Systematic Review

Elevated Body Mass Index Is Associated With Rotator Cuff Disease: A Systematic Review and Meta-analysis

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Purpose: To analyze the literature regarding obesity, body mass index (BMI), and rotator cuff disease (RCD). **Methods:** In this Systematic Review and Meta-analysis, we queried PubMed, Embase, Cochrane, Cumulative Index to Nursing & Allied Health, and Science Direct using key words (August 25, 2023). Analytic observational studies (cohort, case-control, and cross-sectional studies) with more than 30 participants per comparison group, evaluating the association between obesity and rotator cuff pathology, were eligible for inclusion. Meta-analysis was performed to quantitatively summarize associations between BMI and RCD to report odds ratios and corresponding 95% confidence intervals (CIs) for regression-based models and BMI mean differences between cases and controls. Risk Of Bias In Non-randomised Studies − of Interventions tool was used to evaluate risk of bias across all studies in the systematic review. **Results:** After full-text review of 248 articles, 27 presented data on obesity and RCD, and 17 qualified for meta-analysis. Individuals with RCD were 1.21 times (95% CI 1.10-1.34) as likely to have overweight and 1.44 times (95% CI 1.32-1.59) as likely to have obesity compared with those without RCD. Each 5-unit increase in BMI was associated with 35% greater odds of having rotator cuff tear (95% CI 1.06-1.71). In-depth assessment for risk of bias shows quality of studies varies greatly and highlights outcome heterogeneity, lack of temporality, confounding and selection bias as major concerns for individual studies. **Conclusions:** In this study, we found a positive association between elevated BMI and RCD. **Level of Evidence:** Level III, systematic review and meta-analysis of Level II-III studies.

Rotator cuff disease (RCD), a composite term for multiple related pathologies of the rotator cuff, including tendonitis and rotator cuff tear (RCT), is among the most common causes of pain and disability.[1-5] Both intrinsic and extrinsic factors contribute to the pathophysiology associated with RCD.[4,6-9] Intrinsic factors include age-driven degeneration, poor vascularity, shoulder overuse, genetic predisposition, and anatomical features, whereas extrinsic factors include trauma, tensile overload, and repetitive stress.[4,7,10,11] Metabolic factors such as diabetes, cigarette smoking, hypertension, hypercholesterolemia, and obesity may also play a role in the multifactorial etiology of RCD.[9,10,12,13]

Obesity has been identified as a risk factor for various musculoskeletal disorders,[14-16] including RCD.[17-19] Moreover, systematic reviews have identified obesity as a risk factor for tendinopathy, tendon tear and rupture, and postoperative complications.[20,21] Since obesity is one of the few modifiable risk factors associated with RCD, there are clear advantages to studying and understanding the role of obesity in the etiology of RCD.

Several clinical and epidemiologic studies have evaluated the relationship between obesity and RCD. However, evidence across studies has not always been consistent. To address this gap, we conducted a systematic review of observational studies that reported the relationship between measures of obesity and RCD.

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We further performed meta-analyses of studies that reported on the relationship between body mass index (BMI) as a measure of obesity and RCD. The purpose of this study was to analyze the literature regarding obesity, BMI, and RCD. We hypothesized that individuals with greater BMI would have a greater risk of RCT and RCD.

Methods

Search Strategy

We conducted this review following Institute of Medicine, Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA),[22,23] PRISMA in Exercise, Rehabilitation, Sport medicine and SporTs science (PERSiST),[24,25] and Meta-analysis Of Observational Studies in Epidemiology (MOOSE) guidance for systematic reviews and meta-analyses[26] (Rotator Cuff Full Search Criteria is included as Supplementary Material). This review was not registered on PROSPERO.

A research librarian, experienced in conducting systematic reviews, performed systematic queries across multiple databases (PubMed, Embase, Cochrane, Cumulative Index to Nursing & Allied Health, and Science Direct) on August 25, 2023. Studies that included adults at risk for RCD and evaluated the relationship between putative risk factors and RCD were eligible for inclusion. Articles were screened out if they were not available in English, not related to RCD, described surgical procedures, were case reports/series, were not original research articles (opinions, editorials, systematic reviews, and meta-analyses), did not have data available (were abstracts only), or were duplicates. Investigators supplemented electronic searches with hand-searching of reference lists of retrieved articles. The search included MeSH (Medical Subject Headings) terms and key words relating to rotator cuff injuries, rotator cuff tendons/muscles, rotator cuff repair, obesity, adiposity (overall body fat constitution), and BMI. Full search protocol is listed in the Supplementary Section.

We used an inclusive strategy to search for any risk factor rather than specific terms for obesity to maximize capture of all possible studies including those that may not explicitly report the relationship between obesity-related factors and RCD in the title and abstract. This strategy prevents omission of studies that did not find an association (publication bias) and studies in which this was not the primary investigation of interest. Two reviewers (S.H. and A.G.) identified relevant studies. Discrepancies were resolved through discussion by the review team.

Screening identified 248 articles that qualified for full-text review. During full-text review, we identified studies with proper comparison or control groups that reported on the relationship between measures of adiposity, including BMI, and RCD. Studies investigating BMI and RCD were included in the systematic review. We focused our meta-analysis on studies that evaluated the association between BMI and RCD, as this measure of adiposity was most commonly used by studies.

We incorporated independent analytical observational studies that provided appropriate effect estimates or at least the necessary information to calculate them and had at least 30 cases and 30 controls (allows for stable estimates). If articles reported estimates that were based on the same or overlapping populations, the article that reported effect estimate on the largest available sample size was used. When studies published multiple effect estimates, priority was given to adjusted effect estimates from the largest sample size.

Two reviewers (S.H. and A.G.) independently screened studies, reviewed abstracts, and extracted data (including study details, population, setting, results, potential confounders, follow-up, and analytic approach). Discrepancies were reconciled through discussion by the review team.

Assessment of RCD

The outcome evaluated in this meta-analysis is RCD as a composite dichotomous outcome. RCD serves as an umbrella term for the following conditions reported in studies: RCT, supraspinatus tear, infraspinatus tear, teres minor tear, subscapularis tear, rotator cuff syndrome, rotator cuff tendinopathy, rotator cuff tendonitis, rotator cuff tendinosis, rotator cuff injury, and RCD. We used this inclusive approach to allow for aggregation and quantification of studies evaluating the association between obesity and RCD. If studies provided separate estimates for subconditions of RCD, the most inclusive data were included in the meta-analysis for rotator cuff cases. If studies reported estimates by subgroup only and did not provide a combined estimate for RCD, a composite score was created for cases using the independent estimates for each subgroup and appropriately weighted to create a unified case group.

Assessment of Obesity

Studies that did not report on the relationship between a measure of adiposity and RCD were not included in the systematic review. We focused on BMI, a proxy for general adiposity, as a risk factor for RCD. Studies allowing comparison of obesity measures by RCD status were included in the systematic review. Studies that further reported, at the very least, mean BMI and standard deviation by case-control status, raw numbers, or regression-based estimates for the relationship between BMI (as a continuous variable or as a categorical variable) and RCD were considered for meta-analysis.

Data Abstraction and Homogenization

We used a standardized approach for data abstractions considering the following fields for each article: study title, publication date, journal, first author, study

design, RCD definition (tear, syndrome, disease, or tendonitis), method of diagnosis (imaging with magnetic resonance imaging [MRI], computed tomography, ultrasound, surgical repair codes, medical notes), BMI, number of cases and controls, number of cases and controls by BMI status when appropriate to compute effect estimate, mean and standard deviation for BMI by case-control status, unadjusted effect estimate if provided, and multivariable-adjusted effect estimate if provided. We abstracted and flagged all estimates reported in each study to avoid double counting of correlated estimates in any given meta-analysis set when more than one effect estimate was reported for different definitions of RCD. All estimates were abstracted for 2 or more mutually exclusive populations reported in the same study, for example, separate estimates for male and female subjects, if provided.

Studies reported the relationship between BMI and RCD in at least one of these ways: effect estimates (odds ratios [ORs], hazard ratios) from generalized linear models, with or without adjustment for covariates for BMI as a continuous or as categorical variables, as crude numbers sufficient to compute unadjusted ORs when BMI was reported as a categorical variable or as mean and standard deviation for BMI by case-control status. Data were homogenized and grouped to represent the following groups for meta-analysis: (1) comparison of OR for BMI as a categorical variable with modified-World Health Organization BMI categories (Normal weight: <25; overweight: 25-29.9; and obese: ≥ 30); (2) comparison of OR for BMI as a continuous variable; and (3) comparison of mean BMI by case-control status. Across all aforementioned meta-analysis subgroups listed, if 3 or more studies in any group reported on measures of association specific to RCTs (full or partial), a separate meta-analysis for RCT specific risk was also conducted.

Pooling

To maximize capture of data on the association of obesity and rotator cuff disease, this study intentionally used broad search criteria. One of the advantages of broad search criteria is increased sample size and power. This does result in heterogeneity across included study designs. Therefore, to address this, we conduct meta-analyses by grouping studies on the basis of effect measure reported. There were 4 separate effect-estimates: (1) studies reporting ORs for RCD among individuals with overweight versus individuals without obesity, (2) studies reporting ORs for RCD among individuals with versus without obesity, (3) studies reporting ORs for RCD for BMI modeled continuously, and (4) studies reporting the mean difference in BMI among individuals with and without RCD. In this case, pooling by effect measure was not only necessary because of statistical limitation but also in order to ensure that studies are being compiled with similar studies.

Similarly, when more than one study in each analysis provided results for RCT specific risk, a separate analysis was conducted. Because RCD is a composite term that encompasses a variety of pathologies, the risk profile for RCD may differ significantly from that of RCT. Therefore, conducting sub-group analyses for RCT is justified in order to delineate the relationship of obesity with tear as pooled analyses including all RCD might conceal the true tear specific risk. The strategy of an inclusive pooled analyses accompanied by group-specific analyses was implemented to provide a more granular investigation into the relationship between measures of obesity and rotator cuff disease.

Statistical Analysis

Studies reporting ORs for BMI as a categorical variable were used for 2 meta-analysis groups: overweight and obese, both compared with normal weight (BMI <25) as the reference. Studies reporting ORs from regression models with BMI as a continuous variable were meta-analyzed as a separate group. If studies reported estimates from granular categories of BMI, they were homogenized to the modified World Health Organization BMI categories to allow for aggregation using inverse variance weighting based off standard error (SE) computed from given confidence intervals. Similarly, if studies reported estimates for obese versus not obese, these were flagged for inclusion into the obese group analysis. We report ORs and 95% confidence intervals (CIs) as the meta-analysis estimate for studies reporting ratio measures, with OR >1 suggesting greater BMI is associated with increased risk of RCD, and OR <1 suggesting greater BMI is associated with lower risk of RCD. We report ORs for BMI as a continuous variable per 5-unit increase in BMI (as opposed to a 1 kg/m^3) for greater ease of interpretation. When available, SE was calculated from the 95% CI provided using the formula SE = (upper CI − lower CI)/(2*z score[α/2]); otherwise, SE was calculated from the *P* value as described by Altman and Bland.[27] Heterogeneity was assessed among groups using forest plots and evaluation of the I^2 statistic.

Multiple estimates from the same study contributed to a given meta-analysis set only if those studies reported independent effect estimates from nonoverlapping mutually exclusive populations, for example, by sex. We prioritized multivariable-adjusted estimates over unadjusted estimates for inclusion. If studies did not report adjusted or unadjusted ORs, we computed unadjusted ORs when numbers were provided. When studies provided multiple effect estimates by varying definitions of RCD, only the estimate from the larger sample size was considered, as decided a priori. For studies that reported mean BMI and standard deviation

by case-control status, we computed the mean difference and SE and preformed meta-analysis. We report mean differences and corresponding 95% CIs, with a positive number indicating greater BMI on average for cases than controls and a negative number indicating lower average BMI for cases than controls. All meta-analyses were performed using the inverse-variance weighted fixed-effect method. We used contoured-enhanced funnel plots for visual inspection of small study publication bias. Analyses and plotting were performed using the metan package in STATA/MP 16.1 (StataCorp, College Station, TX), and the meta[3] package in R (Version 4.2.1 for macOS 10.13; R Core Team, 2022; R Foundation for Statistical Computing, Vienna, Austria).

Risk of Bias Assessment

Risk of bias was assessed for 24 of the 27 studies included in the systematic review. Atala et al.,[28] Dong et al.,[29] and Haveri et al.[30] were not eligible for risk of bias analysis because they lacked a clear definition of either the outcome or the exposure. Risk of bias was assessed using a modified Risk Of Bias In Non-randomised Studies − of Interventions tool[31] developed by the Cochrane to assess risk of bias in the results of nonrandomized studies. The risk of bias was evaluated among the 5 categories of the Risk Of Bias In Non-randomised Studies − of Interventions tool: (1) bias as the result of confounding, (2) bias in selection of participants into the study, (3) bias as the result of missing data, (4) bias in measurement of outcomes, and (5) bias in selection of the reported result. Assessment of bias as the result of confounding was informed by an a priori directed acyclic graph (Appendix Fig 1, available at www.arthroscopyjournal.org), which we used to identify minimally sufficient set of variables needed for adjustment for confounding in the association between obesity and RCD. These included aging, sex, occupation, smoking, and uncontrolled diabetes (type I). Bias among all 5 domains was evaluated as: low, low/moderate, moderate, moderate/serious, serious, serious/critical or critical. After evaluation across these categories, investigators assigned an overall risk of bias for each study. Bias was independently evaluated by 2 expert investigators who were blinded to the other's assessment. Risk of bias data were collected and managed using REDCap (Research Electronic Data Capture), a secure, web-based software platform designed to support data capture for research studies hosted at Vanderbilt University Medical Center.[32] Average bias was assigned by comparing the scores of the 2 reviewers for each study, such that the score in between the 2 scores was assigned. For example, if one reviewer assigned the study a "Low" and the other reviewer assigned a "Moderate," the average score would be "Low/Moderate." If the reviewers assigned neighboring scores (i.e., reviewer 1 = "Low" and reviewer 2 = "Low/Moderate"), then the overlapping score was assigned as the average (for example, in this case, the study would be assigned "Low"). Inter-rater reliability was assessed by calculating chance-corrected agreement coefficients using Gwet's A1 method across all ROB domains. Overall Gwet A1 coefficient was calculated as the average of the coefficients for all domains.[33,34] As sensitivity analyses, we grouped studies by strata of risk of bias and performed meta-analyses to assess whether studies with greater risk of bias were systematically different from studies with low risk of bias.

Results

Qualitative Review

A total of 14,994 relevant titles and abstracts of articles were available for screening. Screening identified 248 articles that qualified for full-text review. Full-text review identified 27 articles that reported obesity measures in relation to RCD in their study, varying in quality of evidence from Level II to Level III (Fig 1). There were a total of 14,144 unique cases of RCD (5,758 tears, 626 tendinopathy/tendinitis, 237 calcific tendinitis, 7,468 syndrome/disease, 55 injuries) and 511,371 unique controls included in the systematic review. Among the 27 included studies, 22 reported a positive association between RCD and adiposity.[9,17-19,25,30,35-50] Only 3 studies included in the review reported an inverse relationship between BMI and rotator cuff pathology.[28,29,51] Sixteen of those 27 reported relevant associations between BMI and RCD.[17-19,25,35,37,39-43,45,46,48,49,51,52] Ten of 27 studies were ineligible for inclusion in the meta-analysis[9,12,13,28-30,38,43,44,50] either because of a lack of clarity in exposure definition,[28] overlapping populations with other included studies,[12,13,50] possibility of misclassification of cases or controls,[28,29] or lack of comparable quantitative exposure information.[9,38] In total there were 13,457 unique cases (5,308 tear, 626 tendinopathy/tendinitis, 7,468 syndrome/disease, 55 injury) and 509,157 unique controls included in the meta-analysis.

Of the 17 included in the meta-analysis, 8 were case-control studies,[17,19,37,42,46,48,51,53] 2 were cohort studies (1 retrospective cohort[25] and 1 population-based cohort[49]), and 7 were cross-sectional studies.[18,35,39-41,45,52] Three studies specifically reported on rotator cuff tendinopathy/tendonitis,[18,19,35] 9 studies reported on RCT,[17,25,37,40,42,46,51-53] and 2 studies reported on rotator cuff syndrome.[41,45] Three studies,

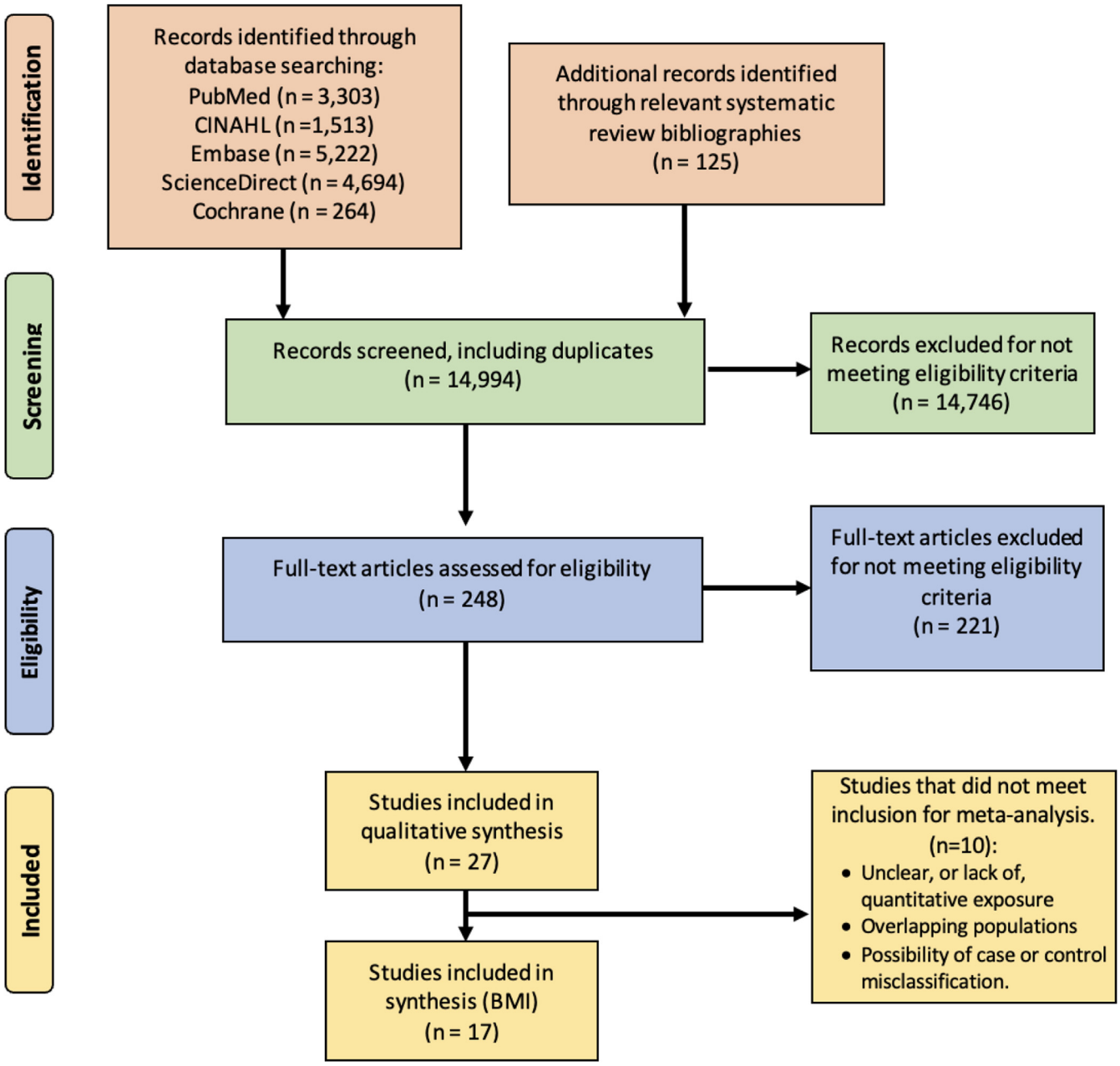

Fig 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses flow chart describing study selection process for meta-analysis. (CINAHL, Cumulative Index to Nursing & Allied Health.)

Gumina et al.,[17] Roquelaure et al.,[41] and Rechardt et al.[18] provided separate estimates for men and women. Roquelaure et al.,[41] only provided estimates for BMI as a continuous variable in the male population (see Table 1). These studies together provided independent effect estimates for meta-analysis in 11,392 individuals with RCD and 507,455 individuals without RCD.

Meta-analysis

In meta-analysis of categorical BMI variables, individuals with overweight were 21% more likely to have RCD compared with individuals in the normal-weight group (fixed effects OR 1.21; 95% CI 1.10-1.34; N-estimates = 9). The model showed little evidence of heterogeneity across studies (I^2 = 28%) (Fig 2A). Evaluation of contour-enhanced funnel plot suggested presence of symmetry (Fig 2B).

In meta-analysis of categorical BMI variables, individuals in the obese group were 44% more likely to have RCD compared with individuals in the normal-weight group (fixed effects OR 1.44; 95% CI 1.32-1.59; N-estimates = 12). The model showed moderate

Table 1. Description of Study Characteristics of 27 Studies Eligible for Meta-analysis

Study	Level of Evidence	Study Design, [#]Sample Size	Age Measurements, y	Obesity Measurement	RCD Measurement	Covariates Adjusted for	Results	Comments
Applegate et al., (2017),[35] U.S.A.	III	Cross-sectional; 1,226 N-RCD (+): 156 N-RCD (−): 1,070	Avg. age RCD (+): 45.6 (± 10.7) Avg. age RCD (−): 41.6 (± 11.4)	No BMI categorization BMI is presented as continuous variable.	RCD define as: presence of tendinopathy	NA	Crude BMI OR (CI): 1.02 (1.00-1.04) Mean BMI (± SD): RCD (+): 29.7 (± 6.4) RCD (−): 29.5 (± 6.8)	Rotator cuff tendinopathy; BMI was collected before sampling. Eligible for meta-analysis.[*†]
Atala et al., (2021),[28] Argentina	II	Prospective case-control; 105 N-RCD (+): 52 N-RCD (−): 53	Avg. age RCD (+): 72 (± 5) Avg. age RCD (−): 71 (± 6)	No BMI categorization BMI is presented as continuous variable.	RCD was identified via MRI.	NA	Mean BMI (± SD): RCD (+): 29.2 (± 4.6) RCD (−): 29.9 (± 5.1)	Rotator cuff tears; BMI was collected before sampling. Ineligible for meta-analysis because of unclear exposure status. Lists obesity as an exclusion criterion and yet BMI range indicates there are likely individuals with obesity in the study.
Blonna et al., (2016),[51] Italy	III	Case- control; 160 N-RCD (+): 80 N-RCD (−): 80	Avg. age Group B RCD (+): 63 (± 11) Avg. age Group C RCD (+): 79 (± 10) Avg. age Group A RCD (−): 70 (± 16)	No BMI categorization BMI is presented as a continuous variable.	RCD was identified via MRI and confirmed intraoperatively. Patients were divided into the following groups: (A) control group; (B) isolated symptomatic full supraspinatus tears; (C) symptomatic cuff tears involving at least the supraspinatus and infraspinatus;	Critical shoulder angle, smoking, gender, dominant arm, hypertension, work, BMI, and age	Multiple regression analysis crude BMI OR (CI): 0.99 (0.99-1.0) Mean BMI (± SD): Group B RCD (+): 25 (± 3) Group C RCD (+): 24 (± 3) Group A RCD (−): 24 (± 4)	Rotator cuff tears; BMI data were collected after sampling. Eligible for meta-analysis.[*]

(continued)

Table 1. Continued

Study	Level of Evidence	Study Design, [#]Sample Size	Age Measurements, y	Obesity Measurement	RCD Measurement	Covariates Adjusted for	Results	Comments
Bodin et al., (2012),[13] France	III	Cross-sectional; 3,710 N-RCD (+): 274 N-RCD (−): 3,435	Avg. age M: 38.5 (± 10.4) Avg. age W: 38.9 (± 10.3)	BMI < 18.5; 18.5-24.99 (reference); 25-29.9; ≥30.0	RCD defined as: Shoulder pain + positive for more than one shoulder test.	NA	Incidence of rotator cuff syndrome by BMI category Men: BMI <25: N = 475 (4.8%) BMI (25-30): 295 (8.8) BMI >30: 60 (1.7) Overall $P < .027$ Women: BMI <25: N = 451 (6.0%) BMI (25-30): 110 (11.8) BMI >30: 60 (10.2) Overall $P = .081$	Rotator cuff syndrome; BMI data collected during examination. Ineligible for meta-analysis because same population as Roquelaure.
Bodin et al., (2012),[12] France	III	Cross-sectional; 1,456 N-RCD (+): 96 N-RCD (−): 1,360	Avg. age M: 38.5 (± 10.4) Avg. age W: 38.9 (± 10.3)	BMI < 18.5; 18.5-24.99 (reference); 25-29.9; ≥30.0	RCD defined as: Shoulder pain + positive for more than one shoulder test.	NA	Incidence of RCD by BMI: Men: BMI <18.5: N = 0 (0%) BMI <18-25: N = 63 (46.3%) BMI (25-30): N = 55 40.4) BMI >30: 18 (13.2) $P = .062$ Women: BMI <18.5: N = 4 (3.1%) BMI <18-25: N = 74 (57.8%) BMI (25-30): N = 37 28.9%) BMI >30: 13 (10.2) $P = .009$	Rotator cuff syndrome; BMI data were collected at baseline Ineligible for meta-analysis because same population as Roquelaure.
Chung et al., (2016),[53]South Korea	II	Prospective case-control; 96 N-RCD (+): 48 N-RCD (−): 48	Avg. age RCD (+): 60.1 (± 6.5); range: 46-76 Avg. age RCD (−): 60.1 (± 6.5)	No BMI categorization BMI is presented as continuous variable.	RCD was identified via MRI; tear size was measured intraoperatively.	NA	Mean BMI (± SD): RCD (+): 23.5 (± 2.6) RCD (−): 22.6 (± 2.4)	Rotator cuff tear; Not specific on when BMI data were collected. Eligible for meta-analysis.[*]

(continued)

Table 1. Continued

Study	Level of Evidence	Study Design, [#]Sample Size	Age Measurements, y	Obesity Measurement	RCD Measurement	Covariates Adjusted for	Results	Comments
Djerbi et al., (2015),[37] France	II	Prospective observational case-control; 306 N-RCD (+): 206 N-RCD (−): 100	Avg. age RCD (+): 57.8 (± 8.6) Avg. age RCD (−): 59.4 (± 12.3)	Obesity was defined as BMI > 30 BMI is also presented as continuous variable.	RCD measured via radiographs and CT arthrography.	Smoking, dyslipidemia, and cardiovascular history.	Multivariable analysis BMI Adj. OR (CI): 1.69 (0.84-3.38) Mean BMI: RCD (+): 27.34 RCD (−): 26.35	Rotator cuff tear; BMI data were collected preoperative. Eligible for meta-analysis.[*‡§]
Dong et al., (2022),[29] China	III	Case-control N-RCD (+): 237 N-RCD (−): 1730	Avg. age RCD (+): 43.6 Avg. age RCD (−): 45.7	No BMI categorization BMI is presented as a continuous variable.	RCD was determined via radiologic evaluation by 2 experienced investigators. Musculoskeletal radiologist examined MRIs in case of disagreement.	NA	Mean BMI (± SD): RCD (+): 20.44 (± 1.71) RCD (−): 21.44 (± 2.34)	Rotator cuff calcific tendinitis; BMI was collected at diagnosis. Ineligible for meta-analysis because of lack of clear control group. Only patients exhibiting shoulder pain and limited motion were recruited for the study. There is no guarantee that the control group is free from rotator cuff pathology since = X-ray would correctly diagnose RCCT is unable to rule out tendinitis or tears.

(continued)

Table 1. Continued

Study	Level of Evidence	Study Design, [#]Sample Size	Age Measurements, y	Obesity Measurement	RCD Measurement	Covariates Adjusted for	Results	Comments
Gumina et al., (2014),[17] Italy	III	Case-control; 681 N-RCD (+): 381 N-RCD (−): 220	Avg. age RCD (+): 65.5 (± 8.52); range: 43-78 Avg. age RCD (−): 65.16 (± 7.24); range: 42-77	BMI ≤ 24.99; 25.00-30.00; ≥30; however, no reference category stated. Body fat % and mean BMIs also reported and compared by tear size (small, large, massive), but no BMI mean BMI/BF% provided for controls.	RCD measured via physical examination, radiographs, and MRI.	NA	Crude OR (CI): BMI ≤24.99 OR: M: 0.23 (0.13-0.39) F: 0.78 (0.45-1.36) BMI 25.00-30.00 OR: M: 2.1 (1.27-3.52) F: 1.94 (1.18-3.18) BMI ≥30, OR: M: 2.49 (1.41-3.90) F: 2.31 (1.38-3.62)	Rotator cuff tear; BMI was collected before sampling. Authors show greater BMI and greater %BF for massive tears compared with small tears. Eligible for meta-analysis. [*‡§‖]
Haveri et al., (2020),[30] India	III	Cross-sectional; 100 N-RCD (+): 69 N-RCD (−): 31	Avg. age RCD (+): 56.20 (± 11.37) Avg. age RCD (−): 47.77 (± 13.29)	No BMI categorization BMI is presented as a continuous variable.	RCD determined via MRI along with orthopaedic surgeon evaluation.	NA	Mean BMI (± SD): RCD (+): 26.33 (± 3.56) RCD (−): 25.77 (± 2.50)	Rotator cuff tear; Not clear on when BMI data were collected. Ineligible for meta-analysis because of unclear definition of outcome. Study only recruited patients with symptomatic rotator cuff tears. But they later specify only looking for supraspinatus tears. Therefore, the control group could have a rotator cuff tear of one of the other muscles.
Kuo et al., (2019),[25] Taiwan	III	Retrospective cohort; 80,604 N-RCD (+): 3,238 N-RCD (−): 77,366	N % ≥ 50 years old: 36.8% Range: 18-60 and up	No BMI categorization Obesity measured as a binary variable (yes/no)	RCD measured via MRI or ultrasonography, diagnosis was confirmed by an orthopaedic surgeon or rheumatologist.	Gender, age, urbanization, income, and comorbidities	Obesity Adj. HR (CI): 1.82 (1.23-2.68)	Rotator cuff tear; BMI data were collected before sampling. Eligible for meta-analysis.[‡§]

(continued)

Table 1. Continued

Study	Level of Evidence	Study Design, [#]Sample Size	Age Measurements, y	Obesity Measurement	RCD Measurement	Covariates Adjusted for	Results	Comments
Longo et al., (2009), [9] United Kingdom	III	Frequency-matched case-control; 194 N-RCD (+): 97 N-RCD (−): 97	Avg. age RCD (+): 62.9; range: 37-82 Avg. age RCD (−): 61.6; range: 36-80	No BMI categorization BMI is presented as continuous variable.	RCD was measured and diagnosed using imaging and clinical data.	NA	Mean BMI: RCD (+): M: 27.90 F: 27.81 RCD (−): M: 26.97 F: 26.85	Rotator cuff tear; BMI data were obtained the day of the operation. Ineligible for meta-analysis because data for BMI was not presented with a standard deviation by case-control status.
Longo et al., (2010), [38] United Kingdom	III	Frequency-matched case-control; 240 N-RCD (+): 120 N-RCD (−): 120	Avg. age RCD (+): 64.86; range: 40-83 Avg. age RCD (−): 63.91; range: 38-78	No BMI categorization BMI is presented as continuous variable.	RCD measured and diagnosed using imaging and clinical data. .	NA	Mean BMI: RCD (+): M: 27.36 F:27.88 RCD (−): M: 27.81 F: 26.82	Rotator cuff tear; BMI was collected before sampling. Ineligible for meta-analysis because data for BMI were not presented with a standard deviation by case-control status.
Pansiere et al., (2022), [39] Brazil	III	Cross-sectional; 235 N-RCD (+): 55 N-RCD (−): 180	Avg. age RCD (+): 46 (± 11.2) Avg. age RCD (−): 38.6 (± 10.4)	Obesity was defined as BMI > 30 BMI is also presented as continuous variable.	RCD was diagnosed using clinical tests (Jobe, Patte and Gerber tests) and a musculoskeletal ultrasound to determine the degree (partial/ complete) of the tear.	NA	Mean BMI (± SD): RCD (+): 37.2 (± 5.5) RCD (−): 36.6 (± 5.7)	Rotator cuff injury; BMI was collected before sampling. Eligible for meta-analysis.*
Park et al., (2018), [40] Korea	III	Cross-sectional; 634 N-RCD (+): 199 N-RCD (−): 435	Avg. age M: 59.1 (± 8.6) Avg. age M RCD (+): 61.9 (± 7.6) Avg. age M RCD (−): 57.7 (± 8.8) Avg. age W: 58.3 (± 8.3)	No BMI categorization BMI is presented as continuous variable.	RCD measured and diagnosed via MRI by radiologist.	Age, dominant-side involvement, manual labor, diabetes, hypertension, ipsilateral carpal tunnel syndrome, and low HDL blood level	Crude OR (CI): 1.10 (1.04-1.18) Multivariable analysis OR (CI): 1.09 (1.02-1.18) Median BMI (± SD): M RCD (+): 25 (± 3) M RCD (−): 24 (± 3)	Rotator cuff tear; Not specific on when BMI data were collected. Eligible for meta-analysis. *†¶

(continued)

Table 1. Continued

Study	Level of Evidence	Study Design, [#]Sample Size	Age Measurements, y	Obesity Measurement	RCD Measurement	Covariates Adjusted for	Results	Comments
Rechardt et al., (2010),[18] Finland	III	Cross-sectional; 5,743 N-RCD (+): 159 N-RCD (−): 5,584	Avg. age M: 50.8 Avg. age W:52.9	BMI <18.5, 18.5-24.9 (reference), 25.0-29.9, ≥30.0	RCD define as: presence of tendinopathy	Age, education, and physical workload.	BMI 25-29.9 Adj. OR: M: 1.6 (0.9-2.7) F: 1.0 (0.6-1.7) BMI >30.0 Adj. OR: M: 1.7 (0.8-3.6) F: 1.2 (0.6-2.3)	Rotator cuff tendinitis; BMI data were collected before sampling. Eligible for meta-analysis.[‡‖]
Roquelaure et al., (2011),[41] France	III	Cross-sectional; 3,535 N-RCD (+): 260 N-RCD (−): 3,275	Avg. age all: 38.7 (± 10.3)	BMI <18.5; 18.5-24.9 (reference); 25-29.9; ≥30 BMI is also presented as continuous variable only for men.	RCD defined as: Shoulder pain + positive for more than one shoulder test.	Authors do not explicitly report which variables they adjust for in multivariable analyses. We assumed variables listed in Table 4: age, diabetes, repetitiveness of the task, perceived workload, sustained or repeated arm posture in abduction (>2 hours/day), psychological demands, skill discretion and decision authority.	Crude OR(CI): BMI 25-29.9: M: 1.0 (0.7-1.5) F: 1.3 (0.8-2.0) BMI ≥30: M: 1.4 (0.8-2.5) F: 1.2 (0.6-2.2) Multivariate Model for continuous BMI (1- increment): OR (CI) M: 1.04 (0.99-1.10)	Rotator cuff syndrome, BMI data were collected during physical examination. Eligible for meta-analysis.[†‡‖]

(continued)

Table 1. Continued

Study	Level of Evidence	Study Design, [#]Sample Size	Age Measurements, y	Obesity Measurement	RCD Measurement	Covariates Adjusted for	Results	Comments
Seo et al., # (2019)[42] South Korea	III	Case-control; 1,069 N-RCD (+): 964 N-RCD (−): 105	Avg. age Group B RCD (+): 58.9 (± 10.1) Avg. age Group C RCD (+): 58.3 (± 9.6) Avg. age Group D RCD (+): 56.1 (± 8.0) Avg. age Group A RCD (−): 49.2 (± 9.2)	No BMI categorization BMI is presented as a continuous variable.	RCD detected via MRI and diagnosed by musculoskeletal radiologist and evaluated by orthopaedic shoulder surgeon. Subjects were divided into four groups: Group A = Control Group B = articular-sided PTRCTs Group C = bursal-sided PTRCTs Group D = FTRCTs	Authors do not explicitly report which variables they adjust for in multivariable analyses. We assumed variables listed in Table 5: critical shoulder angle, greater tuberosity angle, age (per ten years), sex (male/female), arm (right/left), and smoking (smoker/non-smoker) were covariates.	Multivariable analysis Group B BMI OR (CI): 0.95 (0.87-1.04) Group C BMI OR (CI): 0.97 (0.86-1.80) Group D BMI OR(CI): 1.05(0.96-1.15) Mean BMI (± SD): Group B RCD (+): 24.6 (± 3.2) Group C RCD (+): 24.4 (± 3.2) Group D RCD (+): 25.1 (± 2.9) Group A RCD (−): 24.6 (± 3.3)	Rotator cuff tear; BMI was collected before sampling. Eligible for meta-analysis.[*†¶] Note: This Seo publication was eligible because it had the most comprehensive sample size. Groups B, C and D BMI metrics were combined for case definition in the meta-analysis.
Seo et al., (2020),[43]South Korea	III	Case-control; 171 N-RCD (+): 114 N-RCD (−): 57	Avg. age RCD (+): 60.3 (± 10.7) Avg. age RCD (−): 51.3 (± 9.8)	No BMI categorization BMI is presented as continuous variable.	RCD was determined by arthroscopic evaluation.	Same as aforementioned Seo et al. 2019	Multivariable analysis BMI Adj. OR (CI): 0.95 (0.87-1.04) Mean BMI (± SD): RCD (+): 24.8 (± 3.4) RCD (−): 24.3 (± 3.5)	Subscapularis tear; BMI was collected before sampling. Ineligible for meta-analysis because of overlapping population with Seo et al. 2019.
Shinagawa et al., (2018),[44] Japan	III	Cross-sectional; 347 N-RCD (+): 112 N-RCD (−): 183	Avg. age RCD (+): 70 (± 8.7) Avg. age RCD (−): 63 (± 9.3)	NA	RCD measured via MRI or ultrasonography and interpreted by radiologist or orthopaedic surgeons.	Age, sex, height, weight, presence of smoking history	No ORs provided, meta-analyst computed ORs based on raw numbers. Weight (per kg) Adj. OR (CI): 1.03 (0.99-1.06)	Rotator cuff tear; Ineligible for meta-analysis, because only height and weight were reported, but BMI was not computed.
Silverstein et al., (2008),[45] U.S.A.	III	Cross-sectional; 733 N-RCD (+): 55 N-RCD (−): 678	Avg. age RCD (+): 41.8 (± 10.4) Avg. age RCD (−): 39.3 (± 11.0)	No BMI categorization BMI is presented as a continuous variable.	RCD defined as shoulder pain + positive physical examination with no history of acute trauma.	Age and gender.	Full model BMI Adj. OR (CI): 1.04 (0.99-1.09) Mean BMI (± SD): RCD (+): 28.6 (± 6.7) RCD (−): 27.2 (± 5.7)	Rotator cuff syndrome; BMI data were collected before sampling. Eligible for meta-analysis.[*†]

(continued)

Table 1. Continued

Study	Level of Evidence	Study Design, [#]Sample Size	Age Measurements, y	Obesity Measurement	RCD Measurement	Covariates Adjusted for	Results	Comments
Song et al., (2022),[46] U.S.A.	III	Case-control; 2,738 N-RCD (+): 1,731 N-RCD (−): 1,007	Avg. age RCD (+): 64 (± 8) Avg. age RCD (−): 59 (± 9)	No BMI categorization BMI is presented as a continuous variable.	RCD measured via MRI, operative reports documenting RCT, or surgical history of rotator cuff repair. Patients with distinct documentation of MRI or operative findings of rotator cuff tears in the physician notes, despite a lack of formal MRI or operative reports, were also classified as having rotator cuff tears.	Age, Sex, Race, Smoking, Hypertension, depression, dyslipidemia, carpal tunnel syndrome, overhead activity, affected shoulder.	Multivariable logistic regression BMI OR (75th percentile [34] vs 25th percentile [25]): 1.45 (1.24-1.69) Mean BMI (± SD): RCD (+): 31 (± 7) RCD (−): 29 (± 7)	Rotator cuff disease; BMI data were collected before sampling. Eligible for meta-analysis. [*‡§]
Suh et al., (2020),[52] South Korea	III	Cross-sectional; 307 N-RCD (+): 192 N-RCD (−): 115	Avg. age RCD (+): 62.69 (± 7.04) Avg. age RCD (−): 59.10 (± 7.66)	No BMI categorization BMI is presented as a continuous variable.	RCD diagnosed via MRI; shoulder pain report evaluated by 2 musculoskeletal radiology specialists.	Age, sex, level of education, total sum of Kellgren-Lawrence grades, hsCRP, and low HDL.	BMI Adj. OR (CI): 1.08 (0.98-1.19) Mean BMI (± SD): RCD (+): 24.63 (± 2.80) RCD (−): 24.27 (± 2.66)	Rotator cuff tear; BMI was collected before sampling. Eligible for meta-analysis. [*†¶]
Titchener et al., (2014),[48] United Kingdom	III	Case-control; 6,349 N-RCD (+): 3,346 N-RCD (−): 3,003	Median age: 55; range: 44-55	BMI <18.5; 18.5-25 (reference); 25.1-30; 30.1- 40; >40.1.	RCD defined by Read codes: rotator cuff tendinitis, subacromial bursitis, subacromial impingement, rotator cuff tears, and calcific tendinitis of the rotator cuff	Consultation rate, smoking, alcohol use, diabetes, oral steroid use, lateral epicondylitis, medial epicondylitis, de Quervain disease, cubital tunnel syndrome, Achilles tendonitis, trigger finger, rheumatoid arthritis,	Multivariate analysis BMI <18 Adj. OR (CI): 0.83 (0.52-1.32) BMI 25.1-30 Adj. OR(CI): 1.15 (1.02-1.31) BMI 30.1-40 Adj. OR (CI): 1.1 (0.95-1.27) BMI >40 Adj. OR (CI): 0.81 (0.57-1.15)	Rotator cuff disease; BMI data were collected before day of first diagnosis. BMI categories were not consistent with the WHO criteria, so we standardized to the WHO categories to ensure comparability. Eligible for meta-analysis.[‡‖]

(continued)

Table 1. Continued

Study	Level of Evidence	Study Design, [#]Sample Size	Age Measurements, y	Obesity Measurement	RCD Measurement	Covariates Adjusted for	Results	Comments
Wendelboe et al., (2004),[19] U.S.A.	III	Frequency-matched case-control; 1,244 N-RCD (+): 311 N-RCD (−): 933	Range: 53-77	BMI <20.00; 20.00-24.99 (reference); 25.00-29.99; 30.00-34.99; ≥35	RCD identified via surgical procedures (as defined by ICD-9) pertinent to rotator cuff repair or shoulder were used as proxy to assess the risk of rotator cuff tendinitis.	Age	Adj. OR (CI) BMI <20.00: M: — (—) F: 1.20 (0.43-3.38) BMI 25.00-29.99: M: 1.27 (0.79-2.04) F: 1.24 (0.78-1.97) BMI 30-34.99: M 1.86 (1.07-3.22) F 2.43 (1.39-4.22) BMI ≥35: M: 3.13 (1.29-7.61) F: 3.51 (1.80-6.85) Mean difference[**] BMI: 1.57; (beta = 1.57 [0.97-2.17])	Rotator cuff tendinitis; BMI data were collected before sampling. Eligible for meta-analysis. [‡§‖*]
Yanik et al., (2020),[49] U.S.A.	II	Population-based cohort; 417,034N-RCD (+): 2,076 N-RCD (−): 414,958	Avg. age all: 56; range 40-69	BMI < 18.5 kg/m; 18.5 ≤ BMI < 25.0; 25.0 ≤ BMI < 30.0; 30.0 ≤ BMI; unknown BMI BMI is also presented as a continuous variable.	RCD was identified via ICD-10 codes (M75.1 or S46.0).	Age per decade (continuous), Townsend deprivation per 10 pts (continuous), race, education, smoking status, and manual/ physical work.	Bivariate analysis: BMI Adj. HR (CI) = 2.54 (1.84-3.51) Multivariate association BMI Adj. HR (CI) = 1.19 (1.14 to 1.24) Mean BMI: RCD (+): 28.4 RCD (−): 27.3	Rotator cuff disease; BMI data were collected before sampling. Eligible for meta-analysis.[†] But not eligible for mean difference meta-analysis because the provided CI does not produce a consistent standard error.

(continued)

Table 1. Continued

Study	Level of Evidence	Study Design, [#]Sample Size	Age Measurements, y	Obesity Measurement	RCD Measurement	Covariates Adjusted for	Results	Comments
Yoo et al., (2019)[50] Korea	III	Case-control; 315N-RCD (+): 252 N-RCD (−): 63	Avg. age Group B RCD (+): 57.6 (± 6.6) Avg. age Group C RCD (+): 57.7 (± 7.2) Avg. age Group D RCD (+): 58.3 (± 6.9) Avg. age Group E RCD (+): 60.1 (± 7.4) Avg. age Group A RCD (−): 52.7 (± 9.9)	No BMI categorization BMI is presented as continuous variable.	RCD detected via MRI and diagnosed by a musculoskeletal radiologist. Orthopaedic shoulder surgeons classified the delaminated RCTs. Subjects were divided into five groups: Group A = Control Group B = non-delaminated tear Group C = delaminated tear with the articular layer equally retracted to the bursal layer Group D = articular layer more medially retracted delaminated tear Group E = bursal layer more medially retracted delaminated tear	Authors collected information on sex, age, weight, height, dominant hand, smoking history and body mass index. However, they only presented analyses that compared means. There was no attempt to adjust for any factors.	Multivariable analysis Group B BMI OR (CI): 1.07 (0.97-1.18) Group C BMI OR (CI): 1.01(0.90-1.14) Group D BMI OR (CI): 1.03 (0.93-1.15) Group E BMI OR (CI): 0.99 (0.82-1.18) Mean BMI (± SD): Group B RCD (+): 25.5 (± 3.9) Group C RCD (+): 24.8 (± 3.1) Group D RCD (+): 24.9 (± 2.8) Group E RCD (+): 24.6 (± 2.9) Group A RCD (−): 25.7(± 3.2)	Rotator cuff tear; BMI was collected before sampling. Ineligible for meta-analysis because of overlapping population with Seo et al.

Adj, adjusted; Avg, average; BMI, body mass index; CI, confidence interval; CT, computed tomography; F, female; FTRCTs, full-thickness rotator cuff tear; HDL, high-density lipoprotein; HR, hazard ratio; hsCRP, high-sensitivity C-reactive protein; ICD, *International Classification of Diseases*; M, male; MRI, magnetic resonance imaging; NA, not applicable; N-RCD (+), number of individuals that have RCD; N-RCD (−), number of individuals that do not have RCD; OR, odds ratio; PTRCTs, partial-thickness rotator cuff tears; RCD, rotator cuff disease; RCCT, rotator cuff calcific tendinopathy; RCT, rotator cuff tear; SD, standard deviation; WHO, world Health Organization.

*Meta-analysis of mean difference.

[†]Meta-analysis of BMI as a continuous variable for RCD.

[‡]Meta-analysis of BMI as obese category for RCD.

[§]Meta-analysis of BMI as obese category for RCT.

[‖]Meta-analysis of BMI for overweight category.

[¶]Meta-analysis of BMI as a continuous variable for RCT.

[#]Three studies by Seo/Yoo[32,33,45] were eligible; we picked the study with the greater sample size.

**Wendelboe et al. suggests cases on average have 1.5 BMI units greater than con.

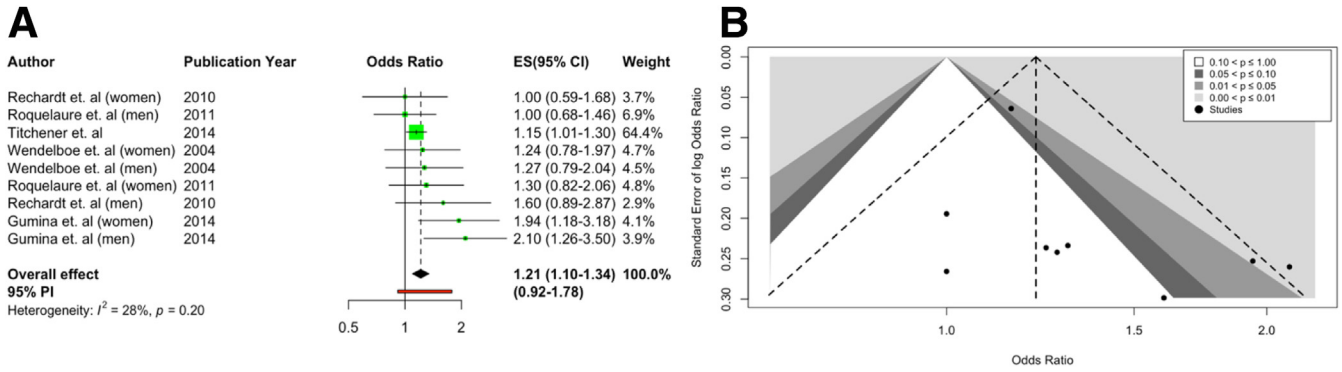

Fig 2. Forest plot of effect estimates from regression models evaluating relationship between being overweight and rotator cuff disease compared with individuals with normal weight (A) and corresponding contour-enhanced funnel plot (B). Overall effect refers to the mean effect size (odds ratio) and 95% CI meta-analysis. The prediction interval represents the range of odds ratios that a future study comparing this association could report, based on estimates from this meta-analysis. In a funnel-plot, asymmetrical spread of studies (dots) around the mean effect size (dashed vertical line) suggests evidence for small-study publication bias, which occurs when smaller studies with statistically significant findings are more likely to get published than null studies. (CI, confidence interval.)

evidence of heterogeneity across studies (I^2 = 69%) (Fig 3A). Contour-enhanced funnel plot showed some deviation from symmetry (Fig 3B).

Among these 12 estimates reporting on associations for the obese group[17-19,25,37,41,46,48] (as defined by BMI category), 7 estimates were specific for RCT.[17,19,25,37,46] In this separate meta-analysis, individuals in the obese group were 71% more likely to have RCT compared with individuals in the normal-weight group (fixed effects OR 1.71; 95% CI 1.52-1.93; N-estimates = 7). The model showed some evidence of heterogeneity across studies (I^2 = 58%) (Fig 3C).

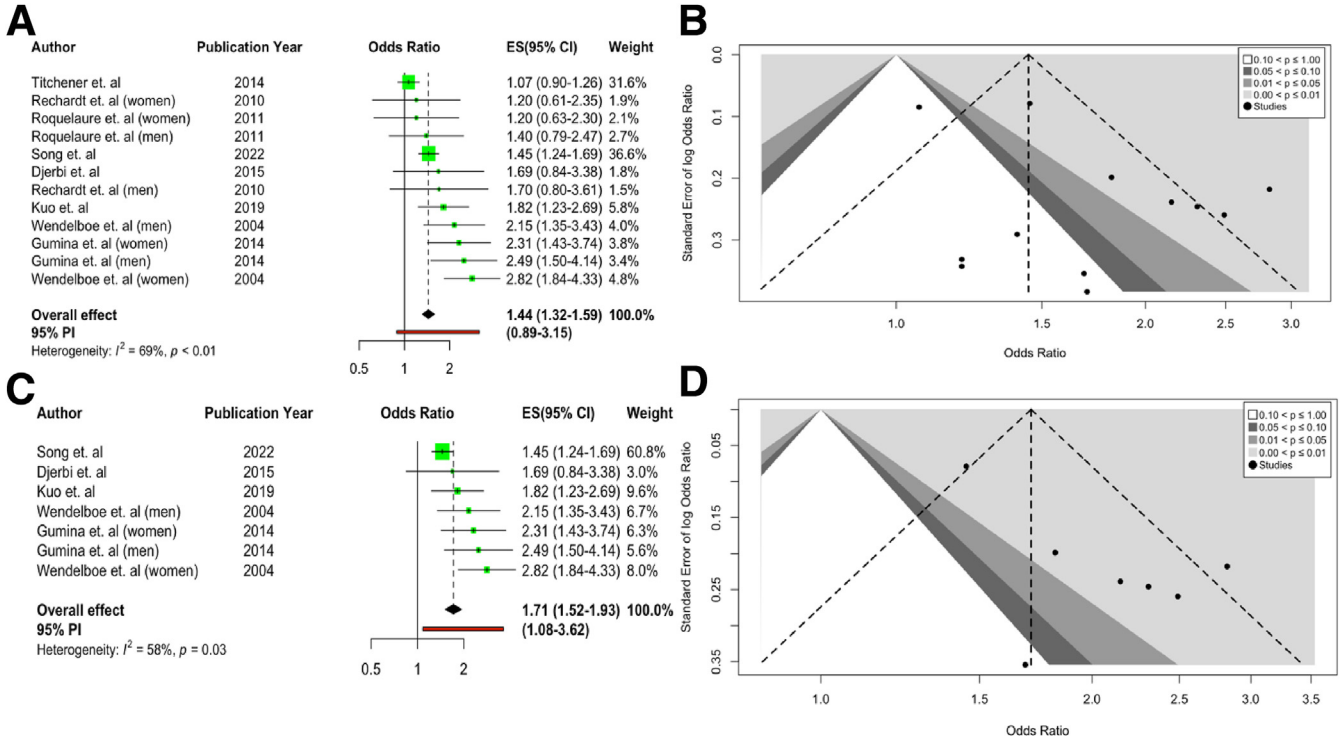

Fig 3. Forest plot of effect estimates from regression models evaluating relationship between being obese and rotator cuff disease compared with individuals with normal weight (A) and corresponding contour-enhanced funnel plot (B). Forest plot estimates for subset of studies evaluating relationship between being obese and randomized controlled trials compared with individuals with normal weight (C) and corresponding counter-enhanced funnel plot (D). Overall effect refers to the mean effect size (odds ratio) and 95% CI meta-analysis. (CI, confidence interval.)

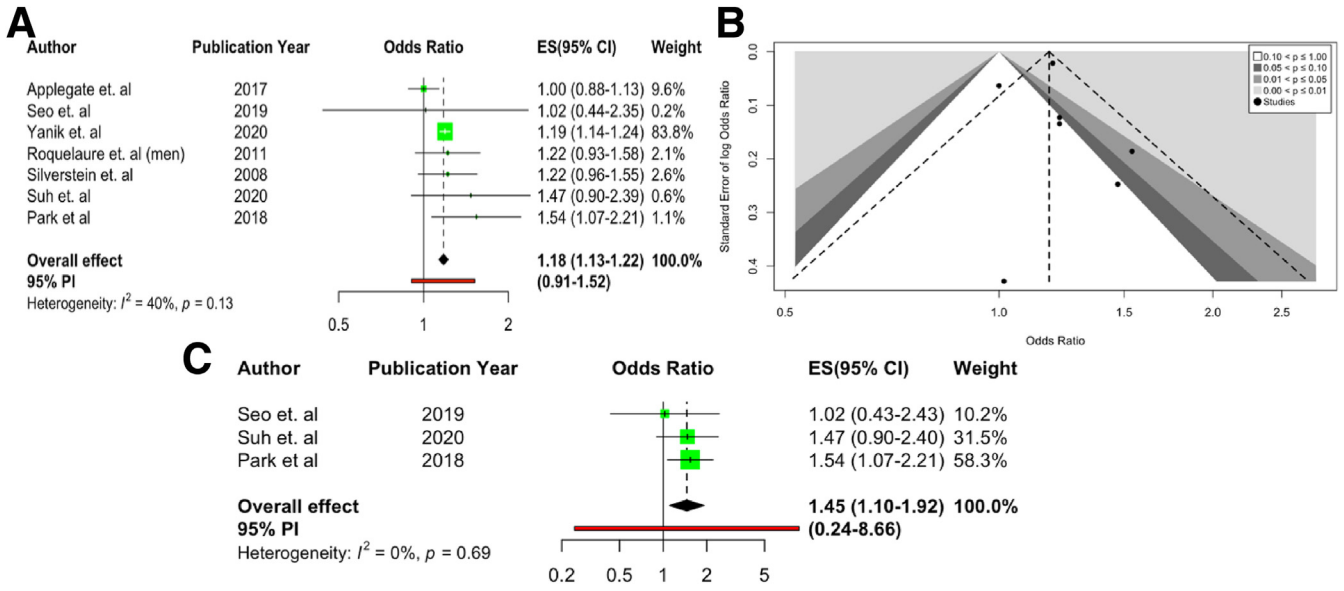

Fig 4. Forest plot of effect estimates from regression models evaluating BMI as a continuous variable and rotator cuff disease compared with individuals with normal weight (A) and corresponding contour-enhanced funnel plot (B). Forest plot estimates for subset of studies evaluating relationship between BMI modeled continuously and randomized controlled trials compared with normal weight individuals (C). OR and 95% CI correspond to each 5-unit increase in BMI. See Supplemental Section for corresponding counter-enhanced funnel plot. Overall effect refers to the mean effect size (OR) and 95% CI meta-analysis. (BMI, body mass index; CI, confidence interval; OR, odds ratio.)

Evaluation of contour-enhanced funnel plot suggested presence of symmetry (Fig 3D).

Meta-analysis of studies reporting BMI as a continuous variable showed each 5-unit increase in BMI is associated with 18% greater odds having RCD (fixed effects OR 1.18; 95% CI 1.13-1.22; N-estimates = 7). The model showed moderate evidence of heterogeneity across studies (I^2 = 40%) (Fig 4A). Evaluation of contour-enhanced funnel plot showed marginal deviation from symmetry (Fig 4B).

Among the 7 estimates reporting on associations reporting BMI as a continuous variable,[35,40-42,45,49,52] 3 estimates were specific for risk of RCT.[40,42,52] Meta-analysis of studies reporting BMI as a continuous variable showed each 5-unit increase in BMI is associated with 45% greater odds having RCT (fixed effects OR 1.45; 95% CI 1.10-1.92; N-estimates = 3). Model showed very little heterogeneity across studies (I^2: 9%) (Appendix Fig 1, available at www.arthroscopyjournal.org).

Meta-analysis of mean differences showed individuals with RCD are on average heavier than individuals without RCD (fixed effects mean difference 1.06; 95% CI 0.82-0-1.31; N-estimates = 11). The model showed moderate evidence of heterogeneity across studies (I^2 = 65%) (Fig 5A). Evaluation of contour-enhanced funnel plot suggested presence of symmetry (Fig 5B).

Among the 11 estimates mean BMI by case-control status,[17,19,35,39,40,42,45,46,51-53] 7 estimates were specific for risk of RCT.[17,40,42,46,51-53] Meta-analysis of mean differences showed individuals with RCT are on average heavier than individuals without RCT (fixed effects mean difference 0.95; 95% CI 0.67-1.23; N-estimates = 7. The model showed little evidence of heterogeneity across studies (I^2 = 23%) (Fig 5C). Evaluation of contour-enhanced funnel plot suggested presence of symmetry (Appendix Fig 2, available at www.arthroscopyjournal.org).

Risk of Bias Assessment

Among the 27 articles included in the systematic review 24 were eligible for inclusion in the risk of bias analysis. Three studies[28-30] were unable to be assessed because of lack of clarity of exposure or outcome definition. Risk of bias scores for each of the 5 bias domains (1-confounding, 2-selection, 3-missingness, 4-measurement of outcomes, 5-selection of reported results), and overall, averaged between the 2 reviewers are summarized in Fig 6, and individual scores are shown in the Appendix Fig 3, available at www.arthroscopyjournal.org.

Overall, there is meaningful concern for bias of the studies that comprised this review, with only 2 of the 23 eligible studies graded overall "low" risk of bias. Four studies were low risk for confounding, and 10 were low risk for selection bias. Across all studies, there was very little concern for bias in missing data, outcome

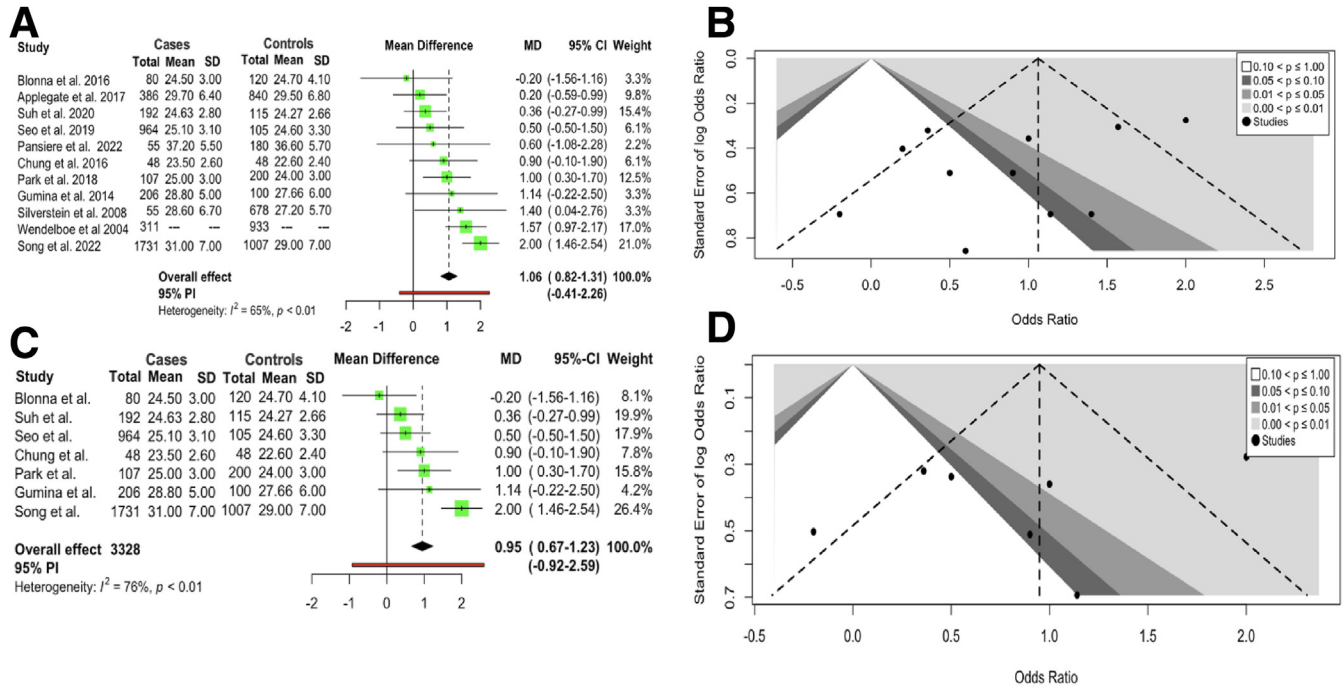

Fig 5. Forest plot of mean difference in BMI between individuals with and without rotator cuff disease from regression models (A) and corresponding contour-enhanced funnel plot (B). Forest plot estimates for subset of studies evaluating relationship between mean difference in BMI between individuals with and without and randomized controlled trials (C) and corresponding counter-enhanced funnel plot (D). Overall effect refers to the mean effect size (odds ratio) and 95% CI meta-analysis. (BMI, body mass index; CI, confidence interval.)

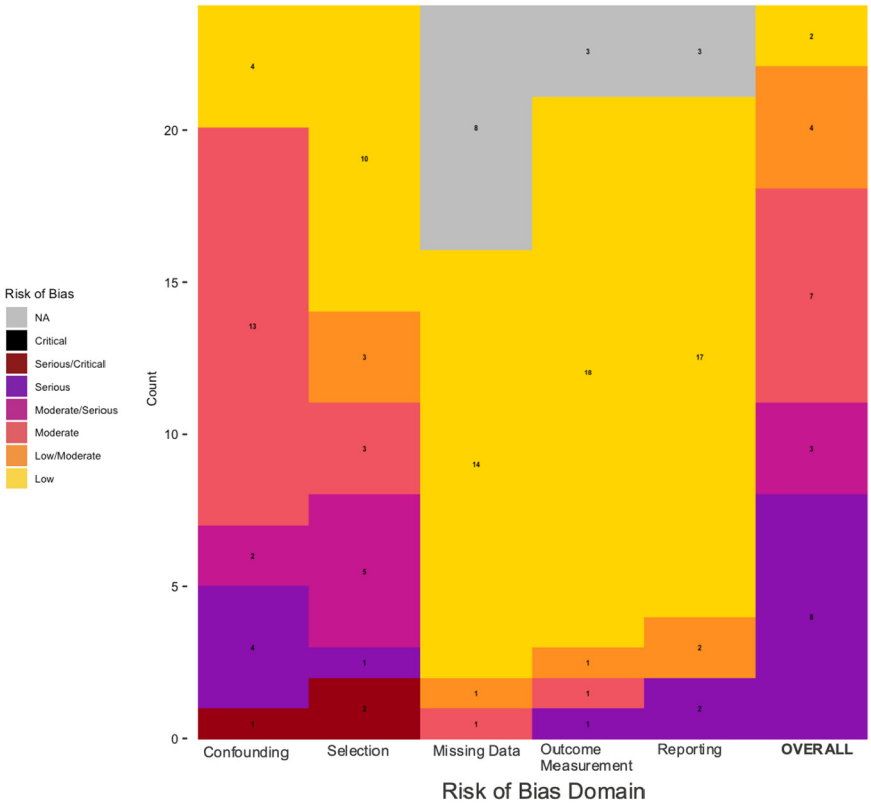

Fig 6. Risk of bias assessment in randomized trials. Heatmap for total categorical and overall risk of bias assessment scores.

measurement, or reporting biases. Inter-rater reliability for risk of bias assessment was high, especially for a multicategory assessment, with an overall Gwet A1 of 0.71 (95% CI 0.594-0.762, $P < .001$). This indicates a high degree of reproducibility in the risk of bias scores.

Subgroup Analyses

Given the wide variation in risk of bias rating among studies, further sensitivity analyses were conducted to assess the robustness and reliability of findings. These analyses involved systematically exploring trends among each subgroup of risk of biases on overall results. Sensitivity analyses consisted further subgroup analyses of the above meta-analyses by overall risk of bias score. In sensitivity analyses, similar results were observed across subgroups of risk of bias (Appendix Figs 4-7, available at www.arthroscopyjournal.org). However, given the heterogeneity of study design and limited number of total included studies, each subgroup analysis is limited to 2 or 3 studies and thus should be interpreted cautiously.

Discussion

In this study, we found a significant association between BMI and risk for RCD and RCT. Although studies report wide ranges of estimates (including inverse, null, and positive associations), overall, our meta-analysis found a positive association between obesity and RCD. We observed a graded response between BMI categories and RCD, and these positive associations were further supported by analyses aggregating studies reporting BMI as a continuous measure and by those reporting mean BMI by case-control status.

Among analyses where RCT specific risk was available, risk estimates for tear were greater than for RCD, suggesting a cumulative effect of BMI on rotator cuff health. Pansiere et al.[39] noted that those with tears reported a longer history of obesity than those without tears, further supporting a compounding effect of increased BMI on cuff injury risk. In combination, these results could suggest that increased BMI might be associated with the progression of disease or even related to RCT through other rotator cuff precursory pathologies. This is a potentially meaningful clinical impact it could signify that early intervention on BMI in patients with RCD, which is usually treated conservatively, could help mitigate the risk of progression to RCT, which is often managed operatively. However, further investigation into this association is necessary to elucidate causal mechanisms.

We took several approaches to reduce bias and ensure validity of our findings. Since statistically nonsignificant findings for obesity and RCD may not get reported in the title and abstract, we used a general search terminology in multiple search engines to increase chances of finding all studies evaluating obesity measures and RCD. We prioritized multivariable-adjusted estimates when possible, to reduce possible effects of confounding, which is a contrast over the only other meta-analysis reporting obesity and RCD, which only reported mean differences.[54] We further examined funnel-plots for small-study bias, the likelihood that smaller studies are more likely to report results when they are statistically significant, and found some evidence of this bias in the obese analysis which also had the largest of the effect estimates. Selection bias was especially high among hospital-based case-control studies, where controls were selected from individuals with MRI for shoulder pathology without RCD. Although this approach provides a "clean" set of controls without RCD, the indication for MRI could lead to enrichment of other shoulder conditions, such as osteoarthritis, for example. By pooling together all available data, our quantitative assessment thus not only includes studies that are possibly biased away from null, but also those that are biased towards the null and collectively, likely captures a realistic picture on average. This idea is supported by analyses stratified by quality scores. The direction of effect estimates did not consistently increase or decrease with the quality score for studies suggesting bias is not dispersed unidirectionally and that meta-analysis estimate from the primary pooled analyses are likely valid.

Most studies were cross-sectional or case-control in design and thus assessed information on BMI and RCD simultaneously, making it impossible to delineate temporality. Only 2 studies[25,49] had temporally sound designs, where measurement of obesity preceded RCD; both reported positive associations.[25] These 2 studies were ranked low risk of bias overall and across domains. The study by Yanik et al.[49] is a population-based cohort, the largest study included in this review, and it reported an adjusted multivariable hazard ratio of 1.19 (1.14-1.24) per 5-unit increase in BMI. The effect estimate for the continuous BMI meta-analysis was largely driven by this high-quality study. The study from Kuo et al.[25] is a retrospective cohort study and the second largest study in this review, reporting an adjusted hazard ratio of 1.82 (1.23-2.68) of RCT for patients with versus without obesity. Effect estimates by Kuo et al.[25] approximate both the median of studies included in these subgroups and the overall effect estimates after meta-analysis (RCD: 1.44 [1.32-1.59], RCT: 1.17 [1.52-1.93]) while contributing minimal weight, indicating that without this study results would have been similar. Thus, adding strength to findings of the meta-analysis collectively, despite drawbacks of individual studies.

It has been postulated that obesity leads to histopathologic musculotendinous changes, such as fatty infiltration of the rotator cuff[8,17,18] or sarcopenia,[53] that may predispose to RCD. However, other possible biologic mechanisms could explain the observed

association. For example, individuals with obesity are also likely to have other medical comorbidities, such as diabetes, which are known to increase risk of RCD. Alternatively, although BMI is widely used as a measure of obesity, it can often misclassify individuals who have a high percentage of skeletal mass (such as body builders). Although it is unlikely, it is also possible that the association between BMI and RCD might be driven by individuals with high skeletal mass percentage who overexercise their shoulders, causing RCD.

Gumina et al.[17] evaluated mean BMI and percent of body fat levels in individuals with small, large, and massive tears and found those with massive tears had the largest mean BMI and the largest body fat percent compared with those having smaller tears. In addition, Chung et al.[53] reported individuals with tears have a higher fat mass index and a lower skeletal muscle mass index than individuals without tears. They further show higher fat mass index in individuals with large-to-massive tears compared with individuals with small-to-medium tears and lower skeletal muscle mass index for those in the large to massive tear group.[53] However, simultaneous measurement of fat mass, muscle mass, and tears make it difficult assess cause and effect.

This systematic review and meta-analysis identify a positive association between obesity and RCD. However, although biological and mechanistic knowledge of obesity and the cuff suggests the plausibility of a causal association, evidence from epidemiologic studies or experimental studies for a causal association between obesity and RCD is limited. High-quality prospective cohort studies could overcome this barrier and provide a better understanding of RCD etiology. Moreover, methods such as Mendelian randomization analysis, in which genetic variants are used as instrumental variables to assess causal relationships between exposure and outcome, can be powerful tools in generating evidence for causality and is a necessary next step in understanding the relationship between chronic diseases (such as obesity) and RCD. Future studies evaluating obesity-mediated tissue degeneration in the rotator cuff musculature, building on existing animal models that have already established a role for fatty infiltration and muscle atrophy in tear risk,[55-58] are essential in laying the foundation for causal inference.

Ultimately, obesity is an epidemic that continues to affect an increasing percentage of our population. This review provides evidence for a positive association of obesity on RCD risk and is an essential first step in expanding our understanding of the role of obesity on the incidence of RCD. Obesity is a modifiable risk factor and better understanding of its effect on incidence and progression of disease can inform better patient management.

Limitations

The limitations in this meta-analysis are inherent to the contributing studies and may explain heterogeneous findings. Namely, numerous definitions of RCD and various modalities used to assign disease status, contribute to outcome heterogeneity. We were not able to determine whether there was a specific cut-off for BMI that confers a greater association between obesity and RCD, but individual-level data were not available in the included studies.

In addition, overall risk of bias for individual studies was high, particularly as the result of confounding and selection, and the direction and effect of bias on each study was variable. We provide a robust framework for understanding how confounding may affect the association between obesity and RCD by constructing a directed acyclic graph, explicitly outlining how factors might relate to obesity or RCD. This approach distinguishes confounders from intermediates and risk factors, provides minimum sets of variables that would need to be adjusted to obtain relatively unconfounded effect estimates in the relationship between obesity and RCTs, and also identifies variables that should not be adjusted for.[59,60] Many studies did not provide estimates adjusted for potential confounders in the association between obesity and RCD, likely because they were not designed to evaluate obesity and RCD. Conversely, several studies over-adjusted in the association between obesity and RCD.[9,25,37,41,49] Adjusting for intermediates attenuates the overall effect of obesity on RCT and can also introduce other sources of bias as the result of stratification on a common effect.[61]

Conclusions

In this study, we found a positive association between elevated BMI and RCD.

Disclosures

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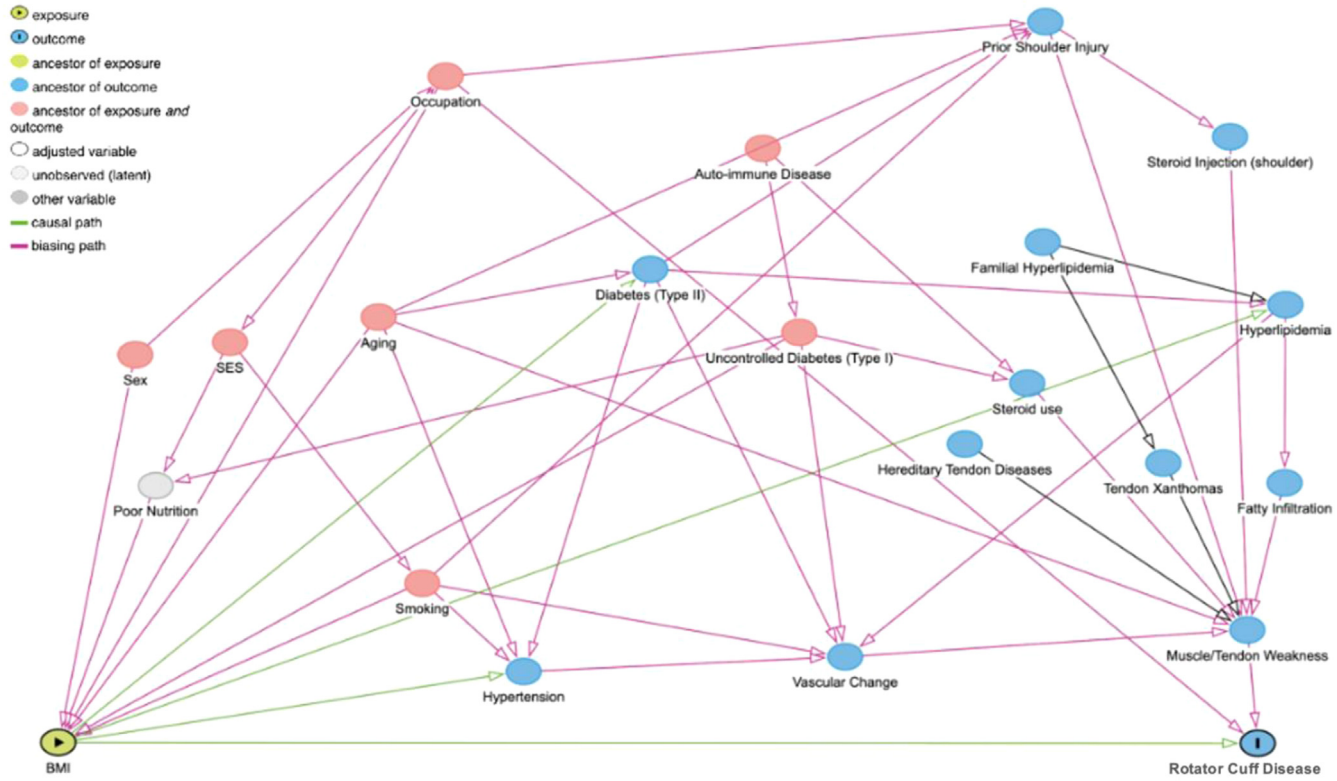
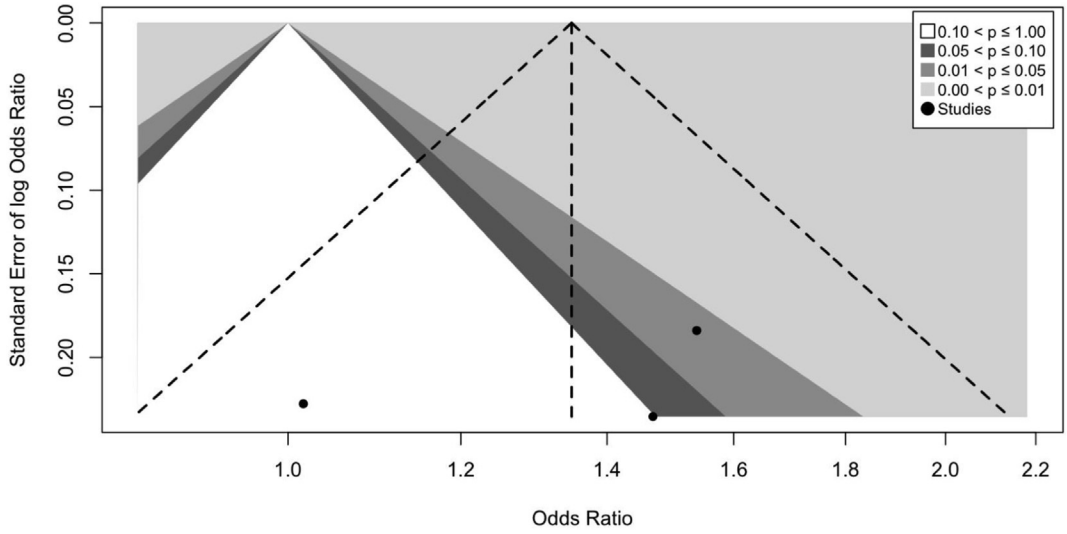


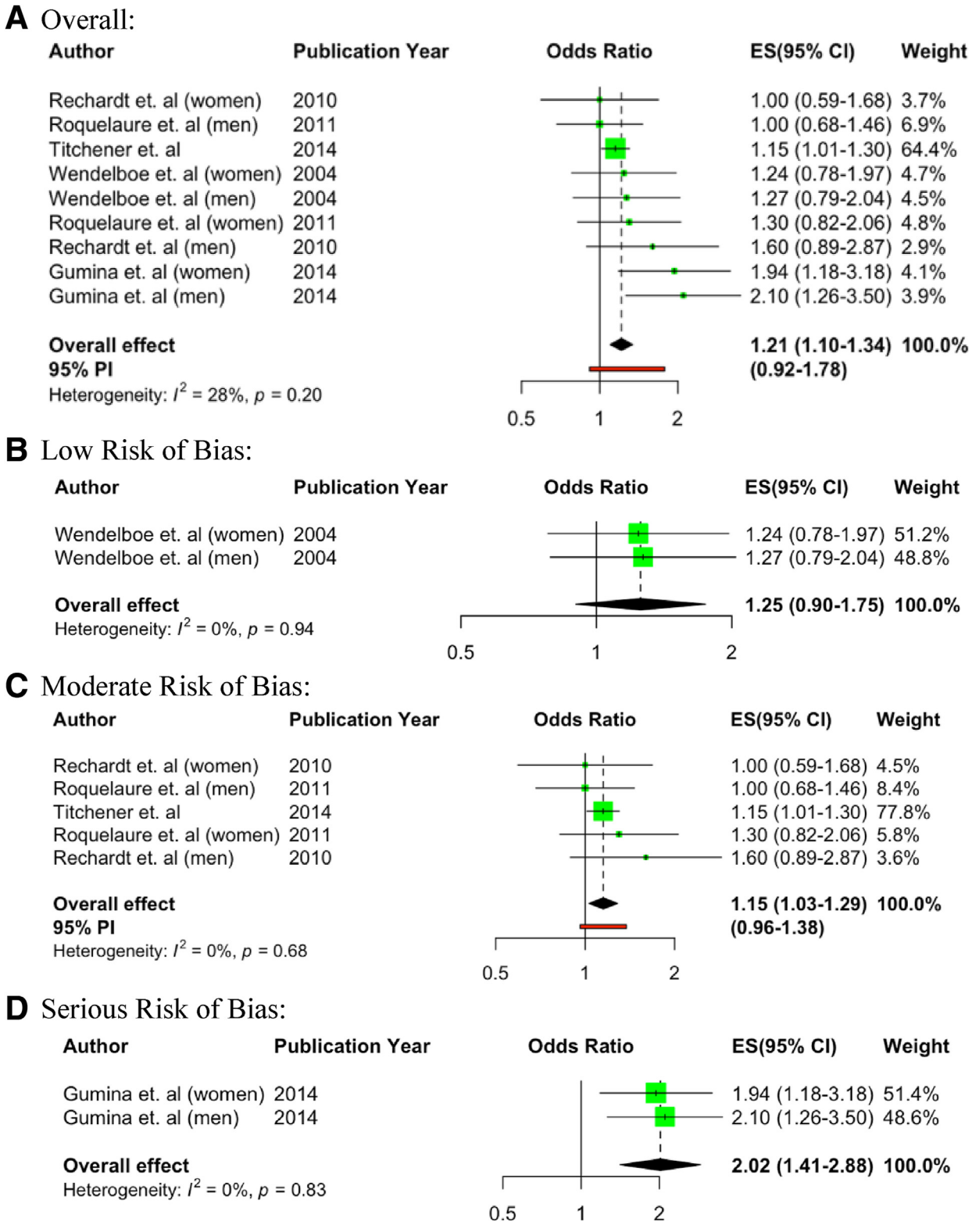
Appendix Fig 1. Directed acyclic graph modeling the relationship between BMI (exposure) and rotator cuff disease (outcome). (BMI, body mass index; SES, socioeconomic.) Status.



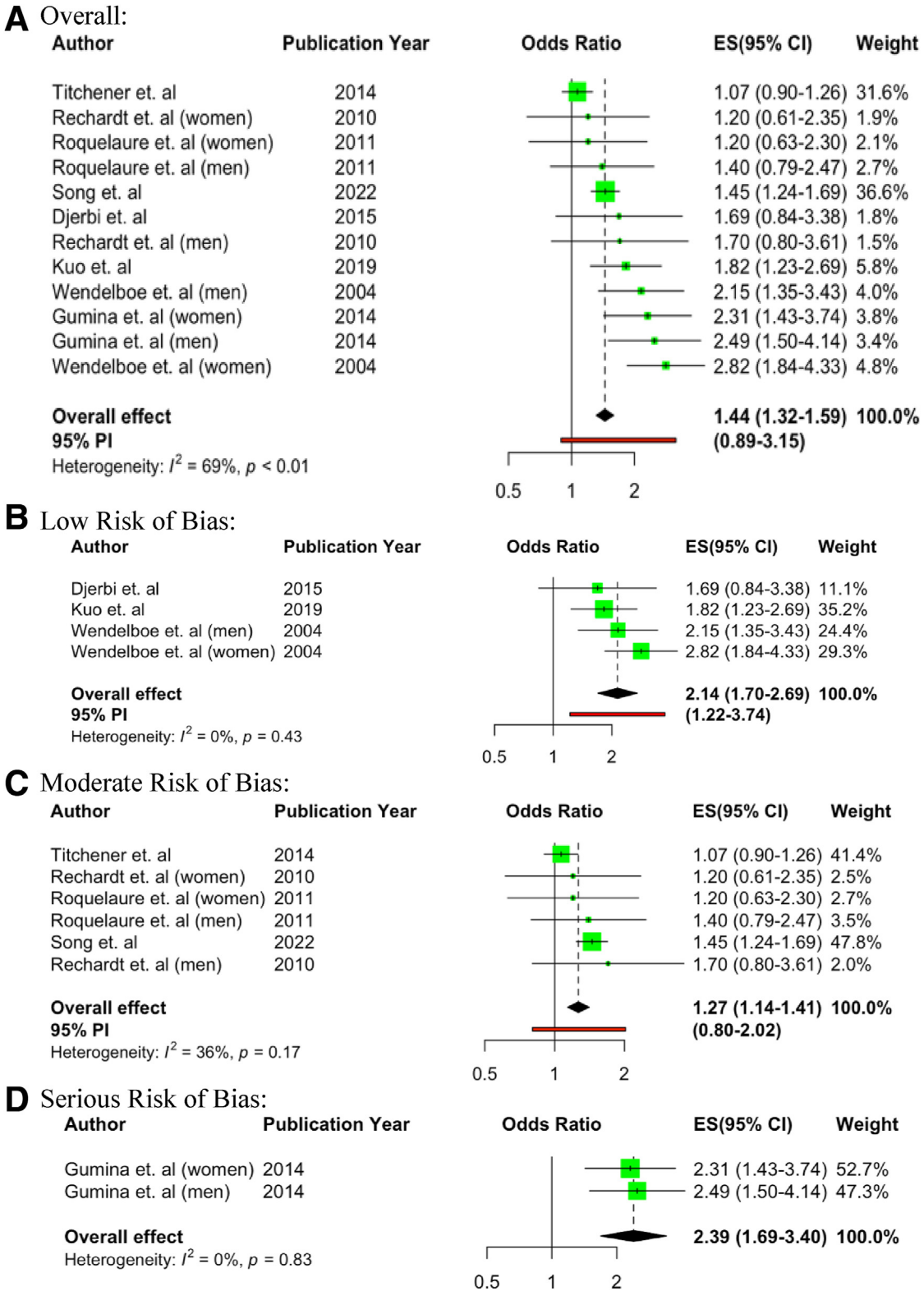
Appendix Fig 2. Contour enhance funnel plot for estimates for subset of studies evaluating relationship between body mass index modeled continuously and rotator cuff tears compared with an individual of normal weight.

Study	Reviewer	Confounding Bias	Selection Bias	Missing Data Bias	Outcome Measurement Bias	Reporting Bias	Overall Bias
Applegate, 2017	herzbesd	Serious	Moderate	Low	Low	NA	Serious
Applegate, 2017	giria	Serious	Low	Low	Low	NA	Serious
Blonna et al. 2016	herzbesd	Moderate	Low	Low	Low	Low	Moderate
Blonna et al. 2016	giria	Low/Moderate	Low	Low	Low	Low	Moderate
Bodin et al. 2012 (Comparison...)	herzbesd	Serious	Low	Low	Low	Low	Serious
Bodin et al. 2012 (Comparison...)	giria	Serious	Low	Low	Low	Low/Moderate	Serious
Bodin et al. 2012 (Risk Factors...)	herzbesd	Moderate	Low	Low	Low	Low	Serious
Bodin et al. 2012 (Risk Factors...)	giria	Serious	Moderate	Low	Low	Moderate	Moderate
Chung et al. 2016	herzbesd	Low/Moderate	Low	Low	Low	Low	Serious
Chung et al. 2016	giria	Moderate/Serious	Low	Low	Low	Low	Serious
Djerbi et al. 2015	herzbesd	Moderate	Low	Low	Serious	Low	Low
Djerbi et al. 2015	giria	Moderate	Low/Moderate	Low	Serious	Low	Moderate
Gumina et al. 2014	herzbesd	Serious	Low	Low	Moderate	Low	Serious
Gumina et al. 2014	giria	Moderate/Serious	Low/Moderate	Low	Moderate/Serious	Moderate	Serious
Kuo et al. 2019	herzbesd	Moderate	Low	NA	Low	Low	Low
Kuo et al. 2019	giria	Low/Moderate	Low	NA	Low	Low	Low
Longo et al. 2008	herzbesd	Moderate	Serious	NA	Low	NA	Moderate
Longo et al. 2008	giria	Low/Moderate	Critical	NA	Low	NA	Serious
Longo et al. 2009	herzbesd	Moderate	Moderate	NA	Low	Serious	Moderate
Longo et al. 2009	giria	Moderate/Serious	Moderate	NA	Low	Serious/Critical	Serious
Pansiere et al. 2022	herzbesd	Moderate/Serious	Serious	Low	Low	Serious	Serious
Pansiere et al. 2022	giria	Serious	Critical	Low	Low	Serious	Serious
Park et al. 2018	herzbesd	Low	Low	Low	Low	Low	Moderate
Park et al. 2018	giria	Low/Moderate	Low/Moderate	Low	Low	Low	Low
Rechardt et al. 2010	herzbesd	Low	Low	Moderate	Low	Low	Moderate
Rechardt et al. 2010	giria	Low/Moderate	Low	Low	Low	Low	Moderate
Roquelaure et al. 2011	herzbesd	Moderate	Low	Low	Low	Low	Moderate
Roquelaure et al. 2011	giria	Moderate	Low	Low	Low	Low	Moderate
Seo et al. 2019	herzbesd	Moderate	Moderate	NA	Low	Low	Moderate
Seo et al. 2019	giria	Low/Moderate	Moderate/Serious	NA	Low	Low	Moderate
Seo et al. 2020	herzbesd	Moderate	Moderate	NA	Low	Low	Moderate
Seo et al. 2020	giria	Low/Moderate	Moderate/Serious	NA	Low	Low	Moderate
Shinagawa et al. 2018	herzbesd	Moderate	Moderate	NA	NA	Low	Serious
Shinagawa et al. 2018	giria	Low/Moderate	Serious	NA	NA	Low	Serious
Silverstein et al. 2008	herzbesd	Low	Moderate	Low	Low	Low	Low
Silverstein et al. 2008	giria	Low	Low/Moderate	Low	Low	Low	Moderate
Song et al. 2022	herzbesd	Moderate	Moderate/Serious	NA	NA	NA	Moderate
Song et al. 2022	giria	Moderate	Moderate/Serious	NA	NA	NA	Moderate
Suh et al. 2020	herzbesd	Low/Moderate	Moderate/Serious	NA	Low	Low	Serious
Suh et al. 2020	giria	Moderate	Serious	NA	Low	Low	Serious
Titchener et al. 2014	herzbesd	Moderate	Low	Low	Moderate	Low	Moderate
Titchener et al. 2014	giria	Low/Moderate	Low	Low/Moderate	Low	Low	Moderate
Wendelboe et al. 2004	herzbesd	Moderate	Low	Low	NA	Low	Moderate
Wendelboe et al. 2004	giria	Low/Moderate	Low	Low	NA	Low	Low
Yanik et al. 2020	herzbesd	Low	Low	Low	Low	Low	Low
Yanik et al. 2020	giria	Low/Moderate	Low	Low	Low	Low	Low
Yoo et al. 2019	herzbesd	Serious/Critical	Moderate/Serious	Low	Low	Low	Serious
Yoo et al. 2019	giria	Serious/Critical	Moderate/Serious	Low	Low	Low	Serious

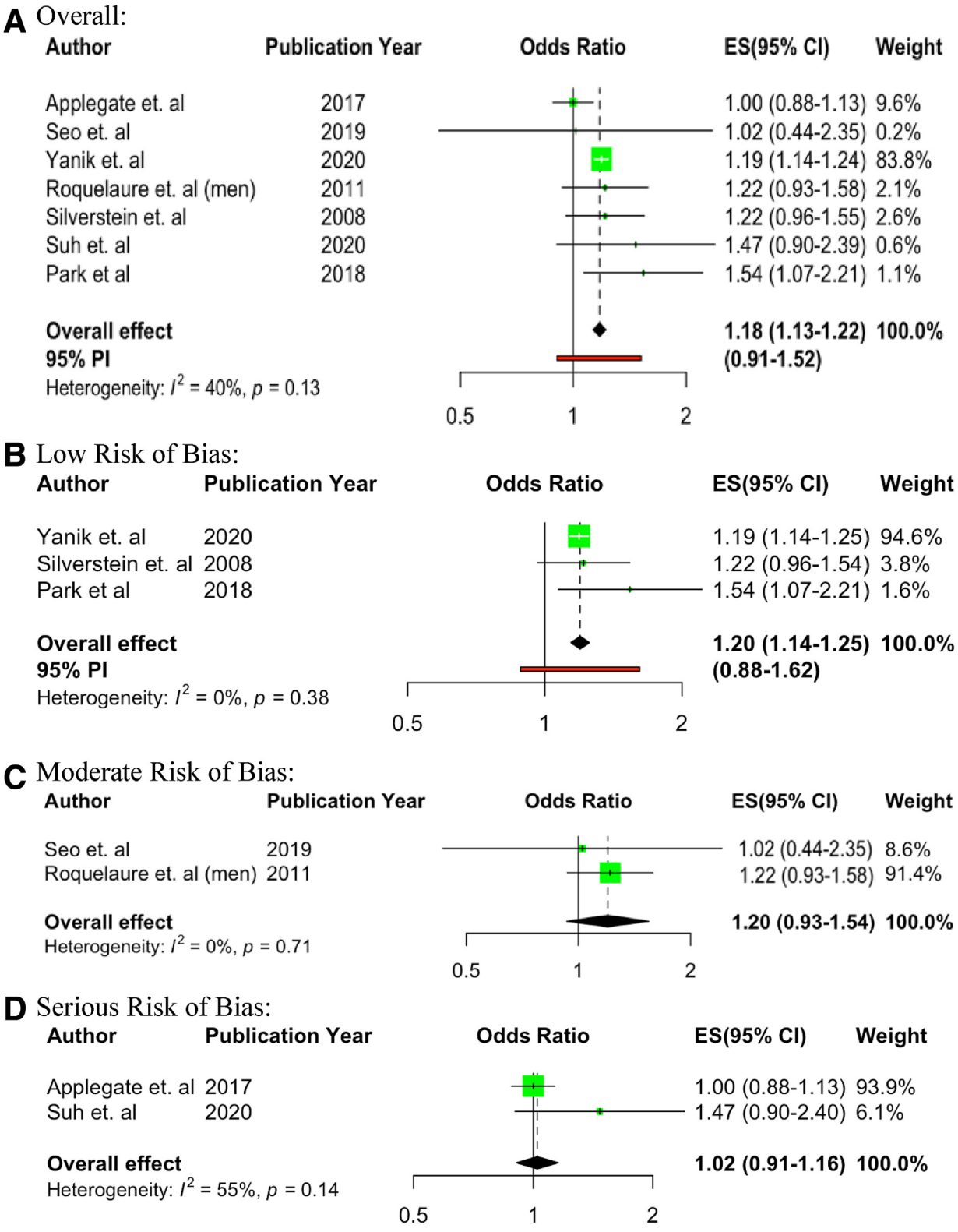
Appendix Fig 3. Study and reviewer-specific bias scores by confounding domain.



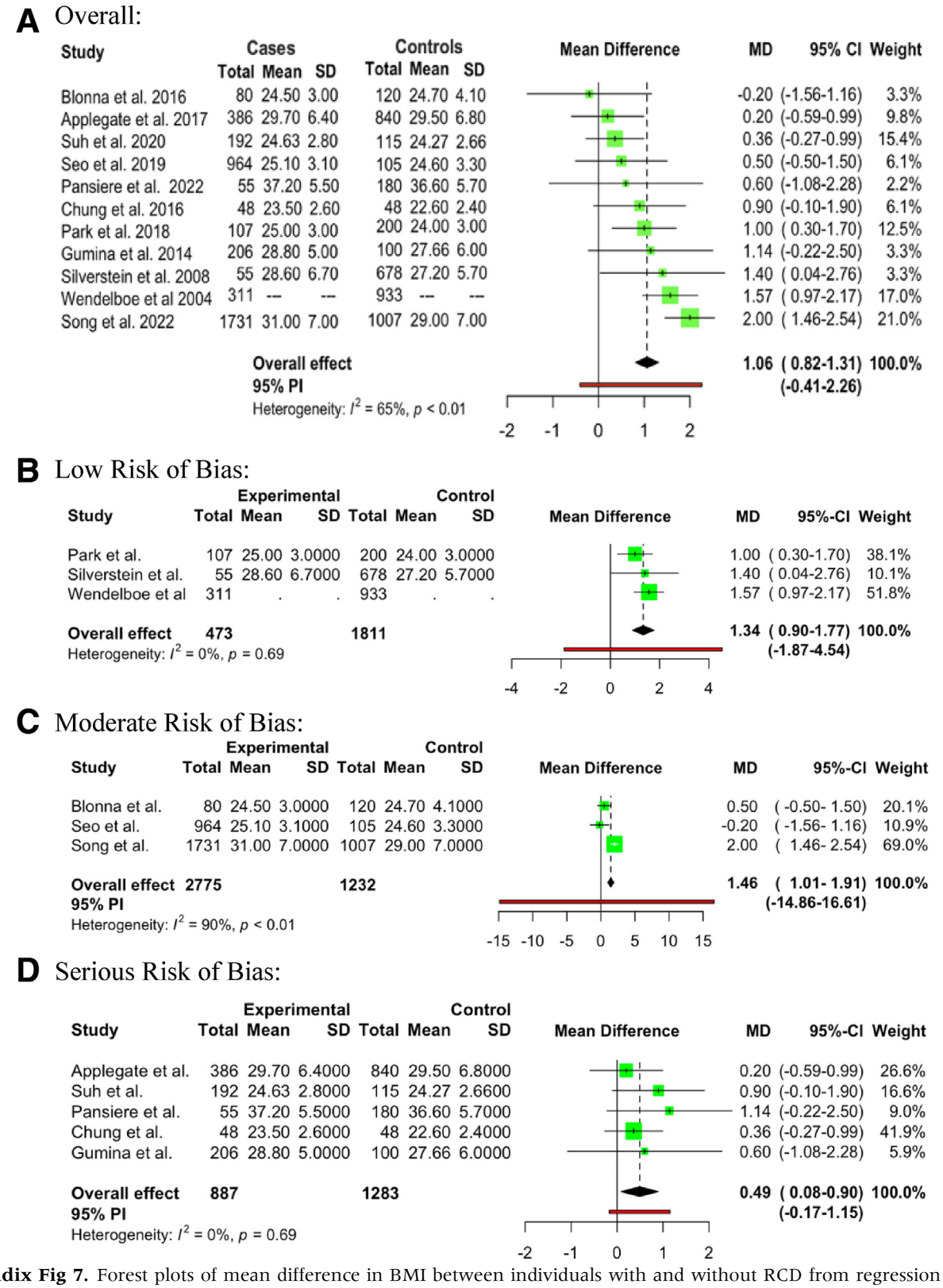
Appendix Fig 4. Forest plots of effect estimates from regression models evaluating relationship between being overweight and RCD compared with individuals of normal weight, meta-analyzed by strata/subgroup of risk of bias. Overall results without stratification (A); studies with low risk of bias (B); moderate risk of bias (C), and serious risk of bias (D). Note: OR = 1, no effect. OR <1, inverse effect. OR >1 positive effect. (CI, confidence interval; ES, estimate; OR, odds ratio; RCD, rotator cuff disease.)



Appendix Fig 5. Forest plots of effect estimates from regression models evaluating relationship between being obese and RCD compared with individuals of normal weight, meta-analyzed by strata/subgroup of risk of bias. Overall results without stratification (A); studies with low risk of bias (B); moderate risk of bias (C), and serious risk of bias (D). Note: OR = 1, no effect. OR <1, inverse effect. OR >1 positive effect. (CI, confidence interval; ES, estimate; OR, odds ratio; RCD, rotator cuff disease.)



Appendix Fig 6. Forest plots of effect estimates from regression models evaluating BMI as a continuous variable and RCD compared with individuals of normal weight, meta-analyzed by strata/subgroup of risk of bias. Overall results without stratification (A); studies with low risk of bias (B); moderate risk of bias (C), and serious risk of bias (D). OR and CI correspond to each 5 unit increase in BMI. Note: OR = 1, no effect. OR <1, inverse effect. OR >1 positive effect. (BMI, body mass index; CI, confidence interval; ES, estimate; OR, odds ratio; RCD, rotator cuff disease.)



Appendix Fig 7. Forest plots of mean difference in BMI between individuals with and without RCD from regression models meta-analyzed by strata/subgroup of risk of bias. Overall results without stratification (A); studies with low risk of bias (B); moderate risk of bias (C), and serious risk of bias (D). Note: MD = 0, no effect. (BMI, body mass index; MD, mean Ddifference; RCD, rotator cuff disease; SD, standard deviation.)