.

* Statistically significant difference at $P < 0.05$

† Mixed model with fixed effects: presence of an RC tear on MRI (yes/no), age (years), sex (male/female), follow-up time in years, presence of an RC tear x follow-up time in years, and a random intercept for subjects.

DISCUSSION

This longitudinal study showed that progressive muscle atrophy of teres minor and deltoid was present in shoulders with an intact RC, but this decline in CSA was unnoticed in case of an RC tear. In patients with a supraspinatus tear, the decline in CSA of non-torn teres minor and deltoid muscle slowed down and an increase in mean muscle CSA was found at follow-up, which was most prominent in the stratified 50 years and younger group.

Our findings in patients with an RC tear are in agreement with cross-sectional data from prior studies.[1, 17, 24, 26, 37] Nevertheless, prior cross-sectional studies were not designed to analyse muscular changes within a single patient over time. Muscular changes in a single patient have been investigated in patients with a supraspinatus tear that underwent surgical repair, with conflicting effects on muscle atrophy.[8, 11, 12, 18, 21] While some authors claimed that atrophic changes are irreversible in RC tears, others claimed reversibility of atrophy after successful tendon reinsertion.[8, 11, 12, 18, 21] The latter suggests that restored mechanical load may induce muscle hypertrophy or growth and may interfere with age-dominated atrophy. Mechanical load has been shown to prompt changes in muscular architecture, even in the elderly.[6, 9, 23, 27] On the contrary, age-associated muscle atrophy should not be excluded as a factor contributing to the development of RC tears, since contractile tissue of the muscle has an undeniable effect on alignment of fibres and function of the tendon.[6, 23] Our data, with an age-associated decline in CSA in intact muscles, suggests that atrophic changes in RC tear patients (partly) reflect an ageing phenomenon. Chung et al. underlined this importance of age-associated atrophy by demonstrating a lower sarcopenic index in patients with an RC tear than controls.[3]

A reduced decline of teres minor CSA in the presence of an RC tear is in line with the results from several cross-sectional studies.[17, 22]. They found hypertrophic changes in the teres minor of patients suffering from an RC tear.[17, 22] Hypertrophy of the teres minor has also been observed after detachment of the RC in rats.[15] A supraspinatus tear causes a shift of glenohumeral forces towards the remaining teres minor, subscapularis and deltoid muscle.[13, 19, 31] It has been demonstrated that the forces generated by the teres minor are crucial to maintain a stable fulcrum for shoulder motion, especially when the infraspinatus muscle is unable to provide a sufficient amount of glenohumeral torque.[13, 19, 31] Like the teres minor, the deltoid muscle compensates for lost torques in RC tears to preserve sufficient torques for elevation of the arm.[7, 13, 20, 31] Mechanical loading of muscles may induce muscle growth resulting in an increase in CSA of the teres minor within RC tear patients, especially in younger patients as indicated by our results in patients < 50 years of age, due to an age-associated capacity for muscle growth.

RC atrophy is an essential predictor for proximal migration of the humerus and shoulder function in RC tears.[11, 12, 14] The increase in CSA of the teres minor and deltoid size in RC tears suggests that altered mechanical load in the shoulder with a supraspinatus tear is counteracted by natural mechanical compensation. The biomechanical importance of the teres minor is also stressed by the superior functional results in reversed total shoulder arthroplasty in patients with an unaffected teres minor.[2, 4, 30] Improved knowledge of dynamic adaptations of intact RC and deltoid muscles in the presence of an RC tear may contribute to the development of novel prognostic determinants and optimization of rehabilitation strategies to train muscles before or following RC repair or shoulder arthroplasty.

This study does have several limitations. Firstly, patients with persistent shoulder complaints are more likely to undergo imaging twice that may lead to forced selection. Because changes of the teres minor and deltoid muscles are assumed favourable biomechanical compensation for lost RC forces, a more noticeable increase in muscle size could be expected in RC tear patients without follow-up due to relieve of pain. Secondly, slight variations in imagined plane on MRI due to cranial translation (i.e. for deltoid) or tendon retraction may impair validity, although semi-quantitative CSA measurements have been shown to be reliable and are frequently applied [1, 14, 22, 37], recent studies question its association with three-dimensional muscle architecture.[36] We chose CSA as a measure for muscle mass, though it measures intra-muscular connective tissue and fat as well leading to an overestimation of contractile tissue.[23] Finally, we assumed a similar development of muscle CSA in all patients with an intact RC, although these patients may suffer from different shoulder pathologies. Thus, changes in muscle mass in these shoulders may deviate from changes in an asymptomatic shoulder.

CONCLUSION

This longitudinal study demonstrated that the size of teres minor, subscapularis and deltoid muscle decrease over time in the absence of an RC tears. Whereas the CSA of teres minor and deltoid decreases over time in patients with an intact RC, the decline in CSA of these muscles was substantially less in the presence of a supraspinatus tear. This association was most prominently found in the population below 50 years of age. These findings may indicate that intact shoulder muscles may compensate for shifts of forces up to midlife and suggests that atrophy is decreased by compensatory enlargement of mechanical load.

ACKNOWLEDGEMENTS

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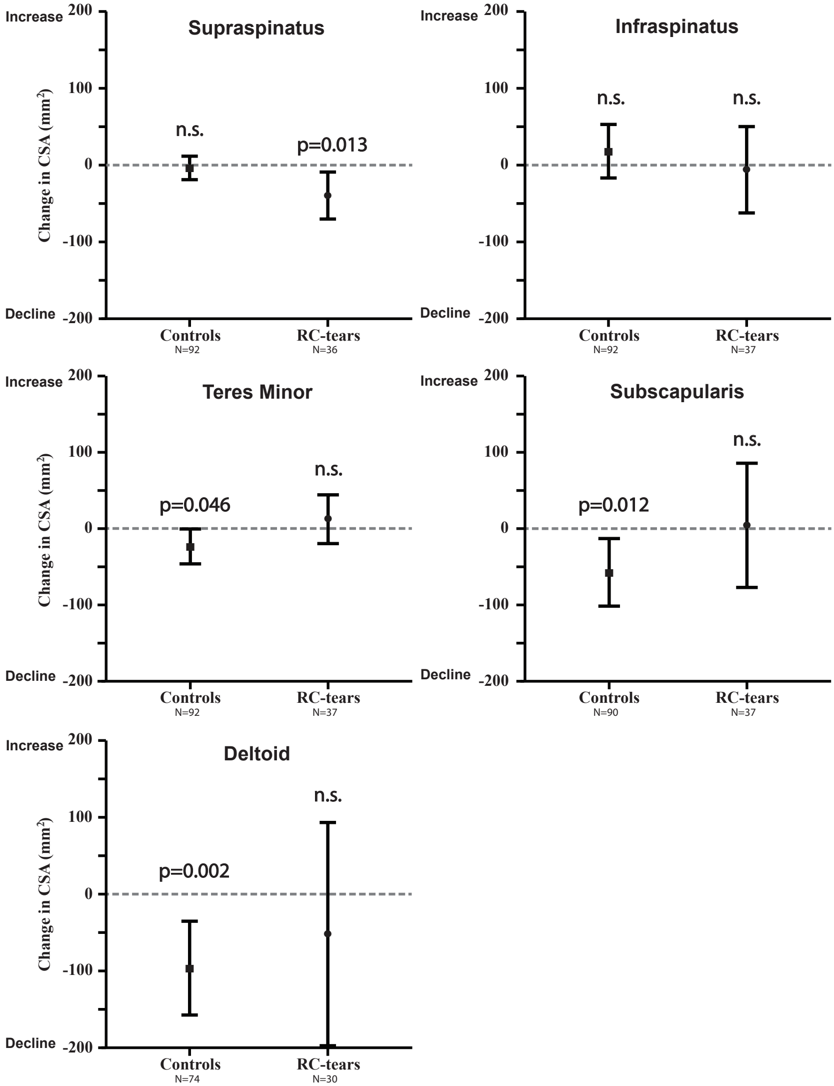
Supplement 1. Mean difference in cross-sectional surface area.



(CSA) between baseline and follow-up and 95% confidence interval for the control group with an intact RC (▪, n=92), and with a supraspinatus-tear (●, n=37) with a mean follow-up of 3 years. Abbreviations: RC, rotator cuff; mm, millimetre.

Supplement 2. Changes in CSA per year during follow-up

	Supraspinatus CSA (mm^2/yr)		Infraspinatus CSA (mm^2/yr)		Subscapularis CSA (mm^2/yr)	
	Mean change (95% CI)	P value	Mean change (95% CI)	P value	Mean change (95% CI)	P value
≤ 50 years						
Model for intact RC[a]	-1 (-7.8 – 5.4)	0.720	11 (-2.7 – 23.9)	0.118	-12 (-28.1 – 4.9)	0.163
Model for RC tear[a]	-2 (-19.3 – 14.4)	0.771	1 (-32.9 – 34.6)	0.960	-9 (-50.0 – 31.7)	0.655
Fixed effect: RC tear	-1 (-19.4 – 16.8)	0.888	-10 (-46.0 – 26.6)	0.596	2 (-41.7 – 46.6)	0.912
> 50 years						
Model for intact RC[a]	-1 (-7.1 – 4.9)	0.720	-0 (-14.8 – 14.2)	0.968	-11 (-31.9 – 9.7)	0.287
Model for RC tear[a]	-3 (-11.5 – 6.0)	0.531	19 (-1.4 – 39.0)	0.068	37 (9.1 – 65.5)	0.010*
Fixed effect: RC tear	-2 (-12.5 – 9.1)	0.758	19 (-6.3 – 44.5)	0.138	48 (12.8 – 84.1)	0.009*
All patients						
Model for intact RC[a]	-1 (-5.9 – 3.7)	0.647	7 (-2.7 – 16.9)	0.155	-11 (-23.3 – 1.2)	0.076
Model for RC tear[a]	-2 (-11.3 – 6.5)	0.594	11 (-7.6 – 28.9)	0.250	22 (-0.1 – 45.0)	0.051
Fixed effect: RC tear	-1 (-11.5 – 8.9)	0.801	4 (-17.3 – 24.5)	0.736	34 (7.6 – 59.5)	0.012*

Minus (-) indicates a decline in cross-sectional surface area. Mixed model analysis enables to deal with the development of an RC tear over time and to adjust for age, sex, differences in interval between two consecutive MRIs. Abbreviations: CSA, cross-sectional surface area; mm^2/yr, square millimetre per year, year CI, confidence interval; RC, rotator cuff.

* Statistically significant difference at $P < 0.05$.

† Mixed model with fixed effects: presence of an RC tear on MRI (yes/no), age (years), sex (male/female), follow-up time in years, presence of an RC tear x follow-up time in years, and a random intercept for subjects.