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REVIEW

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Fatty infiltration predicts retear and functional impairment following rotator cuff repair: systematic review and meta-analysis

Hao-Tian Wu[1†], Qiang Liu[1*] and Jian-Hao Lin[1*]

Abstract

Introduction Fatty infiltration (FI) in rotator cuff (RC) is detected in many patients with complete RC tears. But there remains controversy on the prognostic effects of FI in RC tears, especially for patients with moderate and severe FI. This study aims to systematically review the relationship between the severity of preoperative FI and risk of retear, and the association between preoperative FI and functional outcomes.

Materials and methods We searched PubMed, Embase and Web of Science for studies on association between preoperative FI and retear or functional outcomes following complete RC repair. FI was assessed using Goutallier classification and global fatty degeneration index (GFDI). Meta-analysis was performed to determine odds ratios (ORs) for retear among patients with mild (grade 0–1), moderate (grade 2) and severe (grade 3–4) FI in RC tears. We delivered qualitative synthesis on association between FI and functional outcomes.

Results Eighteen studies with 1997 patients were included in the systematic review and ten studies were included in the meta-analysis. Patients with GFDI ≤ 1 had lower retear odds (OR = 0.08, 95%CI 0.02–0.29, $p < 0.01$). Moderate FI in supraspinatus muscle (SSP) was associated with higher retear odds compared with mild FI (OR = 1.95, 95%CI 1.09–3.48, $p = 0.02$) and severe FI was associated with more retear compared with moderate FI (OR = 3.37, 95%CI 1.08–10.53, $p = 0.04$). Similar effects were observed in FI in infraspinatus muscle (ISP) (moderate vs. mild: OR = 2.22, 95%CI 1.07–4.62, $p = 0.03$; severe vs. moderate: OR = 2.06, 95%CI 1.02–4.16, $p = 0.04$). The severity of FI in subscapularis muscle and teres minor muscle was not observed to be associated with the retear rates. In functional outcomes, lower grade of FI in GFDI was associated with better prognosis. FI in single muscles failed to present prognostic effects on functional outcomes.

Conclusions The severity of FI in SSP and ISP showed effects on retear following complete RC repair. The GFDI was a compatible predictor for risk of anatomic and functional impairment.

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Keywords Shoulder, rotator cuff, Surgery, Fatty infiltration, Clinical assessment, Imaging, computed tomography, Imaging, magnetic resonance

Introduction

Rotator cuff (RC) tear is a prevalent disorder with pain and functional impairment in shoulders [1, 2]. Patients unable to recover through conservative management tend to receive surgeries, among which the complete RC repair is a common surgical treatment [3, 4]. As for postoperative follow-up of RC repair, the anatomic outcome is assessed by retear rates and the functional outcome is assessed by published functional scales, consisting of pains, daily activities, joint range of motion and muscle strength [5, 6]. According to previous reports, patients present great variance in the anatomic and functional outcomes post RC repair. The retear rates range from 10 to 90% [7–9], and the functional outcome varies as well [10–12]. The great variance reminds us to better identify the potential risk factor of poor anatomic and functional outcomes. In light of this, the fatty infiltration (FI) in RC muscles has come into our sight.

In 1994, Goutallier introduced a five-grade classification to assess preoperative FI in RC on computerized tomography (CT), which was later modified to assessment of FI on magnetic resonance imaging (MRI) [13, 14]. Since then, several studies have suggested an association between higher preoperative Goutallier grades and poorer outcomes post repair [15–19]. In general, a tear with mild (grade 0–1) FI is considered to benefit from complete repair, with low risk of retear or functional impairment [20, 21]. But there still remains a controversy whether the complete RC repair is appropriate for RC tears with moderate-to-severe (grade 2–4) FI [10, 22]. Moreover, there are various measurements for FI, including global fatty degeneration index (GFDI), and FI in supraspinatus muscle (SSP), infraspinatus muscle (ISP), subscapularis muscle (SSC) and teres minor muscle (TM) [23]. It is important to identify more efficient prognostic factors for RC repair among those measurements.

The published meta-analyses failed to present dose-response effects of the severity of FI on complete RC repair. Longo et al. found no differences in retear risk between patients with high and low GFDI [24], while the reviews by McElvany et al. and Müller et al. presented the association between higher FI and retear rates [1, 25]. Zhao et al., Khair et al. and Yang et al. showed that moderate-to-severe (grade 2–4) FI in SSP and ISP was a risk factor of retear compared with mild (grade 1) FI, but there lacked further prognostic comparison between moderate (grade 2) and severe (grade 3–4) FI [19, 26, 27]. Recently Tsuchiya et al. showed the prognostic effect of FI in SSP and ISP to retear rates in posterosuperior RC repair, which inspired us to explore the prognostic effect of the severity of FI in each muscle including SSP, ISP, SSC, TM and GFDI in complete RC repair [28]. Consequently, we conducted this systematic review and meta-analysis to: (1) initially evaluate the prognostic comparison of the retear risk among RC with mild (grade 0–1), moderate (grade 2) and severe (grade 3–4) FI in SSP, ISP, SSC and TM; (2) evaluate the prognostic efficiency of different measurements; and (3) assess the association between preoperative FI and functional outcomes post complete RC repair.

Methods

Search strategy and eligibility criteria

We carried out the data search in three databases, including PubMed, Embase and Web of science, with the consistent searching terms: "shoulder", "rotator cuff", "supraspinatus", "infraspinatus", "subscapularis" or "teres minor"; and "Goutallier" or "fat/fatty infiltration/degeneration/fraction". The search was performed in December, 2024. There was no restriction in publication years and the duplicates in different databases were removed through a title comparison.

After data search, two authors screened the titles and abstracts independently. Any disagreement would be adjudicated by a third author. The inclusion criteria were as follows: (1) participants were diagnosed as full-thickness RC tear and received complete repair surgeries; (2) preoperative FI was evaluated by CT or MRI, in at least one muscle from the injured-side RC; (3) the follow-up lasted for at least 6 months post-surgery; (4) the relationship was analyzed between preoperative FI of RC and postoperative anatomic or functional outcomes; and (5) the article was published in English. Studies were excluded when: (1) participants received reconstruction surgeries besides complete RC repair; or (2) the muscle evaluated for FI was not clearly defined. The study was reported following the guideline of Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement.

Data extraction and outcome variables

For each study included, two authors completed the data extraction. Any disagreement in data extraction was adjudicated by a third author. The study design, population characteristics, diagnosis, surgical approach, preoperative FI and postoperative anatomic and functional outcomes were collected [29].

A five-grade Goutallier classification was used to evaluate the preoperative FI in RC on CT or MRI [13, 14]. GFDI was defined as the mean value of FI grades in SSP,

ISP and SSC [11]. According to the Goutallier classification, the FI at grade 0–1, grade 2 and grade 3–4 is defined as mild, moderate and severe [10, 20–22]. The outcome variables consisted of integrity and functional outcomes. The integrity of RC was determined on MRI during follow-up. A postoperative cuff at Sugaya type IV (minor discontinuity) to V (major discontinuity) was considered to be retorn [30]. Other studies reported retear when detecting the fluid-equivalent signal or no tendon visualization on MRI [20, 31]. Additionally, the functional outcomes were measured by published standard scales, such as Constant score, American Shoulder and Elbow Society (ASES), University of California, Los Angeles (UCLA) and Japanese Orthopedic Association (JOA) score [32–37]. The prognostic effects of FI were discussed in retear and functional outcomes respectively.

We delivered the results in the form of subgroup analysis in advance to discover the prognostic effect of FI in each different muscle respectively (GFDI, SSP, ISP, SSC or TM). For the applicability of synthesis, we accepted the heterogeneity in causes of tear (traumatic or degenerative) or follow-up duration. Similar subgroup analyses were conducted in previous studies [28, 38].

Risk of Bias

Two authors assessed the risk of bias for eligible studies with the Quality in Prognosis Studies (QUIPS) assessment instrument independently [39]. The QUIPS tool was designed to assess risk of bias for prognosis studies in 6 domains, consisting of study participation, study attrition, prognostic factor measurement, outcome measurement, study confounding, and statistical analysis and reporting. We rated the studies as low, moderate or high risk of bias in each domain, according to the check with a series of questions. The overall low risk of bias was defined as ≤ 2 moderate-risk domains without high-risk domain. The overall moderate risk of bias was defined as three moderate-risk domains without high-risk domain or ≤ 2 moderate-risk domains with one high-risk domain. The overall high risk of bias was defined as ≥ 2 high-risk domains or > 3 moderate-risk domains [38]. Any disagreement in assessment was adjudicated by a third author.

Effect sizes and data analysis

A study was selected into meta-analysis when it provided with the number of intact and retorn cuffs in patients: (1) with GFDI 0–1 and GFDI > 1, respectively; or (2) with different severities of FI (Goutallier grade 0–1, 2 and 3–4) in at least one muscle in RC. We utilized a standardized effect, odds ratio (OR), for comparison of binary outcomes [27]. The meta-analysis was conducted through a random-effect model by Revman 5.4.1. For GDFI, the comparison of retear odds was conducted between shoulders with GFDI 0–1 and shoulders with GFDI > 1. For FI of each muscle in RC, the comparisons of retear odds were conducted between shoulders with mild and moderate FI, and between shoulders with moderate and severe FI. Forest plots displayed the weighted aggregate effects in meta-analysis, and the funnel plots and Egger's test assessed the publication bias [40]. The Cochran's Q and I^2 statistics test performed the heterogeneity evaluation. When a meta-analysis was inappropriate because of the limited quantity of reported statistics, a systematic review with vote-counting model was delivered to present the effect of direction in previous articles [41, 42]. Consistent evidence was defined as the evidence which was approved in ≥ 2 studies without any negative results. Conflicting evidence was defined as the evidence combined with both positive and negative results in different studies. Limited evidence was defined as the evidence which was discussed in only one study.

Results

Study characteristics and risk of Bias

We identified 1223 records from PubMed, 1292 records from Embase and 1806 records from Web of Science. After the deletion of duplicates, a total of 2373 articles were screened with titles and abstracts and then 192 full-text articles were retrieved and assessed for eligibility. Finally, we included 18 studies in this review, including five prospective studies and 13 retrospective studies (Fig. 1) [11, 15–18, 20, 23, 31, 43–52]. A total of 1997 eligible patients were enrolled. The characteristics of each study were provided in Table 1. Among the 18 studies included in our review, there were 14 studies investigating the associations of FI in retear rates and 7 studies investigating the associations of FI in functional outcomes. After the assessment by QUIPS tool, 11 articles were considered as studies at low risk of bias, while seven articles were evaluated to be at moderate risk of bias (Fig. 2 and Supplementary Table 1). No study was evaluated to be at high risk of bias. Ten of the studies included were selected into meta-analyses.

The effect of FI on postoperative retear

In our review, 14 studies investigated the effect of preoperative FI in RC on postoperative retear after complete repair surgeries. The GFDI, a mean value of FI in SSP, ISP and SSC, was designed for a global assessment on FI of the whole RC. In our review, two studies investigated the effect of GFDI on postoperative retear [11, 16]. In our meta-analysis, the weighted effect of two studies showed that patients with GFDI ≤ 1 experienced lower retear odds than those with GFDI > 1 (OR = 0.08, 95%confidence interval [CI] 0.02–0.29, $I^2 = 60\%$, $p < 0.01$) (Fig. 3) [11, 16].

Besides GFDI, the effect of FI in each single muscle on postoperative retear was investigated as well. We directly

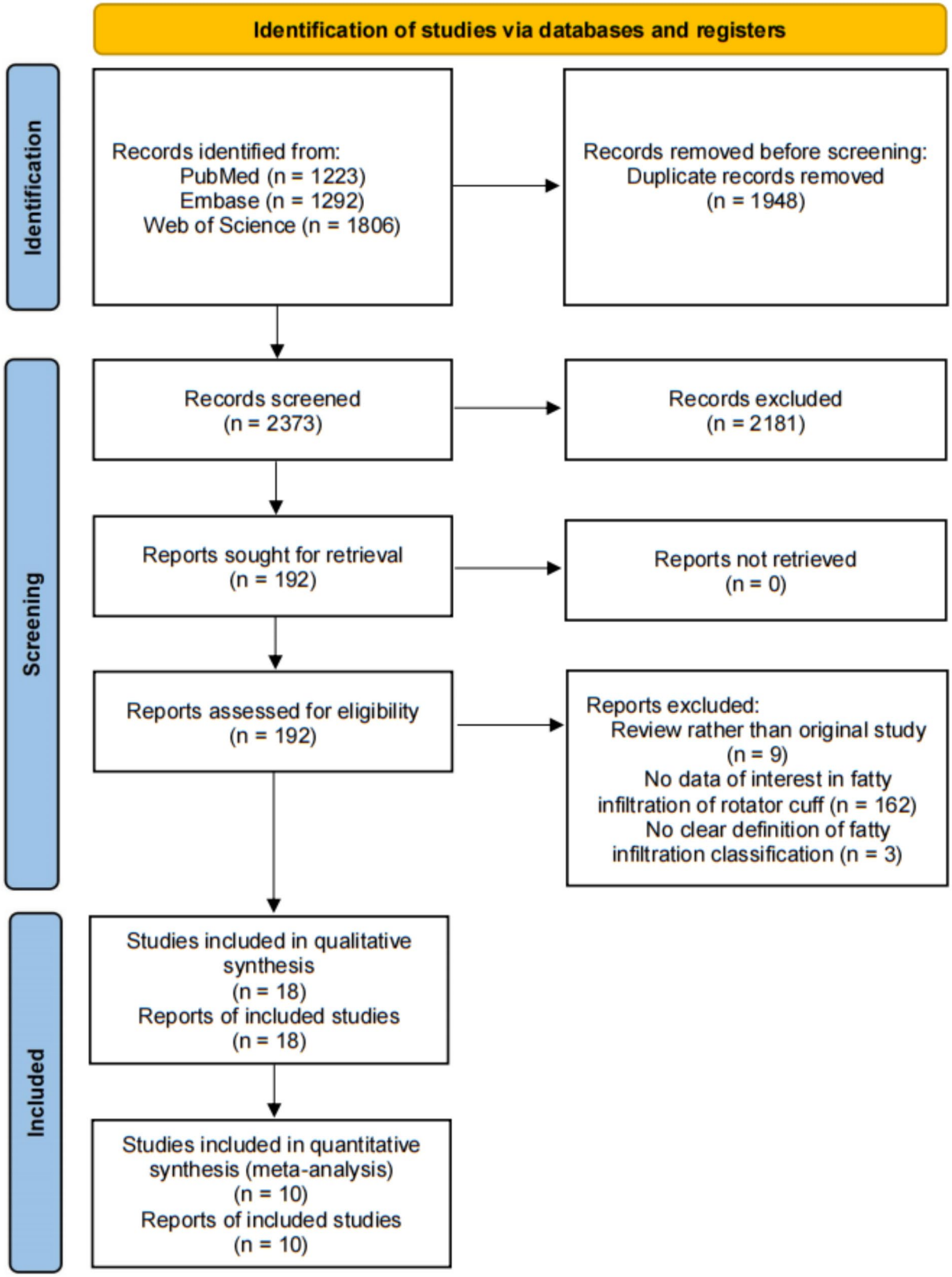


Fig. 1 Flowchart of the study selection and inclusion process

Table 1 Characteristics of the studies included

Authors (Year)	Study design	Participants, *n* (male), age	Disease, RC repair	Follow-up	FI assessment	Outcome Assessment	Outcomes (comparisons at the last follow-up if no emphasis)
Warner (2001)	retrospective case-series	19 (17) 58 (36–72) y	anterosuperior tear, open repair	40 (20–75) m	ISP, SSP, SSC (Goutallier by T1-oblique sagittal MRI)	CS	The FI of RC was graded by muscles with the most severe FI. A significant effect of preoperative FI in RC on postoperative CS was observed ($p < 0.05$).
Goutallier (2003)	retrospective case-series	220 (132) 56 (34–70) y	full-thickness RC tear, open repair	37 (12–56) m	ISP, SSP, SSC, GFDI (Goutallier by axial view CT)	retear (no description)	A higher retear rate of SSP was associated with greater FI of the ISP ($p = 0.0001$) and SSC ($p = 0.006$). A higher retear rate of RC ($p < 0.0001$) and a lower CS ($p < 0.0001$) were associated with higher preoperative GFDI.
Gerber 2007	retrospective case-series	13 56 (41–68) y	Full-thickness SSP tear, open repair	12 m	SSP, ISP, SSC (Goutallier by MRI)	retear (by lateral sagittal and coronary MRI)	The FI in retorn RC was heavier than intact RC ($p < 0.006$).
Gladstone (2007)	prospective cohort	38 62 (36–78) y	full-thickness RC tear, arthroscopic or open repair	≥ 12 (12–15) m	ISP, SSP (Goutallier by T1-coronal view MRI)	ASES and CS; retear (tendon defect on the T2-weighted sequence that filled with fluid)	The preoperative FI of ISP had a strongly negative effect on postoperative ASES (r =-0.364, $p = 0.027$) and CS (r =-0.359, $p = 0.029$) but a non-significant effect on retear rate at one-year follow-up (r =-0.300, $p = 0.076$). The preoperative FI of SSP had a strongly negative effect on retear rate at one-year follow-up (r =-0.457, $p = 0.005$). The FI of SSP didn't have a strongly negative effect on ASES (r =-0.231, $p = 0.17$) and CS (r =-0.236, $p = 0.16$).
Liem (2007)	retrospective case-series	53 (34) 60.9 ± 7.3 y	isolated SSP tear, arthroscopic repair	26.4 ± 4.8 m	SSP (Goutallier by oblique sagittal MRI)	retear (fluid-equivalent signal or no tendon visualization)	The retear rate was higher among patients with preoperative grade 2 FI of SSP, compared with patients with grade 0–1 FI of SSP (40% vs. 17%, $p = 0.021$).
Goutallier (2009)	retrospective cohort	30 (11) 58.1 ± 6.1 y	full-thickness RC tear, open repair	13 ± 4 m	GFDI (Goutallier by horizontal CT)	CS	The CS ($p = 0.0002$), strength ($p = 0.0009$), ROM ($p = 0.0056$) and pain ($p = 0.0177$) were inversely associated with preoperative GFDI.
Cho (2011)	retrospective case-series	120 (59) 55.4 y	full-thickness RC tear, arthroscopic repair	25.2 (16–34) m	GFDI (Goutallier by MRI)	retear (fluid-equivalent signal or no tendon visualization)	The retear risk was greater in patients with a higher preoperative GFDI (OR = 10.0; 95%CI 2.98–33.71, $p < 0.001$).
J.R. Kim (2012)	retrospective case-control	66 (34) 61.2 (50–75) y	massive RC tear, arthroscopic repair	25.4 m	ISP, SSP, SSC (Goutallier by T1-Y-view MRI)	retear (fluid-equivalent signal or discontinuity of tendon)	The preoperative grade of FI of SSP was higher in the retear group (2.54 ± 0.84; 95%CI 2.21–2.86) than in the intact group (1.74 ± 0.92; 95%CI 1.43–2.04) ($p < 0.001$). The preoperative degree of FI of ISP was higher in the retear group (2.07 ± 1.02; 95%CI, 1.68–2.47) than in the intact group (0.71 ± 0.77; 95%CI, 0.46–0.96; $p < 0.001$). There was no significant difference in preoperative FI of SSC between the two groups (0.93 ± 1.12, $p = 0.567$).
J.S. Park (2015)	retrospective cohort	339 (144) 59.76 ± 7.86 y	small/medium-sized RC tear, arthroscopic repair	20.8 (12–66) m	ISP, SSP, SSC (Goutallier by Y-view MRI)	retear (Sugaya type IV-V)	The RC with higher fatty degeneration (grade 2–4 vs. grade 0–1) had higher retear rate of FI in ISP ($p < 0.001$) or SSC ($p < 0.001$). But no difference in retear rate was observed between patients with grade 2–4 and grade 0–1 of FI in SSP ($p = 0.997$).

Table 1 (continued)

Authors (Year)	Study design	Participants, *n* (male), age	Disease, RC repair	Follow-up	FI assessment	Outcome Assessment	Outcomes (comparisons at the last follow-up if no emphasis)
D.H. Kim (2016)	prospective cohort	132 (50) 60.8 ± 6.9 y	full-thickness RC tear, arthroscopic repair (SR)	12.7 ± 3.2 m	ISP, SSP, SSC, TM (Goutallier by MRI)	retear (Sugaya type IV-V)	Patients in retear group had greater FI of ISP than those in intact group ($p = 0.022$). No signifcant diferences in retear rate were detected in FI of SSP ($p = 0.062$), SSC ($p = 0.140$) or TM ($p = 0.593$) in two groups.
Nozaki (2016)	prospective cohort	50 (18) 67.0 ± 8.0 y	full-thickness RC tear (at least with SSP tear), arthroscopic repair	12 m	SSP (Goutallier MRI sequence)	retear (Sugaya type IV-V)	The preoperative FI in SSP was higher in patients with retorn SSP than in those without retorn SSP ($p < 0.001$).
Barth (2017)	prospective cohort	176 (84) 56.0 ± 9.0 y	full-thickness RC tear, arthroscopic repair (DR)	35.5 (12–61) m	ISP (Goutallier by CT/MRI)	retear (Sugaya type IV-V)	A higher retear rate was related to a higher preoperative FI of ISP ($p = 0.002$).
Collin (2017)	retrospective case-series	288 (145) 56.5 ± 8.3 y	full-thickness isolated SSP tear, arthroscopic or open repair	120 m	SSP (Goutallier by T1 transverse and sagittal MRI)	CS	The postoperative CS at 10-year follow-up was most associated inversely with the preoperative FI grade of SSP ($p < 0.001$).
Godenèche (2017)	retrospective cohort	147 (69) 56.0 ± 7.7 y	full-thickness isolated SSP tear, arthroscopic or open repair	120 m	ISP, SSP (Goutallier by T1-transverse and sagittal MRI)	retear (Sugaya type IV-V)	The 10-year CS ($p = 0.006$) and intact rate ($p = 0.001$) were inversely influenced by preoperative FI of SSP. The 10-year CS ($p = 0.422$) and intact rate ($p = 0.979$) were not influenced by preoperative FI of ISP.
J.W. Park (2018)	retrospective cohort	77 (28) 60.2 ± 8.9	full-thickness RC tear, arthroscopic repair	12 m	ISP, SSP, SSC (Goutallier by Y-view MRI)	retear (Sugaya type IV-V)	The retear group had a greater preoperative FI in ISP ($p = 0.017$) and SSP ($p < 0.001$) compared with the intact group. No difference in FI of SSC was detected between two groups ($p > 0.05$).
Shin (2018)	retrospective cohort	83 (28) 61.2 (44–75) y	full-thickness SSP tear, arthroscopic or open repair	10 (8–14) m	ISP, SSP (Goutallier by T2-Y-view MRI)	retear (Sugaya type IV-V)	There was a significant difference in the preoperative grade of FI in SSP ($p = 0.034$) and ISP ($p = 0.023$) between the retear and intact groups.
Iijima (2019)	prospective cohort	107 (63) 67 (46–82) y	large or massive RC tear, arthroscopic repair	12 m	ISP, SSP (quantitative T2 mapping and Goutallier by Y-view MRI)	retear (Sugaya type IV-V)	The first study to judge the preoperative FI of RC by T2 mapping: The preoperative T2 values of SSP (77.4 ± 13.2 vs. 66.5 ± 11.1, $p < 0.001$) and ISP (73.2 ± 15.3 vs. 58.6 ± 10.7, $p < 0.001$) were higher in retorn shoulders than in intact shoulders when the Goutallier grade showed no difference.
Tanaka (2021)	retrospective case-series	39 (24) 64.2 ± 8.7 y	large/massive RC tear, arthroscopic repair	24 m	GFDI (Goutallier by T2-Y-view MRI)	JOA and UCLA	The preoperative GFDI was inversely associated with the UCLA (r =-0.75, $p < 0.05$) and JOA score (r =-0.61, $p < 0.05$) at two-year follow-up.

RC = rotator cuff, FI = fatty infiltration, Goutallier = Goutallier classification, DR = double-row suture anchor, SR = single-row suture anchor, ISP = infraspinatus muscle, SSP = supraspinatus muscle, SSC = subscapularis muscle, TM = teres minor muscle, CS = Constant score, UCLA = University of California at Los Angeles score, ASES = American Shoulder and Elbow Society score, ROM = range of motion, JOA = Japanese Orthopedic Association score, GFDI = global fatty degeneration index = the mean FI value of SSP, ISP and SSC, r = correlation coefficient, OR = odds ratio

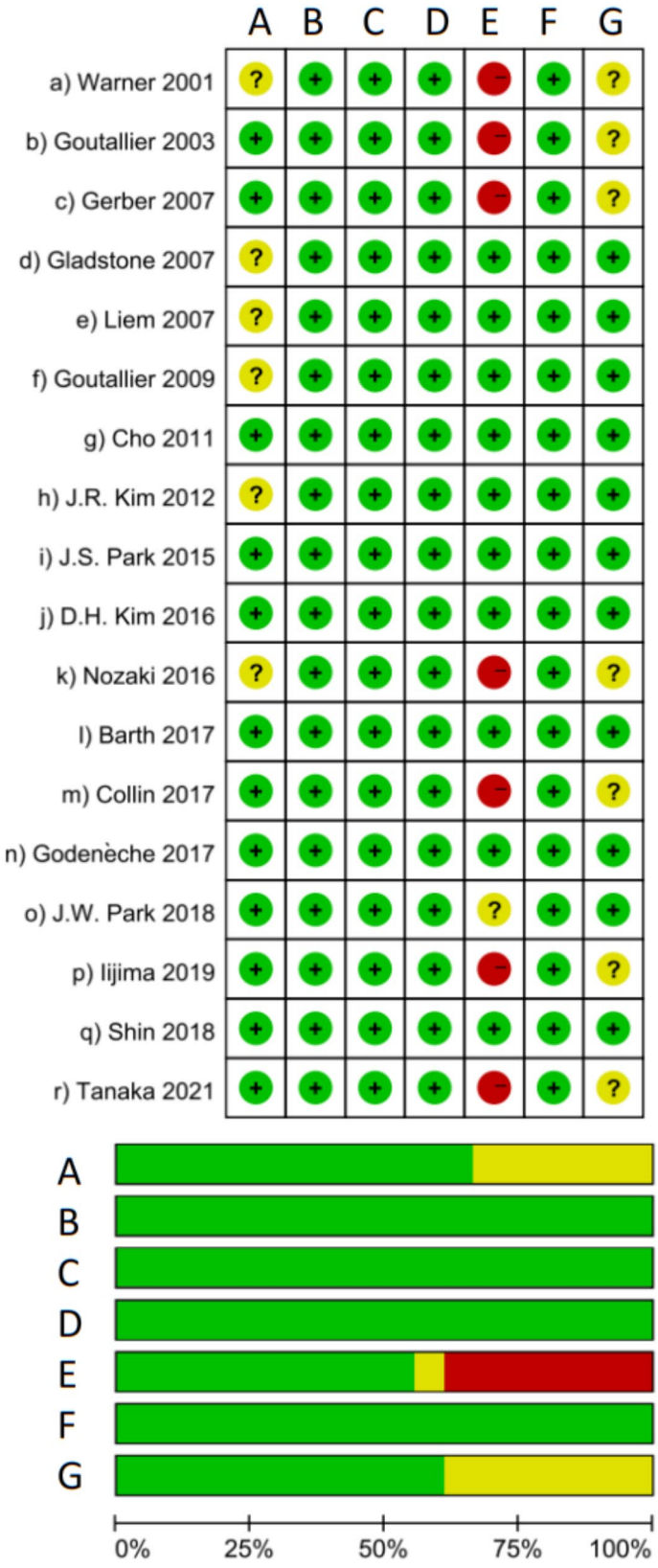


Fig. 2 Risk of bias for the included studies. A = study participation, B = study attrition, C = prognostic factor measurement, D = outcome measurement, E = study confounding, F = statistical analysis and reporting, G = overall risk of bias; green color represents low risk of bias, yellow color represents moderate risk of bias, red color represents high risk of bias

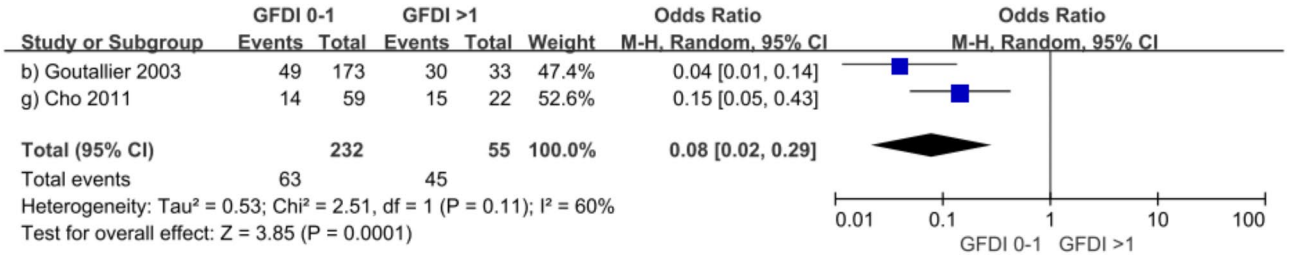


Fig. 3 Forest plot of postoperative retear odds between patients with 0–1 and > 1 GFDI for complete RC repair. GFDI = global fatty degeneration index, RC = rotator cuff

extracted the numbers of retorn shoulders with mild, moderated and severe FI, respectively, from the studies included (Supplementary Tables 2–4). Patients with mild, moderate and severe FI in SSP presented different retear rates (16.1%, 33.6% and 53.2% respectively). The rates differed in patients with mild, moderate and severe FI in ISP as well (18.6%, 26.8% and 46.8% respectively). Whereas there was no significant difference in retear rates among patients with mild, moderate and severe FI in SSC (15.0%, 24.0% and 28.6% respectively). The weighted effect of FI in TM was not well calculated because of the limited data provided.

There was a significant effect of the severity of FI in SSP on the risk of retear. In our review, ten studies investigated the relationship between preoperative FI in SSP and postoperative retear [20, 23, 31, 43–49, 52]. Eight of the studies suggested a significantly greater risk of retear in patients with higher FI in SSP, compared to those with lower FI in SSP [20, 31, 43–45, 47–49]. For further comparison among patients with mild, moderate and severe FI in SSP, meta-analyses in seven studies with sufficient data were performed [20, 23, 45, 47–49, 52]. Patients with grade 2 FI in SSP had significantly higher retear odds after complete RC repair than those with grade 0–1 FI (OR = 1.95, 95%CI 1.09–3.48, $I^2 = 0\%$, $p = 0.02$) (Fig. 4a), and patients with grade 3–4 FI in SSP had significantly higher retear odds after complete RC repair than those with grade 2 FI (OR = 3.37, 95%CI 1.08–10.53, $I^2 = 54\%$, $p = 0.04$) (Fig. 4b). These findings inspired us that there was a dose-response effect in retear odds among mild, moderate and severe FI in SSP. Patients with moderate FI in SSP could expect a better prognosis than those with severe FI in SSP, although the retear odds was obviously higher than patients with mild FI.

A similar effect was observed in the severity of ISP. Eleven studies investigated the association between preoperative FI in ISP and postoperative retear [11, 15, 23, 31, 43, 45–49, 52]. Eight studies suggested a greater retear odds in patients with higher FI in ISP [11, 15, 23, 31, 45, 46, 48, 49]. Meta-analyses in a total of seven studies with sufficient data were performed [15, 23, 45, 47–49, 52]. In our meta-analysis, patients with grade 2 FI in ISP had significantly higher retear odds after complete RC repair than those with grade 0–1 FI (OR = 2.22, 95%CI 1.07–4.62, $I^2 = 36\%$, $p = 0.03$) (Fig. 5a). Patients with grade 3–4 FI in ISP had significantly higher retear odds after complete RC repair than those with grade 2 FI (OR = 2.06, 95%CI 1.02–4.16, $I^2 = 20\%$, $p = 0.04$) (Fig. 5b). There was a dose-response in retear odds among mild, moderate and severe FI in ISP.

However, according to five studies included, the FI of SSC was not associated with the risk of retear [23, 31, 46, 48, 52]. Four of five studies suggested no significant difference in retear rates among patients with different FI in SSC [23, 31, 48, 52]. The meta-analyses showed no differences in retear odds between patients with grade 2 and grade 0–1 FI in SSC (OR = 1.22, 95%CI 0.45–3.29, $I^2 = 0\%$, $p = 0.70$) (Fig. 6a), or between patients with grade 3–4 and grade 2 FI (OR = 1.21, 95%CI 0.19–7.69, $I^2 = 0\%$, $p = 0.84$) (Fig. 6b) [23, 48, 52].

Limited evidence was collected for assessment in prognostic effect of FI in TM on retear. There was only one study concentrating on the relationship between preoperative FI in TM and postoperative retear rate [23]. In that study, the overall grade of FI in TM among these 131 patients was relatively low, in which 129 patients had shoulders with grade 0–1 FI and only three had shoulders with grade 2. The FI of TM was not significantly higher in patients who suffered from retear, compared to those with an intact RC after arthroscopic repair ($p = 0.59$).

The funnel plots and Egger's test presented no evidence of publication bias in meta-analyses ($p > 0.05$).

The effect of FI on postoperative functional outcomes

Besides retear, the FI in RC was associated with the functional impairment after complete RC tear repair surgery as well. In our synthesis, a total of seven studies investigated the effect of preoperative FI on postoperative functional outcomes [11, 17, 18, 43, 47, 50, 51] (Table 2). The published standard scales were adopted for assessment. These studies were mainly focused on the effects of GFDI, SSP and ISP, while the effect of SSC or TM was not investigated among articles included in our review.

In our vote-counting model, three studies reached the consistent evidence that a higher GFDI was associated

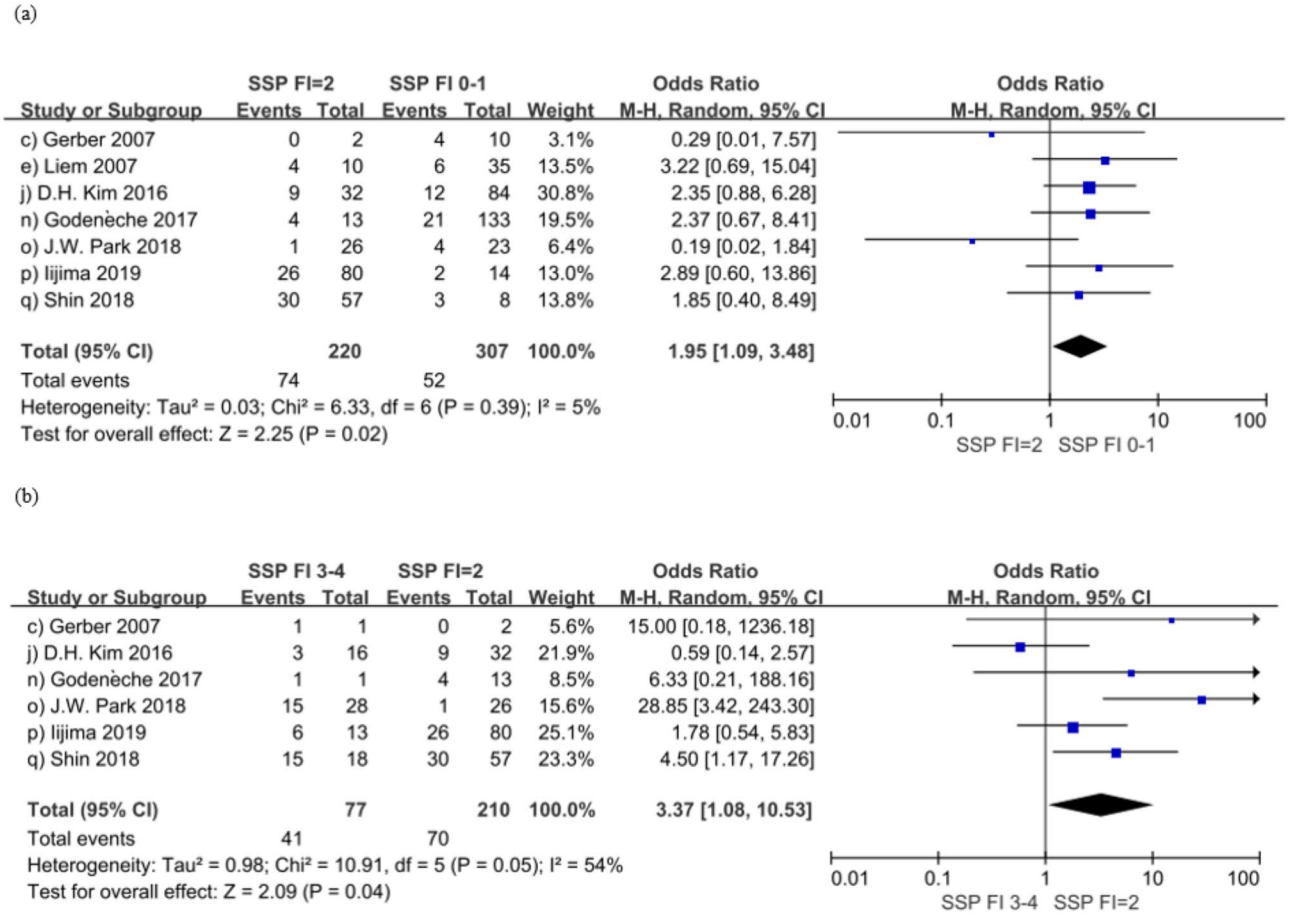


Fig. 4 Forest plot of postoperative retear odds among patients with mild, moderate and severe FI of SSP for complete RC repair. (**a**) Forest plot of postoperative retear odds between patients with mild and moderate FI of SSP. (**b**) Forest plot of postoperative retear odds between patients with moderate and severe FI of SSP. FI = fatty infiltration, SSP = supraspinatus muscle

with poorer functional outcomes after complete RC repair [11, 17, 51]. In addition to these studies, Warner et al. were interested in the effect of the muscle with the most severe grade of FI in RC [50]. A significant association between greater FI and poorer Constant score was observed among the patients with anterosuperior RC tear ($p < 0.05$). The effect of FI in SSP or ISP on postoperative functional outcomes remained conflicting.

Discussion

The FI in RC is commonly visualized in patients with full-thickness RC tears [53]. Multiple studies have demonstrated that greater FI in RC predicts worse postoperative outcomes after complete RC repair [15–19]. However, previous meta-analyses merely uncovered the relationship between higher FI and poorer outcomes, failing to make further comparison among patients with mild (grade 0–1), moderate (grade 2) and severe (grade 3–4) FI [19, 27]. In this study, we made the first meta-analysis to examine the dose-response relationship on postoperative retear among patients with mild, moderate and severe FI in RC. We also paid attention to the association of preoperative FI with functional outcomes. Our findings would be beneficial for clinical decision making, providing more prognostic evidence for patients especially who have the moderate-to-severe FI in RC.

Our review showed that shoulders with heavier GFDI were at higher retear odds. Previously the effect of GFDI on retear was uncertain [24]. Müller et al. proved that the GFDI > 1.5 was a risk factor for postoperative retear [25]. Our results added to the study that patients with GFDI > 1.0 were at high odds of retear, which encouraging more patients to pay attention to the management of GFDI. When it comes to the FI of each single muscle in RC, the majority studies reported the prognostic differences between mild and moderate-to-severe FI, without further investigation in differences between moderate and severe FI [1, 19, 25–27]. The study by Tsuchiya et al. initially aroused the attention on the prognostic differences between mild-to-moderate and severe FI in SSP and ISP [28]. In our study, we reported the effects of the severity of FI in SSP and ISP on postoperative retear

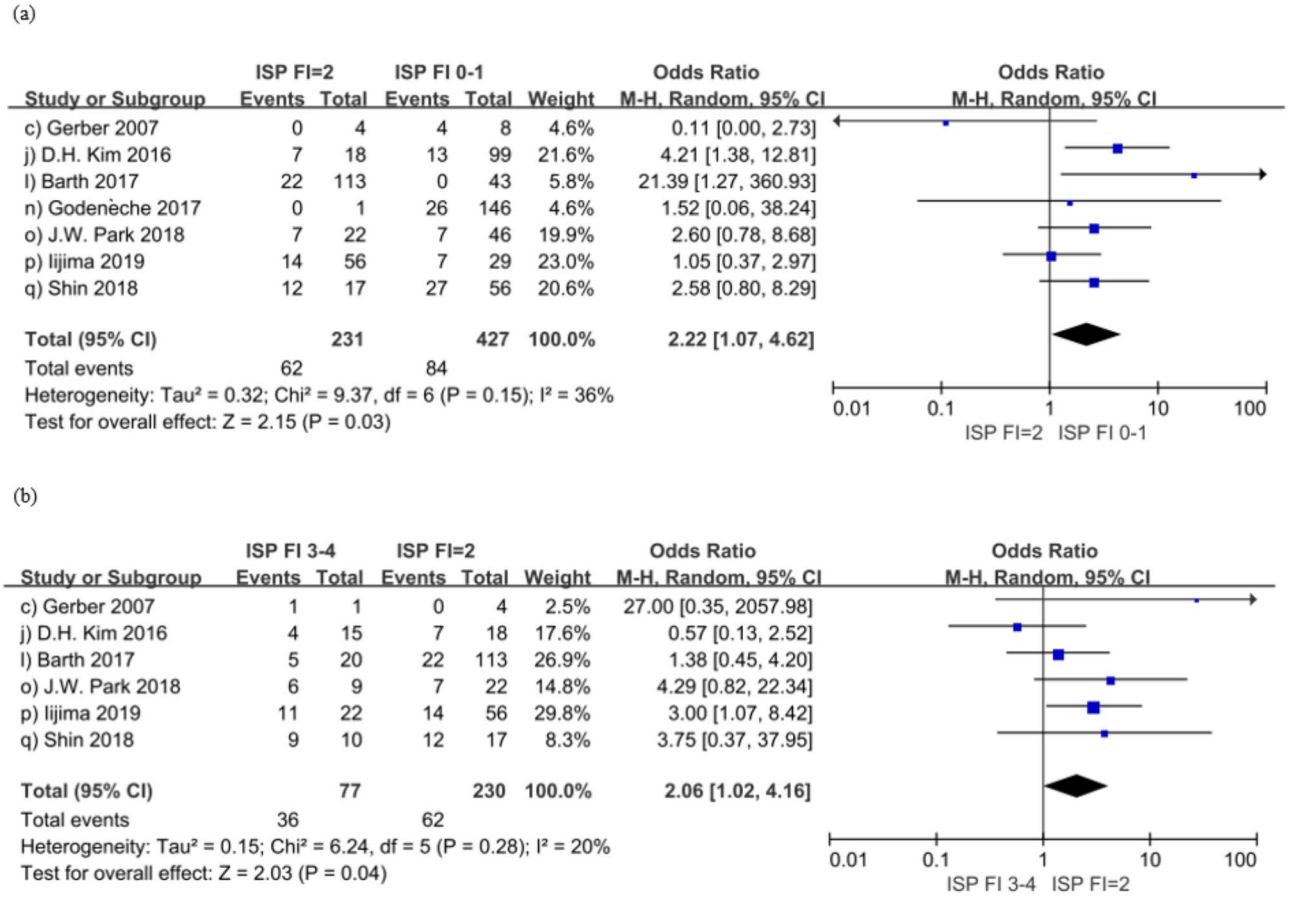
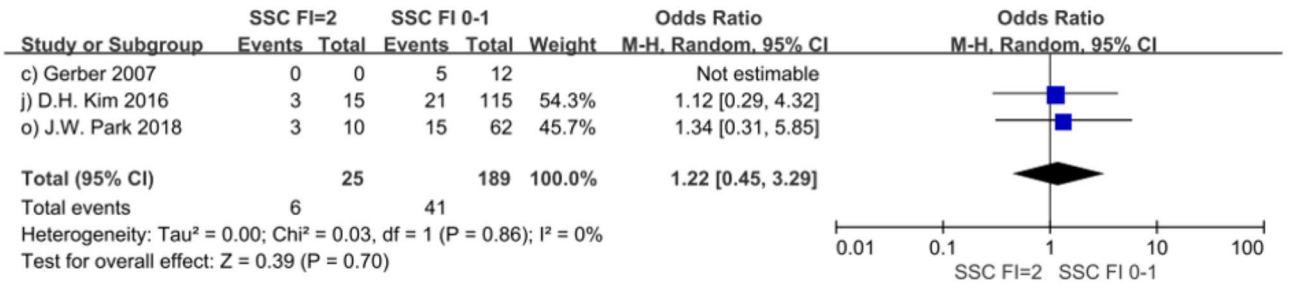


Fig. 5 Forest plot of postoperative retear odds among patients with mild, moderate and severe FI of ISP for complete RC repair. (**a**) Forest plot of postoperative retear odds between patients with mild and moderate FI of ISP. (**b**) Forest plot of postoperative retear odds between patients with moderate and severe FI of ISP. FI = fatty infiltration, ISP = infraspinatus muscle

after complete repair. The majority of tears occurred in an avascular zone called the rotator crescent, which was located in the intersection of the SSP and ISP tendons. The tears in the rotator crescent could be partially compensated by the tendons of SSP and ISP before complete healing [54], which could be an explanation why the FI in SSP and ISP played an important role in healing of RC tears. Moreover, there were more factors as well as FI affecting the retear rates after RC repair. In published reviews, larger tear size, tear with osteoarthritis, more tendons affected in tear, patients > 55 years old, and the follow-up > 1 year were all considered to be at higher risk of retear [25, 55]. Besides, the retraction of the tendon was also associated with the retear risk, and Dominik et al. suggested a combination of Goutallier FI classification and preoperative tendon length as a predictor for retear during the follow up [56].

As for functional outcomes, the GFDI was the only efficient predictor with consistent evidence in our vote-counting model. Patients with lower GFDI had better functional outcomes after complete RC repair. Goutallier et al. made the earliest investigation in this field, involving 220 shoulders receiving open repair for full-thickness tear [11]. The patients with higher preoperative GFDI were more likely to have worse postoperative Constant scores at a 3-year follow-up. Another study conducted by Goutallier et al. also reported a negative correlation between preoperative GFDI and Constant score at 9-year follow-up after open repair [17]. As for arthroscopic repair, Tanaka et al. showed that the 2-year UCLA scores and JOA scores were inversely related with the higher GFDI among patients with large or massive RC tears [51]. Whereas the effect of single muscle on functional outcomes was limited or conflicting. Collin et al. and Godenèche et al.found that the Constant score was inversely associated with the preoperative FI grade of SSP among patients with isolated SSP tear [18, 47]. However, Gladstone et al. reported that the SSP FI failed to predict the Constant scores after open or arthroscopic surgeries [43]. We further divided the functional outcomes into various components, including strength and pain. As for strength component, Godenèche et al. and Gladstone et al. both suggested a significant association between lower FI in SSP and higher strength after repair, while Collin et

(a)



(b)

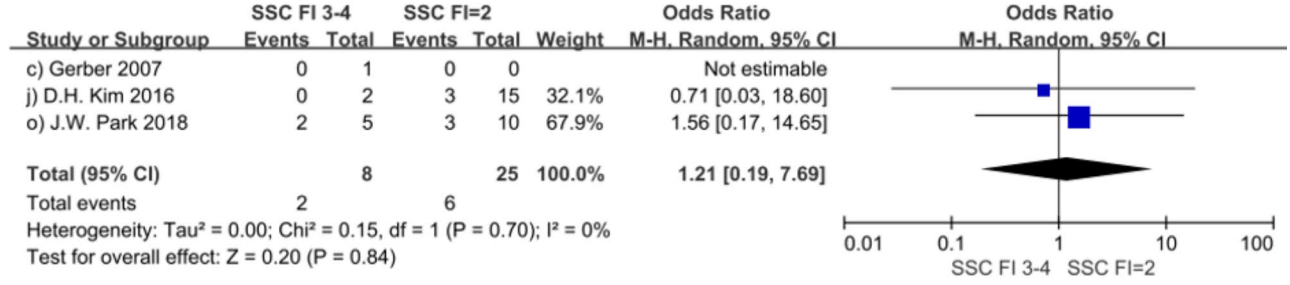


Fig. 6 Forest plot of postoperative retear odds among patients with mild, moderate and severe FI of SSC for complete RC repair. (**a**) Forest plot of postoperative retear risk between patients with mild and moderate FI of SSC. (**b**) Forest plot of postoperative retear risk between patients with moderate and severe FI of SSC. FI = fatty infiltration, SSC = subscapularis muscle

Table 2 The evidences in functional outcomes concluded from studies included

Results	Levels	Studies
Preoperative GFDI can predict the clinical outcomes after RC repair.	**Consistent (3/3)**	
S: Greater GFDI was correlated with lower 2-year UCLA (r=-0.75, $p<0.05$) and JOA (r =-0.61, $p<0.05$) scores post arthroscopic repair in patients with large or massive RC tear.		Tanaka 2021
S: Greater GFDI was associated with lower CS post open repair in patients with full-thickness RC tear at 3-year follow-up ($p<0.0001$).		Goutallier 2003
S: Greater GFDI was correlated with lower CS post open repair in patients with full-thickness RC tear at 9-year follow-up ($p=0.0002$).		Goutallier 2009
FI of the muscle with the most severe preoperative FI can predict the clinical outcomes after RC repair.	**Limited (1/1)**	
S: FI of muscle with the more severe FI in T1-oblique sagittal view predicted lower CS post open repair in patients with anterosuperior RC tear ($p<0.05$).		Warner 2001
Preoperative FI of SSP can predict the clinical outcomes after RC repair.	**Conflicting (2/3)**	
S: Greater FI of SSP was correlated with lower CS post arthroscopic or open repair in patients with isolated SSP tear ($p<0.001$).		Collin 2017
S: Greater SSP FI was correlated with lower 10-year CS post arthroscopic or open repair in patients with isolated SSP tear ($p<0.05$).		Godenèche 2017
U: SSP FI was no correlated with the ASES ($p=0.17$) or CS ($p=0.16$) post arthroscopic or open repair in patients with full-thickness RC tear.		Gladstone 2007
Preoperative FI of ISP can predict the clinical outcomes after RC repair.	**Conflicting (1/2)**	
S: Greater ISP FI was correlated with lower ASES (r =-0.364, $p=0.027$) and CS (r =-0.359, $p=0.029$) post arthroscopic or open repair in patients with full-thickness tear.		Gladstone 2007
U: ISP FI was not correlated with 10-year CS post arthroscopic or open repair in patients with isolated SSP tear ($p=0.644$).		Godenèche 2017

GFDI = global fatty degeneration index = the mean FI value of infraspinatus, supraspinatus and subscapularis muscle, SSP = supraspinatus muscle, ISP = infraspinatus muscle, RC = rotator cuff, FI = fatty infiltration, UCLA = University of California at Los Angeles score, ASES = American Shoulder and Elbow Society score, CS = Constant score, JOA = Japanese Orthopedic Association score, S = supported, U = unsupported, r = correlation coefficient

al. didn't support that association [18, 43, 47]. When it comes to postoperative pain, Godenèche et al. discovered a significant association between lower FI in SSP and less pain after repair, but Collin et al. and Gladstone et al. didn't support that association. The effect of FI in ISP on postoperative functional outcomes remained conflicting as well [43, 47]. One explanation was that the function of shoulder relied on cooperation with all RC muscles, and the GFDI provided the global assessment on RC condition. More studies were required to better identify the prognostic functional effect of FI in each single muscle.

There existed some limitations in our systematic review and meta-analysis. First, the publication bias assessment relied on the small number of studies included in synthesis. Consequently, a possibility of publication bias existed even though the funnel plots and Egger's test indicated no evidence for bias. Second, although we have made a subgroup analysis with different measured muscles (GFDI, SSP, ISP, SSC or TM), respectively, there were still some heterogeneities in our study. In our study, we decided to accept the heterogeneity in causes of diseases (traumatic or degenerative) and operations (open, single-row and double-row), for a feasibility of meta-analysis [28, 38]. A cohort enrolling consecutive 1300 patients showed that there was no difference in retear rates between patients with and without a history of trauma [57]. Whether the postoperative outcomes were influenced by open, arthroscopic single-row and arthroscopic double-row repair remained uncertain. Müller et al. showed that the patients treated by double-row repair expected better outcomes than those treated by single-row repair [25], while others presented no significant differences among these surgical technics [58, 59]. Besides, researches showed that a patient with lower socioeconomic status, early repair after trauma or more tendons affected in the RC tear was at higher risk of retear post RC repair, and the retear risk kept increasing after one year post RC repair [1, 25, 60, 61]. Those were some confounding factors which were unavoidable in our meta-analysis. Moreover, the inclusion of study at low level of evidence and the limited number of studies on functional outcomes were also limitations for our study, which inspired researchers to conduct more studies at high level of evidence such as randomized controlled trials on the prognostic factors of RC repair, especially on the functional outcomes including pains, daily activities, joint range of motion and muscle strength.

Conclusion

In conclusion, our study revealed that there was a relationship between the severity of FI in SSP and ISP and postoperative retear. Patients with severe FI in SSP and ISP were at an increased odds of postoperative retear following complete RC, compared with patients with moderate FI in SSP and ISP. The higher grade of GFDI was a compatible predictor for higher risk of both retear and poorer functional outcomes postoperatively.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13018-025-05702-6.

Supplementary Material 1

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Author contributions

J.L. was responsible for study design. All authors completed the data search, study inclusion and data extraction. H.W. and Q.L. made the data synthesis. H.W. wrote the main manuscript and prepared figures and tables. All authors reviewed the manuscript.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Competing interests

The study was approved by National Key Research and Development Program of China (No. 2022YFC2505500). All authors declare no other conflicts of interest concerning this work.

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