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SCIENTIFIC ARTICLE

# Predictors of infraspinatus muscle degeneration in individuals with an isolated supraspinatus tendon tear

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## Abstract
**Objective** Determine the demographic and clinical factors that predict infraspinatus muscle degeneration in individuals with an isolated supraspinatus tendon tear.

**Materials and methods** A retrospective analysis was performed using the medical records of patients who had a shoulder MRI interpreted by 1 of 3 fellowship-trained musculoskeletal radiologists since the implementation of a standardized MRI 3 T protocol within our healthcare system. Demographic (e.g., age, sex) and clinical data (e.g., tear size, muscle degeneration, co-morbidities) were collected. Patients with an isolated supraspinatus tendon tear ($n = 121$) were assigned to one of two groups based on whether any infraspinatus muscle degeneration was present. Logistic regression was used to assess the univariate relationships between infraspinatus muscle degeneration and patient and clinical data, while least absolute shrinkage and selector operator (LASSO) logistic regression was used to assess the multivariable relationship.

**Results** Of the patients with an isolated supraspinatus tendon tear, 16.5% had evidence of infraspinatus muscle degeneration. The presence of infraspinatus muscle degeneration was independently associated with cardiovascular disease ($P = 0.01$), supraspinatus muscle degeneration ($P < 0.01$), and subscapularis muscle degeneration ($P = 0.01$). When the multivariable relationship is assessed, supraspinatus muscle degeneration emerged as the only variable of significant importance for detecting infraspinatus muscle degeneration (specificity: 87.1%, sensitivity: 80.0%).

**Conclusion** Infraspinatus muscle degeneration is not uncommon in individuals with an isolated supraspinatus tear and is most associated with concomitant supraspinatus muscle degeneration. These findings highlight the need for clinicians to specifically assess the status of each rotator cuff muscle, even when the tendon itself is intact.

**Keywords** Infraspinatus muscle degeneration · Supraspinatus tendon tear · MRI shoulder · Rotator cuff repair · Rotator cuff retear

## Introduction

Rotator cuff repair is a common orthopaedic surgery that is often indicated when conservative treatment fails to improve pain or function in individuals with a rotator cuff tear. Unfortunately, approximately 20–70% of individuals undergoing a rotator cuff repair experience a retear [1–7]. Previous research has identified several risk factors for retear including patient age [8, 9], tear size [8–14], and the degree of rotator cuff muscle degeneration (i.e., atrophy and fatty infiltration) [9–15]. Degeneration of the infraspinatus muscle may be especially problematic due to the muscle's crucial role supporting dynamic shoulder function [16–18]. Indeed, infraspinatus muscle degeneration has been associated with higher retear rates [9, 11] and poorer clinical outcomes [19] following arthroscopic rotator cuff repair.

Although infraspinatus muscle degeneration is often found in rotator cuff tears involving the infraspinatus tendon [20], there is evidence that it can occur in individuals with a rotator cuff tear isolated to the supraspinatus tendon [20–22]. This finding is surprising given the infraspinatus tendon itself remains intact in these individuals. However, previous research suggests that the phenomenon tends to

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occur in individuals with a tear in the anterior supraspinatus tendon [20] or in individuals with more severe supraspinatus muscle degeneration [22]. However, it remains unclear the extent to which other potentially relevant factors (e.g., comorbidities) as well as a combination of factors are associated with infraspinatus muscle degeneration in individuals with an isolated supraspinatus tendon tear.

The objective of this study is to determine the demographic and clinical factors that predict infraspinatus muscle degeneration in individuals with an isolated supraspinatus tendon tear. Based on previous findings in the literature [21, 22], we hypothesized that supraspinatus anterior–posterior dimension tear size and concomitant supraspinatus muscle degeneration will be significant predictors of infraspinatus muscle degeneration.

## Materials and methods

This study was performed in accordance with the ethical standards of our institutional research committee and with the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards. Institutional review board approval was obtained for this study, and informed consent was waived due to the study's retrospective nature. Our study complied with the Health Insurance Portability and Accountability Act.

### Selection of study cohort

This retrospective study had a target population including all adult patients found during a comprehensive query of the health system's radiology information system database. Specifically, the query searched for shoulder MRI examinations that met the following criteria: (1) acquired on a 3 T scanner, (2) performed between January 2014 and October 2021 (corresponding with when a standardized MRI protocol was implemented system-wide and the start of the current study), and (3) read by 1 of 3 experienced fellowship-trained musculoskeletal radiologists. This search resulted in 637 MRI examinations, which were subsequently linked to the medical record of the patient associated with each examination for further analysis.

### Medical records review

A first round of medical records review was performed to determine study eligibility. Patients were excluded if they had a history of shoulder surgery or glenohumeral joint dislocation, or if the associated MRI was incomplete (e.g., due to patient intolerance). If a patient was found to have multiple MRI examinations within the database, then only the most recent examination was included so that the assumption of independence was not violated during statistical analysis. A total of 172 patient records were excluded during this round of review (Fig. 1).

A second round of medical records review was performed on the remaining 465 patient records to collect demographic and relevant clinical data. Demographic data including patient age and sex were populated directly from the medical records. Problem lists retrieved from the medical record were used to determine the presence of comorbidities including diabetes, hypertension, hyperlipidemia, cardiovascular disease, and obesity.

### MRI examination protocols

All MRI examinations were performed on one of three 3 T scanners depending on the location within the health system at which the examinations were performed: a Philips Ingenia (Philips Medical Systems, Cleveland, OH), a GE Signa Premier (General Electric Company, Milwaukee, WI), or a GE Discovery MR750. All scans were performed with a dedicated shoulder coil and a standardized shoulder imaging protocol. The images were obtained with the following sequences: coronal oblique T1-weighted spin echo (TR/TE 650–750 ms/15 ms, 3 mm thick, matrix 384 × 384, nex 1, echo train length 4), fat-suppressed T2-weighted fast spin echo (TR/TE 3500–5500 ms/70 ms, 3 mm thick, matrix 384 × 256, nex 1, echo train length 18), fat-suppressed axial proton density fast spin echo (TR/TE 2500–3500 ms/30 ms, 4 mm thick, matrix 384 × 256, nex 1, echo train length

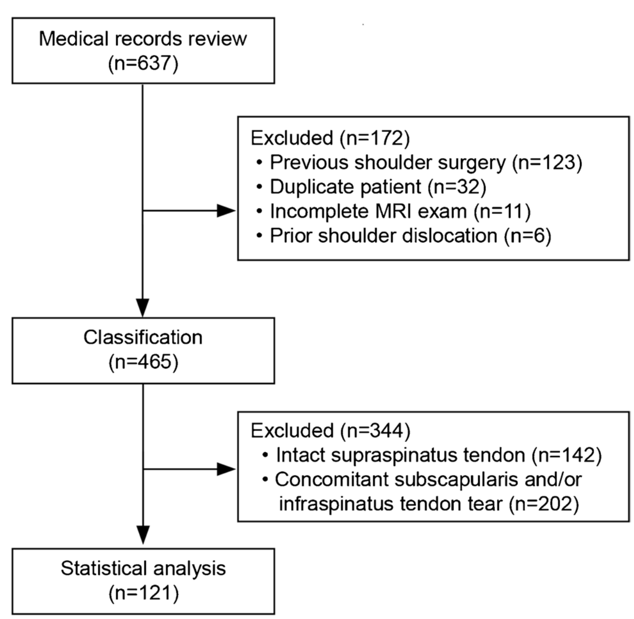


**Fig. 1** CONSORT flow diagram showing the flow of patient records through the initial medical records query and review, classification, and statistical analysis

8), sagittal oblique proton density fast spin echo (TR/TE 2500–3500 ms/30 ms, 4 mm thick, matrix 384 × 384, nex 1, echo train length 9), and fat-suppressed sagittal oblique proton density fast spin echo (TR/TE 2500–3500 ms/30 ms, 4 mm thick, matrix 384 × 256, nex 1, echo train length 9). The field of view for the different sequences was 16 cm. Additionally, in order to optimize imaging of the rotator cuff muscle bellies, the sagittal oblique sequences were prescribed perpendicular to the coronal oblique slices (perpendicular to the supraspinatus tendon and muscle and paralleling the glenohumeral joint). The sagittal sequence covered from the deltoid muscle (one slice lateral to the humeral head), medially to include the entire coracoid to the medial aspect of the scapular body.

## MRI examination interpretations

All the MRI examinations had been initially interpreted by 1 of 3fellowship-trained musculoskeletal radiologists (12, 13, and 36 years of clinical experience). These examinations were performed and interpreted in real time, prior to the inception of this study. Differentiating the supraspinatus from the infraspinatus tendon was done by utilizing the sagittal sequences, at the lateral aspect of the greater tuberosity. Measuring from anterior to posterior, the tendon located along the anterior 2.3 cm of the greater tuberosity was designated the supraspinatus, while the tendon located further posterior was designated the infraspinatus [23–25]. Muscle degeneration was assessed via the known Goutallier classification but converted to the following for reporting: grade 0, none; grade 1, mild; grades 2–3, moderate; grade 4, severe [26].

## MRI exam categorization

MRI results were extracted from the examination reports by 2 investigators. Specifically, the following 14 variables were documented: (1) supraspinatus tendon status (intact, torn), (2) supraspinatus tear type (N/A if intact, bursal-sided partial-thickness tear, articular-sided partial-thickness tear, intrasubstance partial-thickness tear, full-thickness tear), (3) supraspinatus tendon (and infraspinatus tendon, when involved) anterior/posterior tear dimensions (if applicable), (4) supraspinatus tendon (and infraspinatus tendon, when involved) medial/lateral tear dimensions or retraction (if applicable), (5) infraspinatus tendon status (intact, torn), (6) subscapularis tendon status (intact, torn), (7) subscapularis tear type (N/A if intact, bursal-sided partial-thickness tear, articular-sided partial-thickness tear, intrasubstance partial-thickness tear, full-thickness tear), (8).

subscapularis tendon superior/inferior tear dimensions (if applicable), (9) subscapularis tendon medial/lateral tear dimensions or retraction (if applicable), (10) supraspinatus muscle degeneration (none, mild, moderate, severe), (11) infraspinatus muscle degeneration (none, mild, moderate, severe), (12) subscapularis muscle degeneration (none, mild, moderate, severe), (13) long head biceps tendon status (intact, torn), and (14) glenohumeral joint osteoarthritis (positive, negative). Any ambiguities in the examination report were clarified by a single fellowship-trained musculoskeletal radiologist with 13 years of clinical experience.

Once MRI findings were entered into the database, the final study sample was determined based on the presence of a rotator cuff tear and infraspinatus muscle degeneration. Specifically, the objective of the study was to identify factors associated with infraspinatus muscle degeneration in patients with an isolated supraspinatus tear. Therefore, 344 patients were excluded because they did not have a supraspinatus tendon tear or had a concomitant subscapularis or infraspinatus tendon tears (Fig. 1). Therefore, subsequent statistical analysis was performed on the remaining 121 patients with an isolated supraspinatus tendon tear, who were assigned to one of two groups based on whether any infraspinatus muscle degeneration was visible on the MRI (i.e., negative/positive). Although the MRI reports provided ordinal levels of muscle degeneration (none, mild, moderate, severe), muscle degeneration data was binarized to negative (i.e., none) and positive (i.e., any) to minimize the effect of inter-rater variability given 3 radiologists read the examinations and to ensure adequate sample size within each group.

## Statistical analysis

Demographic and clinical data were compared between infraspinatus muscle degeneration groups using independent *t*-tests or chi-square tests, as appropriate. The relationships between infraspinatus muscle degeneration and patient and tissue characteristics were assessed in two ways. First, univariate relationships were assessed using logistic regression. Odds ratios and risk ratios (i.e., relative risks) were subsequently calculated for each individual predictor. Second, multivariable relationships were assessed using least absolute shrinkage and selector operator (LASSO) logistic regression. This analysis identifies a combination of variables that are associated with infraspinatus degeneration while also eliminating non-important variables (i.e., those that do not add unique predictive value above variables already in the model). The aim is to create a parsimonious model with high predictive accuracy. Fivefold cross-validation was performed on the LASSO model to determine an unbiased estimate of the prediction error. This procedure allows for internal validation of the multivariable model by partitioning the full dataset into five independent subsets, then fitting a model to an individual subset (training) and testing the model's predictive accuracy on the combined data from the remaining 4 subsets (testing). Model accuracy during both the training and testing stages was described using the area under the receiver operating characteristic curve (AUROC), and the final multivariable model was selected based on the highest testing AUROC. Models are considered to have "reasonable" and "good" accuracy when the AUROC is 70–80% and 80–90%, respectively. The optimal probability threshold was also determined to facilitate clinical utility when predicting whether patients had infraspinatus degeneration in the presence of an isolated supraspinatus tendon tear. Univariate statistical analysis was performed in SAS (SAS Institute; Cary, NC) and the LASSO multivariate analysis was performed in Sanford Predictive Modeler (Minitab, LLC; State College, PA). Statistical significance was defined as a $P<0.05$.

## Results

Six hundred thirty-seven (637) records were returned from the initial medical records query (Fig. 1). Of these, 172 were excluded due to prior shoulder surgery ($n=123$), duplicate patient ($n=32$), prior glenohumeral dislocation ($n=6$), or incomplete scan ($n=11$). Of the remaining 465 patients, 121 (26.0%) had a rotator cuff tear isolated to the supraspinatus tendon. These patients became the cohort used in all subsequent statistical analyses.

Of the 121 patients with an isolated supraspinatus tendon tear, 101 (83.5%) had no evidence of infraspinatus muscle degeneration while 20 (16.5%) had at least mild infraspinatus muscle degeneration (Fig. 2). The presence of infraspinatus muscle degeneration was significantly associated with cardiovascular disease (35.0% vs. 12.9%, $P=0.01$), supraspinatus muscle degeneration (80.0% vs. 12.9%, $P<0.01$), and subscapularis muscle degeneration (15.8% vs. 1.0%, $P=0.01$) (Table 1). These group differences were also reflected in higher odds ratios in the univariate logistic regression analyses (Table 2). In particular, an individual with an isolated supraspinatus tendon tear is 12.7 times more likely to have infraspinatus muscle degeneration if they have supraspinatus muscle degeneration ($P\leq0.01$), and 5.8 times more likely if they have subscapularis muscle degeneration ($P\leq0.01$). Furthermore, an individual with an isolated supraspinatus tendon tear is 2.7 times more likely to have infraspinatus muscle degeneration if they have cardiovascular disease ($P=0.02$).

The results of the multivariable LASSO model suggest that supraspinatus muscle degeneration is the only variable of significant importance when predicting the presence of infraspinatus muscle degeneration in individuals with an isolated supraspinatus tear (Table 3). The equation for the final LASSO model is $L_{score}=-0.9171-1.00721$*(if no supraspinatus muscle degeneration), with an optimal probability cutoff of 0.17 corresponding with the underlying prevalence of infraspinatus atrophy across the study sample. During cross-validation, this model yielded AUROCs of 84.0% for training and 80.0% for testing. The presence of any supraspinatus muscle degeneration was found to be 87.1% specific and 80.0% sensitive for detecting infraspinatus muscle degeneration.

## Discussion

This study aimed to classify the patient and tissue characteristics that are associated with infraspinatus muscle degeneration in individuals with an isolated supraspinatus tendon tear. The results suggest that the presence of muscle degeneration in other rotator cuff muscles—the supraspinatus in particular—and cardiovascular disease are statistically significant independent predictors of infraspinatus muscle

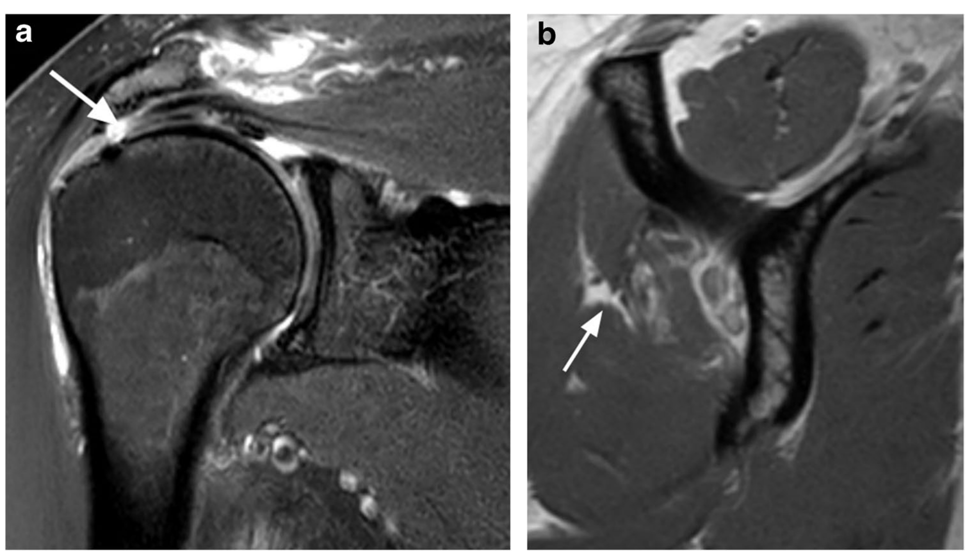


**Fig. 2** A 62-year-old woman with an isolated full-thickness tear of the supraspinatus tendon and isolated infraspinatus muscle degeneration. **a** Fat-suppressed coronal oblique T2-weighted image demonstrates a full-thickness retracted tear of the supraspinatus tendon (arrow). **b** Sagittal oblique proton density image demonstrates isolated infraspinatus muscle degeneration (arrow)

**Table 1** Study demographics. Numerical data is represented as mean ± standard deviation (SD) or percentage, as appropriate. FTT, full-thickness tear; PTT, partial-thickness tear

| | All ($n=121$) | Infraspinatus atrophy | | $P$ value |
|---|---|---|---|---|
| | | Negative ($n=101$) | Positive ($n=20$) | |
| Demographics | | | | |
| Age | 62 ± 7 | 62 ± 7 | 64 ± 9 | 0.17 |
| Sex (% female) | 49.6% | 48.5% | 55.0% | 0.60 |
| Comorbidities | | | | |
| Obesity (% positive) | 18.% | 17.8% | 20.0% | 0.82 |
| Type 2 diabetes (% positive) | 22.3% | 23.8% | 15.0% | 0.39 |
| Hypertension (% positive) | 26.5% | 24.8% | 35.0% | 0.34 |
| Hyperlipidemia (% positive) | 30.6% | 30.7% | 30.0% | 0.95 |
| Cardiovascular disease (% positive) | 16.5% | 12.9% | 35.0% | 0.01 |
| MRI findings | | | | |
| Supraspinatus tear type | – | – | – | 0.14 |
| PTT bursal sided | 18.2% | 77.3% | 22.7% | – |
| PTT intrasubstance | 17.4% | 95.2% | 4.8% | – |
| PTT articular sided | 14.9% | 94.4% | 5.6% | – |
| FTT | 49.6% | 78.3% | 21.7% | – |
| Anterior/posterior tear size (cm) | 1.2 ± 0.6 | 1.2 ± 0.6 | 1.4 ± 0.5 | 0.17 |
| Tear retraction (cm) | 1.1 ± 0.9 | 1.0 ± 1.0 | 1.3 ± 0.8 | 0.34 |
| Supraspinatus degeneration (% positive) | 24.0% | 12.9% | 80.0% | < 0.01 |
| Subscapularis degeneration (% positive) | 4.1% | 1.0% | 15.8% | < 0.01 |
| Biceps tendon tear (% positive) | 10.2% | 11.2% | 5.0% | 0.69 |
| Glenohumeral osteoarthritis (% positive) | 59.5% | 60.4% | 55.0% | 0.65 |
| Suprascapular or spinoglenoid notch cyst | 1.7% | 1.7% | 0% | 0.53 |
| Paralabral cyst | 4.1% | 3.3% | 0.8% | 0.83 |

**Table 2** Results of univariate logistic regression analysis predicting the presence of infraspinatus muscle degeneration in individuals with a rotator cuff tear isolated to the supraspinatus tendon. For odds ratio calculations, the reference is a negative finding in all cases except sex (female) and supraspinatus tear type (PTT bursal sided tear). No results are reported for suprascapular or spinoglenoid notch cyst because the logistic regression model fit was invalid given the very low prevalence of the predictor (1.7%). CI, confidence interval; FTT, full-thickness tear; NA, not applicable; NR, not reported. OR, odds ratio; PTT, partial-thickness tear; RR, risk ratio (i.e., relative risk)

| | OR (95% CI) | RR (95% CI) | $P$ value |
|---|---|---|---|
| Demographics | | | |
| Age | 1.04 (0.98–1.11) | NA | 0.17 |
| Sex | 0.77 (0.29–2.02) | 0.80 (0.36–1.80) | 0.60 |
| Comorbidities | | | |
| Obesity | 1.15 (0.34–3.86) | 1.13 (0.42–3.04) | 0.82 |
| Type 2 diabetes | 0.57 (0.15–2.10) | 0.61 (0.19–1.94) | 0.39 |
| Hypertension | 1.64 (0.59–4.56) | 1.50 (0.66–3.42) | 0.35 |
| Hyperlipidemia | 0.97 (0.34–2.75) | 0.97 (0.41–2.33) | 0.95 |
| Cardiovascular disease | 3.65 (1.23–10.82) | 2.72 (1.24–5.95) | 0.02 |
| MRI findings | | | |
| Supraspinatus tear type | | | 0.21 |
| PTT intrasubstance | 0.17 (0.02–1.60) | 0.21 (0.03–1.65) | 0.27 |
| PTT articular sided | 0.20 (0.02–1.90) | 0.24 (0.03–1.91) | 0.37 |
| FTT | 0.94 (0.29–3.03) | 0.95 (0.38–2.36) | 0.08 |
| Anterior/posterior tear size | 1.72 (0.79–3.73) | NA | 0.17 |
| Tear retraction | 1.27 (0.78–2.06) | NA | 0.33 |
| Supraspinatus degeneration | 27.08 (7.83–93.64) | 12.69 (4.61–34.95) | < 0.01 |
| Subscapularis degeneration | 25.00 (2.62–238.13) | 5.80 (3.08–10.91) | < 0.01 |
| Biceps tendon tear | 0.42 (0.05–3.42) | 0.46 (0.07–3.17) | 0.41 |
| Glenohumeral osteoarthritis | 0.80 (0.30–2.11) | 0.83 (0.37–1.86) | 0.65 |
| Suprascapular or spinoglenoid notch cyst | NR | NR | NR |
| Paralabral cyst | 1.28 (0.14–12.06) | 1.22 (0.20–7.39) | 0.83 |

**Table 3** Results of the LASSO multivariable analysis using the regression equation: score = −0.9171 − 1.00721*(supraspinatus muscle degeneration = none). The score is converted to a probability using the equation: $\frac{1}{1+e^{-score}}$. Finally, a patient was predicted to have infraspinatus muscle degeneration if their calculated probability was > 0.17, corresponding to the underlying prevalence of infraspinatus muscle degeneration across the study sample

| Statistic | Value |
|---|---|
| AUC (95% CI) | 0.80 (0.67–0.93) |
| Specificity | 87.1% |
| Sensitivity | 80.0% |
| Positive predictive value | 55.2% |
| Negative predictive value | 95.7% |
| Positive likelihood ratio | 4.00 |
| Negative likelihood ratio | 0.15 |

degeneration. However, the multivariable model suggests that supraspinatus muscle degeneration is the only variable of significant importance when predicting the presence of infraspinatus muscle degeneration. Clinically, these findings identify key characteristics associated with infraspinatus muscle degeneration which may help during the pre-surgical planning for individuals with rotator cuff tear, as infraspinatus degeneration has been associated with higher retear rates [9, 11] and poorer clinical outcomes [19].

From a univariate perspective, an individual with a rotator cuff tear isolated to the supraspinatus is 12.7 times more likely to have infraspinatus muscle degeneration if they have supraspinatus muscle degeneration, and 5.8 times more likely if they have subscapularis muscle degeneration. However, the magnitude of the confidence intervals associated with both the odds and risk ratios suggest that they should be interpreted with caution (Table 2). Even so, the association between muscle degeneration across multiple portions of the rotator cuff is consistent with previous investigations [21, 22]. From a multivariable perspective, however, only supraspinatus muscle degeneration offers unique predictive value. Secondary analysis suggests that this may be because 100% of the individuals with subscapularis muscle degeneration also had supraspinatus degeneration, thus making the variable redundant in the multivariable model. Importantly, the prediction value of the multivariable model was good (specificity: 87.1%, sensitivity: 80.0%) despite its simplicity (i.e., having only a single predictor), suggesting a consistent relationship within the study sample. Taken together, the predictive value of the supraspinatus status in both univariate and multivariate models as well as in previous research [21, 22] suggests that the health of the supraspinatus tendon is likely an important factor in the health of the infraspinatus muscle.

As early as 1994, Goutallier et al. reported that infraspinatus muscle degeneration can occur even with an isolated supraspinatus tendon tear and had a highly negative influence on the outcome of supraspinatus tendon tear repairs [27]. However, the reason the infraspinatus muscle was affected was unknown. Furthermore, Shimizu and colleagues reported that simply the site of the tear may lead to atrophy in those respective muscles [28]. On the contrary though, even when taking into consideration the newer anatomical findings of Mochizuki et al., which demonstrated that the infraspinatus tendon occupies a substantially larger portion of the greater tuberosity insertion than traditionally believed [29], Table 1 reveals that the average anterior/posterior tear size (1.2 cm) would still localize these tears to only the supraspinatus tendon.

Therefore, the finding that muscle degeneration in other rotator cuff muscles increases the risk of having infraspinatus muscle degeneration invites the question of mechanism: what causes muscle degeneration to occur? One theory is that the suprascapular nerve undergoes a traction injury as a result of a chronic, retracted supraspinatus tear [30] or during overhead athletics [31, 32]. Another theory postulates that muscle degeneration (i.e., fatty infiltration) occurs as a result of changes to the muscle's pennation angle due to tendon retraction [33]. Still, a third theory suggests that suprascapular or spinoglenoid notch paralabral cysts or ganglia can compress the suprascapular nerve leading to infraspinatus muscle degeneration [21, 34, 35]. However, the results of this study do not seem to support these mechanisms given: (1) the prevalence of infraspinatus degeneration despite the relatively small amount of tendon retraction observed in this study (mean: 1.1 cm, median: 0.9 cm), (2) the average age of the cohort was 62 years old and was not limited to overhead athletes (Table 1), (3) the lack of a significant association between tear size and infraspinatus atrophy (Table 2), and (4) suprascapular or spinoglenoid notch cysts or ganglia were not frequently observed in the MRI examination in the current study (Table 1), nor were they associated with infraspinatus muscle degeneration (Table 2). Taken together, these data suggest that suprascapular nerve traction or entrapment and muscle geometric changes cannot fully explain the presence of infraspinatus muscle degeneration within our sample.

In addition to these theorized physical or mechanical causes of muscle degeneration, there is growing evidence that the pathophysiology is likely related to cellular and signaling mechanisms [36, 37]. However, many of these theories are often predicated on the mechanical unloading that occurs in the presence of a tendon tear, which is not applicable in the patient population for the current study (i.e., infraspinatus muscle degeneration when the tendon itself remains intact). As a whole, attempting to integrate the findings of the current study with the existing literature highlights the inherent complexity of trying to understand the pathogenesis of rotator cuff muscle degeneration.

Clinically, the finding that infraspinatus muscle degeneration is present in 16.5% of individuals with an isolated supraspinatus tear suggests that radiologists and surgeons interpreting MRI examinations should take care to specifically comment on the appearance of each of the rotator cuff muscles. Anecdotally, subscapularis or infraspinatus muscle degeneration is sometimes not reported, especially if the tear is isolated to the supraspinatus tendon. This leaves ambiguity as to whether no degeneration exists, or muscle quality was not assessed. Given the importance of rotator cuff muscle degeneration as an indicator of tear chronicity [38, 39] and predictor of surgical outcomes [9, 11, 19], we advocate for direct and explicit reporting across each of the rotator cuff muscles.

The importance and relevance of the statistically significant association between infraspinatus muscle degeneration and a significantly higher prevalence of cardiovascular disease is uncertain. Kennel, et al. mention that many cardiac diseases have a major impact on exercise performance which could cause skeletal muscle changes [40]. Furthermore, McNally and colleagues report that canonical transforming growth factor-β signaling contributes to both heart and skeletal muscle dysfunction [41]. Given our findings and these prior studies, disuse as a mechanism could potentially explain how having an isolated supraspinatus tendon tear could lead to multiple rotator cuff muscles with degeneration and concurrent cardiovascular disease. However, this topic warrants further studies.

The limitations of this study should be acknowledged when interpreting the results. First, this is a retrospective analysis with multiple raters and previous research suggests that some MRI measures of rotator cuff tear characteristics may be impacted by inter-rater reliability [42–44]. The decision to use multiple raters was based on the need to acquire an adequate sample size for statistical analysis. Although variability between raters is possible, these 3 musculoskeletal radiologists have worked together for at least 5 years and hold a daily divisional meeting to discuss cases to ensure education as well as consistency in reporting findings. Additionally, the division has instituted a reporting template and procedures to help ensure consistency and accuracy when reporting rotator cuff tear characteristics, including measuring size and retraction as well as reporting degrees of rotator cuff muscle degeneration. Furthermore, we attempted to minimize the effect of inter-rater reliability by binarizing MRI findings as positive/negative. Second, the use of a problem list to determine the presence of comorbidities may have resulted in false negatives. For example, the low prevalence of obesity relative to published values [45] suggests the problem list may not be comprehensive. Future studies should seek to more directly assess these factors while also limiting MRI interpretation to a single reviewer. Third, despite the average anterior/posterior supraspinatus tear size being approximately 1.2 cm, the ability to precisely determine whether a tear involving the supraspinatus tendon is isolated to the anterior or posterior aspect of the supraspinatus tendon, or possibly involves the anterior-most fibers of the infraspinatus tendon may have influenced the results of the study. However, the lack of a significant association between infraspinatus muscle degeneration and anterior/posterior tear size suggests this consideration may not have substantially altered the findings.

In conclusion, infraspinatus muscle degeneration is present in 16.5% of individuals with an isolated supraspinatus tear and primarily associated with the presence of concomitant supraspinatus muscle degeneration. Clinically, these findings highlight the need for radiologists and orthopaedic surgeons to specifically assess the status of each rotator cuff muscle, even when the tendon itself is intact.

## Declarations

**Ethical standards** All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent was waived.

**Conflict of interest** The authors declare no competing interests.

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