

Research Article

# Surgical management for massive rotator cuff tears: a network meta-analysis of randomized controlled trials

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## Abstract

**Background:** Multiple surgical strategies have been developed for treating massive rotator cuff tears (mRCTs). However, there is still no consensus on the best surgical option for mRCTs. Through a network meta-analysis, we aimed to comprehensively and systematically analyse the evidence in randomized controlled trials to help clinicians make evidence-based clinical decisions for patients with mRCTs.

**Methods:** Our study was a network meta-analysis of the surgical management of mRCTs (PROSPERO Registration ID: CRD42023397971). We searched PubMed, EMBASE, Cochrane and Web of Science for randomized controlled trials that examined the efficacy of surgical management for mRCTs up to 3 November 2022. A three-step method was employed for the study process. Study selection, data extraction and risk of bias evaluation were conducted by two independent reviewers. R software (version 4.2.1) and Stata (version 15.1) were used for the data analysis.

**Results:** From 10,633 publications, we included 15 randomized controlled trials (996 participants) for the quantitative analysis. In terms of both long-term and short-term surgical effects, there were no statistically significant differences among surgical interventions such as patch-augmented rotator cuff repair (RCR), RCR with platelet-rich plasma, arthroscopic decompression, bridging reconstruction, arthroscopic RCR with platelet-leukocyte membrane, open RCR, mini-open RCR, arthroscopic debridement, superior capsular reconstruction, arthroscopic suture-spanning augmented repair, subacromial balloon spacer and latissimus dorsi tendon transfer. Based on algorithms, the probability ranking suggests that patch augmentation is the most highly ranked surgical intervention for achieving better short-term surgical outcomes. Furthermore, arthroscopic-associated mini-open RCR was ranked as the highest surgical intervention for achieving better long-term surgical effects.

**Conclusions:** Based on the available data from the included studies, similar surgical efficacies were observed among the reported intervention measures for mRCTs. The patch augmentation technique was found to potentially achieve better short-term surgical outcomes, which is consistent with previous reports. However, the best surgical interventions for achieving long-term surgical

effects remain unknown. More high-quality research is needed to evaluate the efficacy and safety of these interventions and to guide clinical practice.

**Key words:** Surgical management, Massive rotator cuff tears, Shoulder, Network meta-analysis

## Highlights

- A network meta-analysis was conducted to compare the efficacy of various surgical interventions for treating massive rotator cuff tears (mRCTs).
- No statistically significant differences were observed among the surgical interventions in terms of both long-term and short-term surgical effects.
- Patch augmentation technique was found to potentially achieve better short-term surgical outcomes, while arthroscopic-associated mini-open rotator cuff repair was ranked as the highest surgical intervention for achieving better long-term surgical effects.
- More high-quality research is needed to guide clinical practice in selecting surgical interventions for achieving long-term surgical effects.

## Background

Massive rotator cuff tears (mRCTs) severely impair shoulder function, thereby negatively affecting the quality of life of patients. mRCTs account for up to 40% of all rotator cuff tears, imposing a major economic burden on society and individuals [1]. Several classification systems have been proposed to aid in the evaluation and treatment of mRCTs. DeOrto *et al.*'s classification system defines mRCTs as tears that exceed 5 cm in size in either the anterior–posterior or medial–lateral dimension [2]. Gerber *et al.*'s classification focuses on the involvement of multiple tendons in defining mRCTs. According to Gerber, a tear is considered massive if it involves complete tears of at least two tendons [3]. mRCTs adversely affect the shoulder's biomechanics, thereby decreasing range of motion (ROM) and function. The tear size of the rotator cuff (RC) has a significant impact on the surgical outcomes and prognosis. Typically, large and massive tears are associated with a higher degree of tissue retraction and muscle atrophy, making the repair more technically demanding. Studies have shown that larger tears tend to have a higher risk of retear, weaker tendon integrity, and potentially slower recovery and rehabilitation [3]. Furthermore, evidence has shown that retracted mRCTs can cause traction on the suprascapular nerve, which can accelerate the progression of atrophy and fatty infiltration of the supraspinatus and infraspinatus muscles [4,5]. Several factors can contribute to the development of mRCTs, including acute trauma, chronic degenerative changes and overhead activities [6]. Other factors, such as structural abnormalities in the shoulder, shoulder instability, muscle imbalances, metabolic diseases or inflammatory conditions, may also increase the risk of mRCTs [7]. With advances in surgical and arthroscopic techniques, surgical intervention is often advised for managing mRCTs. However, studies have shown that mRCTs are often complicated by structural failure, thereby resulting in a poor prognosis, higher rate of retearing after surgery,

increased pain and decreased ROM and strength. Therefore, it is crucial to consider the potential risks and benefits of any proposed treatment for mRCTs when making decisions about surgical strategies [4,6,8].

Surgical strategies for mRCTs can be divided into shoulder debridement surgeries, rotator cuff repair (RCR) surgeries and reconstructive surgeries. Shoulder debridement surgeries mainly include arthroscopic subacromial decompression and the long head of the biceps tenodesis/tenotomy technique. RCR surgeries mainly include RC suturing and mesh repairs, while reconstructive surgeries include superior capsular reconstruction (SCR), muscle/tendon transfer and reverse total shoulder arthroplasty. SCR is a surgical technique that is designed to prevent superior migration of the humeral head and restore normal shoulder biomechanics, which can completely restore superior stability of the glenohumeral joint [9]. The tendon transfer technique, a relatively newly developed surgical technique, allows for the reconstruction of the shoulder joint and the restoration of its ROM [10]. The choice of donor tendon for a tendon transfer procedure is based on the location of the RC deficiency. Studies have demonstrated that transfers of the latissimus dorsi and pectoralis major tendons can effectively alleviate pain. However, the functional benefits of the procedure are not always guaranteed [11]. Balloon spacers are filled with biodegradable saline, placed beneath the acromion and used to prevent superior migration of the humeral head [12]. All of these surgical strategies aim to alleviate symptoms and improve the quality of life of patients with mRCTs. However, due to the complexity of the surgical management for mRCTs, there is no consensus on the best option for treatment, making it difficult for surgeons to select the most appropriate surgical option.

Clinical decisions must nevertheless be made based on the best available evidence. However, relying only on individual randomized controlled trial results or even pairwise

meta-analyses makes it challenging to determine the best surgical options for mRCTs. A network meta-analysis, also called mixed treatments comparison or multiple treatments comparison meta-analysis, is a new systematic and comprehensive evaluation method that was developed based on the traditional pairwise meta-analysis and can be used to conduct comparison analysis among various interventions, even if the two interventions have never been directly compared [13]. No network meta-analysis of high-quality randomized controlled trials has been explicitly conducted on surgical strategies for mRCTs in recent years. Therefore, the aim of this study was to (1) analyse the outcomes of surgical management for mRCTs reported by a series of randomized controlled trials using the method of network meta-analysis and (2) establish a probability ranking of these interventions and surgical strategies that can provide valuable information for clinicians.

## Methods

### Protocol registration

Our study was conducted based on the guidelines and standards set by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). The study protocol has been registered at the International Prospective Register of Systematic Reviews (ID: CRD42023397971).

### Data sources and search strategy

Databases, including PubMed, EMBASE, Cochrane and Web of Science, were used to search for all relevant studies from inception to 3 November 2022. The search terms used were tailored to each database and included both medical subject headings (MeSH) and free text terms to ensure that all relevant studies were identified and included. The detailed search strategies are given as follows: (large OR irreparable OR massive) AND ('rotator cuff injuries' [MeSH] OR rotator cuff injury OR rotator cuff tears OR rotator cuff tear OR rotator cuff tendinosis OR rotator cuff tendinosis OR rotator cuff tendinitis OR rotator cuff tendinitides OR glenoid labral tears OR glenoid labral tear OR cuff injury OR cuff lesion OR rotator cuff disease OR rotator cuff disorder OR rotator cuff disorders OR rotator cuff injuries OR rotator cuff lesions OR rotator cuff pathology OR rotator cuff tendinopathies OR rotator cuff tendinopathy OR shoulder rotator cuff degeneration).

### Inclusion and exclusion criteria

The inclusion criteria for this study were (1) randomized controlled trials or prospective randomized studies published in scientific peer-reviewed journals; (2) published from the establishment of the database to 3 November 2022; and (3) written in English. The exclusion criteria for this study were as follows: (1) randomized clinical trials with a sample size of <10; (2) interventions or populations that did not meet the

criteria; (3) studies for which the full text could not be found; and (4) incomplete outcome data.

### Study selection

The two independent reviewers conducted a comprehensive literature search to identify relevant studies for our network meta-analysis of surgical management for mRCTs. Any disagreement was discussed and decided by a third party. A three-step method was employed for the study selection process. Step 1: the two researchers conducted a preliminary screening of the studies based on their study designs, writing language and type of literature. Step 2: the two independent reviewers reviewed all articles selected from the initial phase by abstract and assessed them for eligibility. Step 3: the two researchers conducted a full-text screening of the eligible studies to exclude literature with missing original text, incomplete data, interventions or populations that did not meet the study criteria.

### Data extraction

The two researchers extracted all relevant information regarding the study characteristics independently. If there was any disagreement, it was resolved by a third researcher. To ensure the validity and reliability of the study results, the two researchers used standardized forms to extract data from the included literature. The main contents of data extraction included the first author, year of publication, sample size, gender, age, interventions, duration of follow-up and any other relevant information.

### Outcomes

The primary outcome was the response to surgical treatment, which was assessed using various well-established tools, such as the Constant Score, the University of California, Los Angeles (UCLA) Shoulder Score, the disabilities of the arm, shoulder and hand (DASH), and the American Shoulder and Elbow Surgeons (ASES) Score. When multiple outcome measures were reported in a study, the most commonly used measurement outcome was selected for analysis. Secondary outcomes include surgical complications. The outcomes reported from radiological measurements, specifically magnetic resonance imaging (MRI), such as 'intact cuffs' and 'retear' rates of RC, were extracted for analysis.

### Risk of bias evaluation

The Cochrane collaborative bias tool was used to assess the quality of the literature in our study. Two independent researchers completed this process. Any disagreements were resolved by consultation with the third researcher. The quality assessment included seven aspects: random sequence generation (selection bias), allocation concealment (selection bias), blinding of participants and personnel (performance bias), blinding of outcome assessment (detection bias), incomplete outcome data (attrition bias), selective reporting (reporting

bias) and other bias. The included studies were evaluated by using the above criteria and classified as “low risk”, “high risk” or “unclear risk” according to the above items. Review Manager (version 5.4.1) was used to assess the quality and bias of the literature, which helped to visually represent the risk of bias in the included studies.

### Data analysis

In this study, the data analysis was conducted using R software (version 4.2.1) and Stata (version 15.1). The main outcome measure of effectiveness was the functional score. Continuous outcomes were calculated as the standardized mean difference (SMD), along with 95% confidence intervals (CIs) for effect sizes. The effectiveness of various interventions was compared using Bayesian analysis with a random effects model to compare the effects between interventions, allowing for combining results from numerous studies and estimating the overall effect of the interventions. The Markov chain Monte Carlo method was utilized to construct a Markov chain, a sequence of random variables related to each other. This chain was then used to generate a series of samples from the probability distribution to estimate the model's parameters. The deviation information criterion (DIC) was used to assess the fitting and global consistency of the model by measuring the difference between the observed data and the model predictions. Furthermore, the intervention measures were ranked according to the surface under the cumulative ranking (SUCRA), and a ranking table was generated to compare the effect differences between intervention methods. The intervention measures were also ranked according to the SUCRA score, which measured the relative effectiveness of different interventions. The DerSimonian–Laird random-effects model was used to estimate the heterogeneity between studies [14]. Additionally, a funnel chart, a data visualization tool, was used to represent the heterogeneity between studies. Finally, a *p* value of 0.05 was set as the threshold for determining statistical significance.

## Results

### Literature selection

We conducted a comprehensive and systematic search of the literature about the surgical management of mRCTs in the following databases: PubMed (2810), Embase (3757), Cochrane (290) and Web of Science (3776). A total of 10,633 literature records were retrieved for preliminary screening. Strict inclusion and exclusion criteria were applied in rescreening the included studies to ensure that the study results were based on the best available evidence. After conducting the initial screening, 49 studies were selected for further evaluation through full-text review, and 27 studies were excluded due to reasons such as discrepancies in the study population or study design. The remaining 22 studies underwent data extraction, although 7 were subsequently excluded due to incomplete outcome data. Ultimately, 15 studies were deemed eligible for

inclusion in the quantitative analysis. The literature screening process is shown in [Figure 1](#).

### General information and characteristics of included studies

[Table 1](#) provides a detailed overview of the general information about the 15 included studies. The 15 studies comprised a total of 996 participants. The majority of the studies (~73.3%) were single-center studies [15–25], while only four studies (~26.7%) were multicenter studies [26–29]. The follow-up period for the participants ranged from 3 months to 5 years. These studies were conducted in various countries worldwide, including Korea (4 studies, 26.7%), Canada (4 studies, 26.7%), the USA (2 studies, 13.3%), China (2 studies, 13.3%), Germany (1 study, 6.7%), the United Arab Emirates (1 study, 6.7%) and Italy (1 study, 6.7%) ([Table 2](#)).

### Quality assessment

The Cochrane Collaboration Bias Tool was employed to evaluate the quality of the included studies, and the results are depicted in [Figure 2](#). [Figure 2a](#) provides an overview of the assessments conducted by independent reviewers regarding each risk of bias item for all the studies included in the analysis. The majority of the included studies were assessed to have a low risk of bias in terms of random sequence generation and allocation concealment, while some studies did not provide clear reporting on relevant information in their methods section. Blinding of participants and personnel was assessed as high risk in 7 studies, accounting for 46.7% of all included studies. It is worth noting that performing surgical interventions under blinded conditions can pose significant challenges for both patients and surgeons, which may increase the risk of performance and detection bias in the included studies. Nevertheless, randomized allocation in the included studies was found to be effective in reducing other possible sources of bias. Four of the included studies were assessed to have a low risk of bias for blinding of outcome assessment. However, the remaining studies did not provide clear reporting on this aspect in their studies. The majority of included studies exhibited outstanding research designs and reported complete results data with low risks of attrition and reporting biases. The potential biases, other than those assessed, in all of the included studies were unclear. The independent reviewers' judgments regarding each item of bias risk are presented as percentages across all studies and are shown in [Figure 2b](#).

### Network meta-analysis

Out of the 15 studies, 5 studies were not connected in the principal network because the interventions they investigated were isolated from the principal network and did not demonstrate any connections with other surgical interventions in the primary network. To address the issue of repeated measurements of patients, we established two distinct time frames

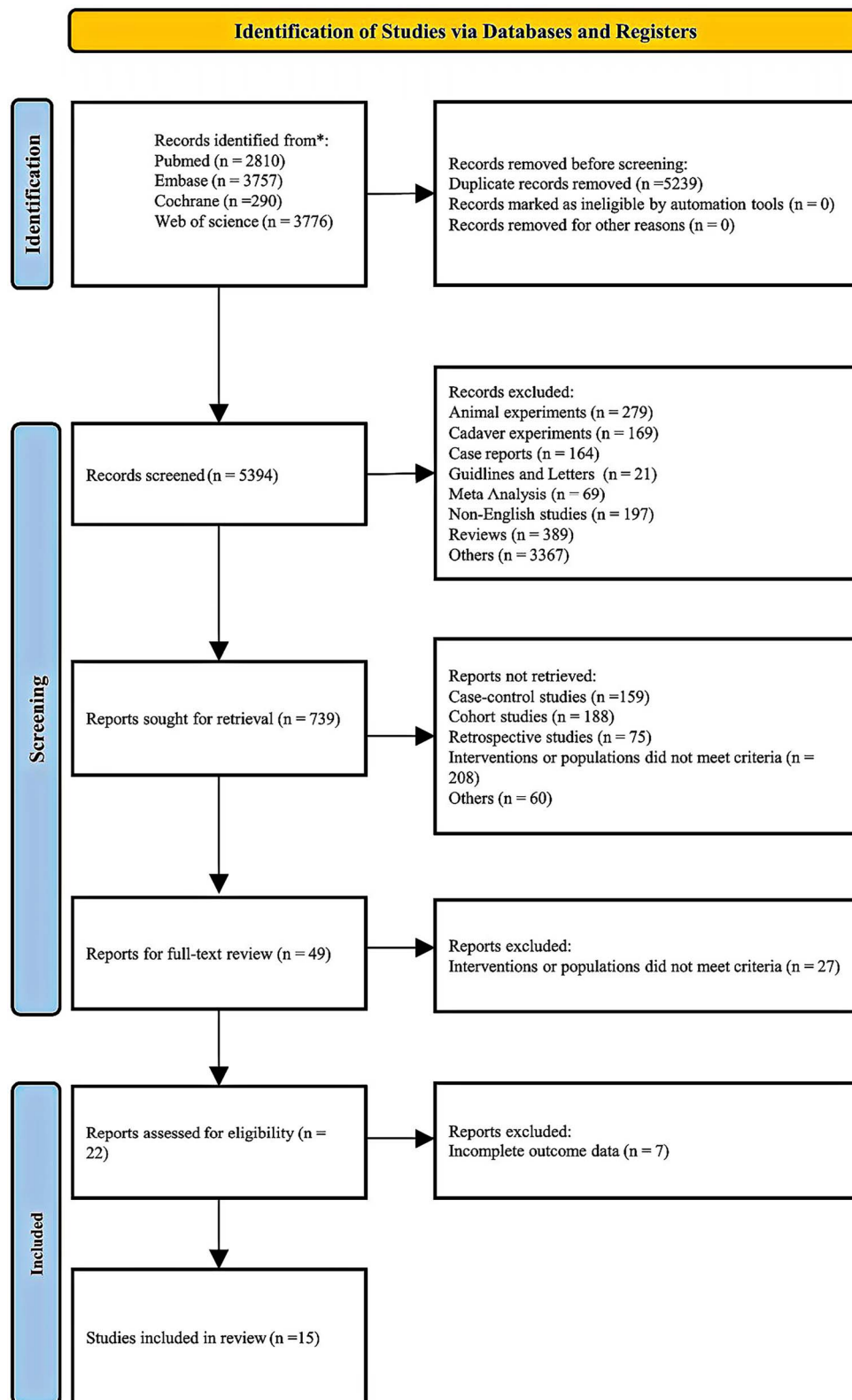


**Figure 1.** Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram for the quantitative analysis of surgical management for massive rotator cuff tears

Table 1. General information about included literature

| Study                      | Year | Single-center/<br>multicenter Study | Group               | Surgical strategy                                            | Sample size<br>(male/female) | Age, years<br>(mean ± SD) | Follow-up<br>(months)       |
|----------------------------|------|-------------------------------------|---------------------|--------------------------------------------------------------|------------------------------|---------------------------|-----------------------------|
| Berth <i>et al.</i> [15]   | 2010 | Single-center study                 | Group 1<br>Group 2  | Arthroscopic partial rotator cuff repair                     | 21 (15/6)                    | 62.5 ± (2.30)             | 24.2 (21–28) <sup>#</sup>   |
| Ozturk <i>et al.</i> [16]  | 2021 | Single-center study                 | Group 1<br>Group 2  | Arthroscopic debridement, subacromial decompression          | 21 (16/5)                    | 64.3 ± (3.40)             |                             |
|                            |      |                                     |                     | Arthroscopy-assisted LDT                                     | 21 (8/13)                    | 63.7 ± (6.70)             | 31.7 ± (5.20) <sup>*</sup>  |
| Jo <i>et al.</i> [17]      | 2013 | Single-center study                 | Group 1<br>Group 2  | Arthroscopy-assisted SCR                                     | 20 (6/14)                    | 61.8 ± (9.10)             |                             |
|                            |      |                                     |                     | Arthroscopic rotator cuff repair with PRP                    | 24 (10/14)                   | 65.0 ± (6.00)             | 15.88 ± (5.54) <sup>*</sup> |
| Jo <i>et al.</i> [18]      | 2015 | Single-center study                 | Group 1<br>Group 2  | Conventional arthroscopic rotator cuff repair                | 24 (14/10)                   | 64.2 ± (6.09)             | 17.26 ± (7.18) <sup>*</sup> |
|                            |      |                                     |                     | Arthroscopic rotator cuff repair with PRP                    | 37(8/29)                     | 60.08 ± (4.88)            | 13.03 ± (1.79) <sup>*</sup> |
| Bryant <i>et al.</i> [26]  | 2016 | Multicenter study                   | Group 1<br>Group 2  | Conventional arthroscopic rotator cuff repair                | 37(9/27)                     | 60.92 ± (7.34)            | 13.08 ± (1.98) <sup>*</sup> |
|                            |      |                                     |                     | Augmentation using porcine small intestine submucosa         | 34 (29/5)                    | 55.3 ± (11.30)            | 24                          |
| Barber <i>et al.</i> [27]  | 2012 | Multicenter study                   | Group 1<br>Group 2  | Without augmentation                                         | 28 (22/6)                    | 58.3 ± (10.20)            |                             |
|                            |      |                                     |                     | Graft jacket acellular human dermal matrix augmentation      | 22 (18/4)                    | 56 ± (6.50)               | 24 (12–38) <sup>#</sup>     |
| Lee <i>et al.</i> [19]     | 2022 | Single-center study                 | Group 1<br>Group 2  | Without augmentation                                         | 20 (13/7)                    | 56.0 ± (9.50)             |                             |
|                            |      |                                     |                     | With allograft patch augmentation                            | 21 (7/14)                    | 58.3 ± (7.0)              | 68.4 ± 12 <sup>*</sup>      |
| Ma <i>et al.</i> [20]      | 2019 | Single-center study                 | Group 1<br>Group 2  | Suture-spanning augmentation technique of single-row repair  | 22 (7/15)                    | 60.2 ± (8.4)              |                             |
|                            |      |                                     |                     | Single-row repair                                            | 35 (9/26)                    | 65.3 ± (7.78)             | 24                          |
| Wong <i>et al.</i> [21]    | 2021 | Single-center study                 | Group 1<br>Group 2  | Maximal repair                                               | 36 (15/21)                   | 65.0 ± (7.24)             |                             |
|                            |      |                                     |                     | Bridging reconstruction using dermal allograft               | 15 (13/2)                    | 60.9 ± (6.67)             | 24                          |
| Oh <i>et al.</i> [22]      | 2020 | Single-center study                 | Group 1<br>Group 2  | Optimum tension group                                        | 32 (17/15)                   | 60.2 ± (8.5)              |                             |
|                            |      |                                     |                     | Maximum tension group                                        | 32 (17/15)                   | 64.1 ± (7.3)              | 27.4 (24–45) <sup>#</sup>   |
| Mohtadi <i>et al.</i> [28] | 2008 | Multicenter study                   | Group 1<br>Group 2  | Open acromioplasty and rotator cuff repair                   | 30 (22/8)                    | 56.2 ± (8.25)             | 28 (20–43) <sup>#</sup>     |
|                            |      |                                     |                     | Arthroscopic acromioplasty and mini-open rotator cuff repair | 33 (20/13)                   | 57 ± (12.25)              | 28 (22–41) <sup>#</sup>     |
| Verma <i>et al.</i> [29]   | 2022 | Multicenter study                   | Group 1<br>Group 2; | InSpace Implant compared with partial repair                 | 93 (50/43)                   | 66.8 ± (7.7)              | 24                          |
|                            |      |                                     |                     | Partial repair                                               | 91 (43/48)                   | 64.7 ± (7.9)              | 28 (22–41) <sup>#</sup>     |
| Gumina <i>et al.</i> [23]  | 2012 | Single-center study                 | Group 1<br>Group 2  | With platelet-leukocyte membrane                             | 39 (20/19)                   | 60 ± (4.4)                | 13                          |
|                            |      |                                     |                     | Without platelet-leukocyte membrane                          | 37 (21/16)                   | 63 ± (5.9)                |                             |
| Ono <i>et al.</i> [24]     | 2022 | Single-center study                 | Group 1<br>Group 2  | Superior capsular reconstruction                             | 25 (21/4)                    | 60.5 ± (6.3)              | 25 (18–33) <sup>#</sup>     |
|                            |      |                                     |                     | Bridging grafts                                              | 25 (21/4)                    | 60.0 ± (5.9)              |                             |
| Cai <i>et al.</i> [25]     | 2018 | Single-center study                 | Group 1<br>Group 2  | Without any augmentation                                     | 60 (32/28)                   | 61.3 ± (7.6)              | 28.2 (24–36) <sup>#</sup>   |
|                            |      |                                     |                     | With graft augmentation of 3D biological collagen            | 47 (24/23)                   | 62.9 ± (9.7)              |                             |

<sup>\*</sup>Data was presented as shown as mean ± SD. <sup>#</sup>Data was presented as mean and ranges. LDT latissimus dorsi tendon transfer, SCR superior capsular reconstruction, PRP platelet-rich plasma



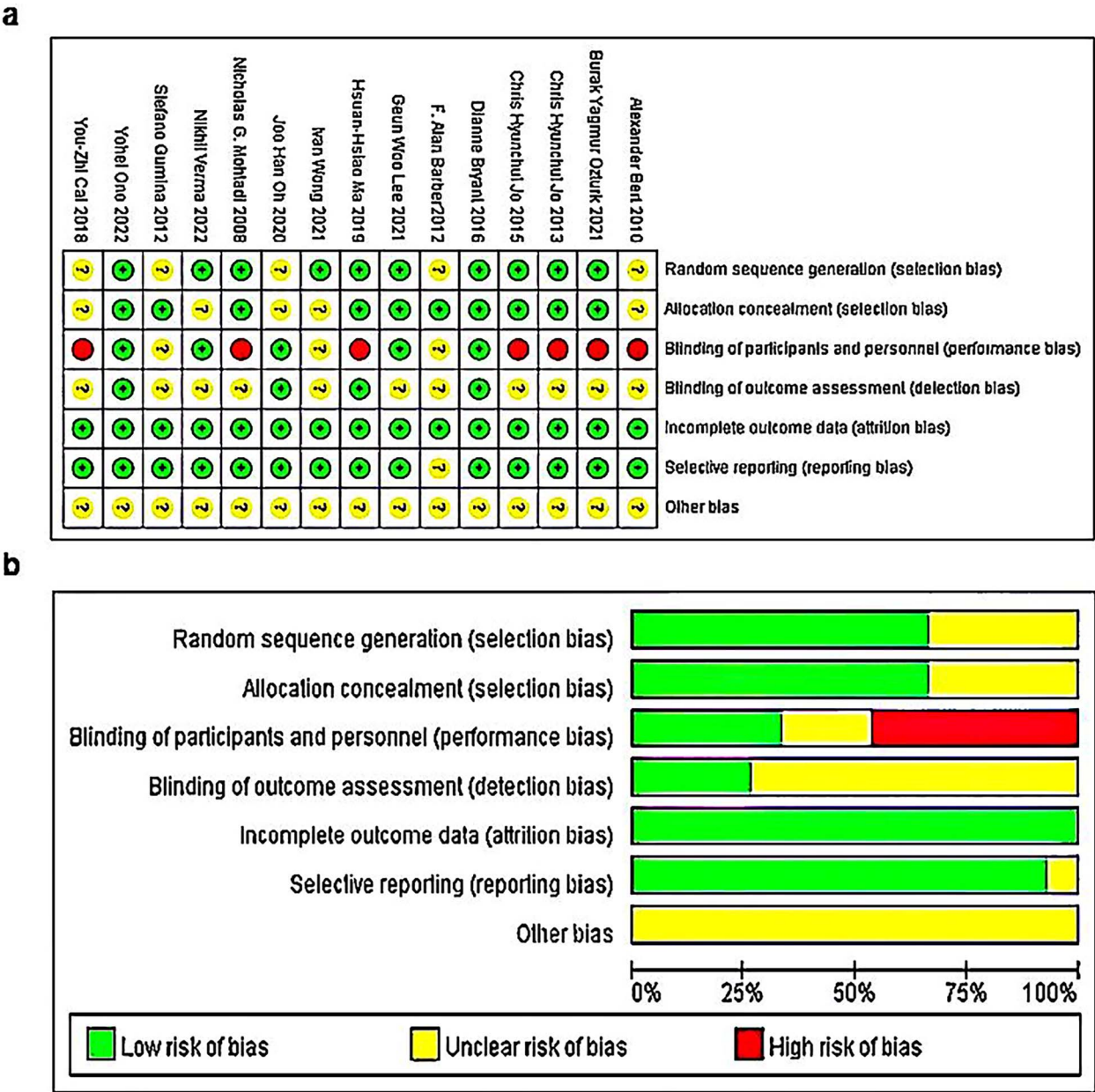


**Figure 2.** Quality assessment of the included studies. (a) Risk of bias summary: independent reviewers’ judgments about each risk of bias item for each included study. (b) Risk of bias: independent reviewers’ judgments about each risk of bias item are presented as percentages across all included studies

A net-league (Table 2) comparing the SMD and 95% CIs of these interventions showed no statistically significant differences among them. Figure 3b shows the probability ranking of these ten interventions (each intervention has ten different colored bar charts, and the colors gradually become lighter from left to right, representing the ranking order. The darker the color, the higher the ranking). The comprehensive ranking probability results are as follows: patch (SUCRA 63.18%), PRP (SUCRA 61.08%), bridging (SUCRA 58.35%), arthroscopic RCR (SUCRA 55.64%), PLM (SUCRA 53.07%), open (SUCRA 46.10%), mini open (SUCRA 40.80%), debridement (SUCRA 36.86%) and SCR (SUCRA 34.93%). However, based on the results

of Figure 3b, patch may be a promising intervention for achieving better short-term surgical effects.

**Long-term effect of surgical interventions**  
Figure 4a shows the comparative results of the network analysis of the long-term effects of surgical interventions. Of the literature included, 10 studies reported the long-term surgical effects of 10 interventions, with arthroscopic RCR being the most frequently studied intervention. Table 3 presents a net-league comparing these interventions pairwise, showing the SMD and 95% CIs for each comparison. Figure 4b presents a probability ranking for these 10 interventions.

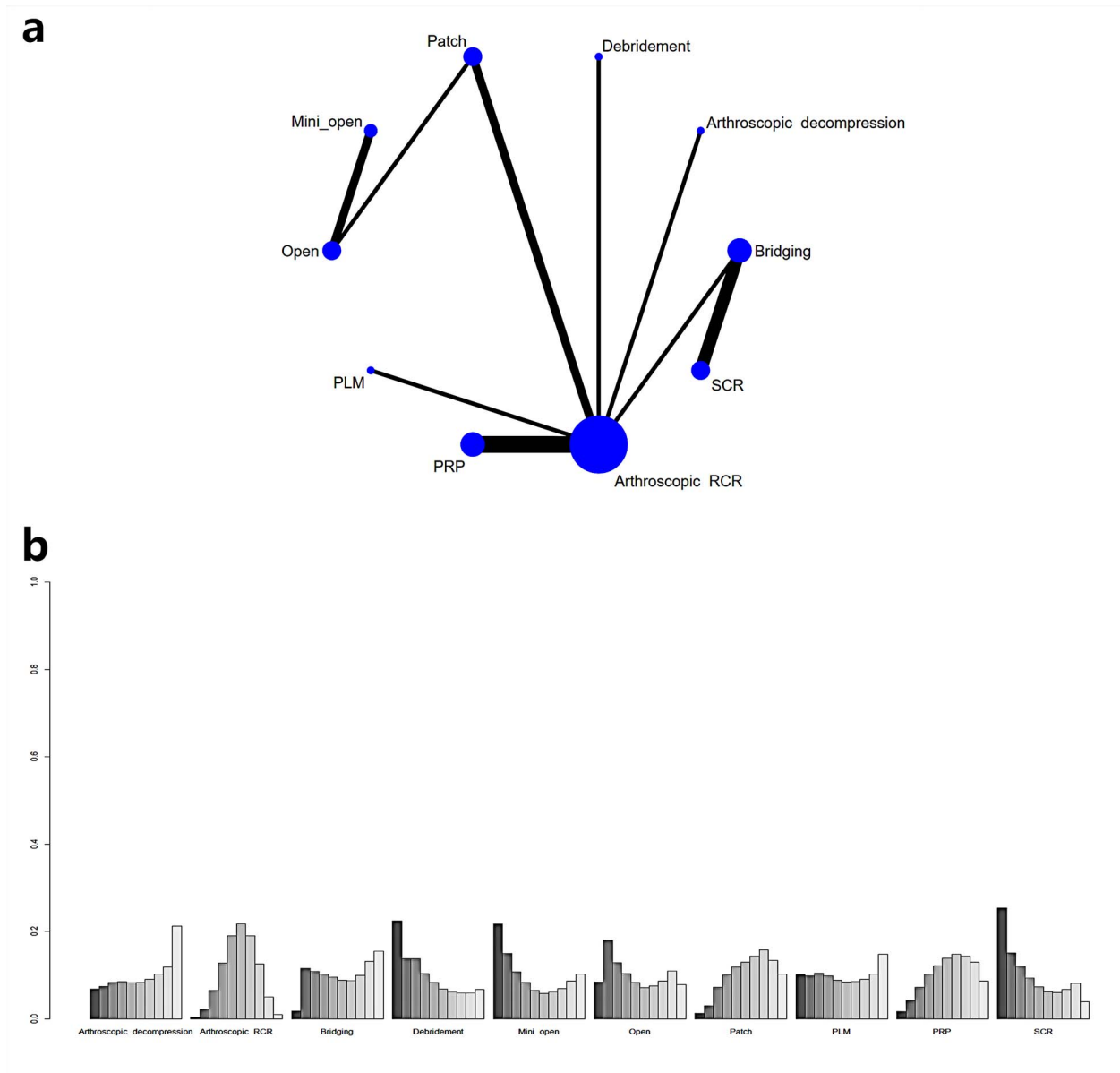


**Figure 3.** Network analysis of surgical interventions on short-term effects. (a) Network map of surgical interventions for massive rotator cuff tears. (b) Probability rankings of short-term surgical effects across different interventions. *RCR* rotatory cuff repair, *PLM* platelet-leukocyte membrane, *SCR* superior capsular reconstruction, *PRP* platelet-rich plasma

The comprehensive probability ranking results are as follows: mini-open (SUCRA 85.9%), SSA (SUCRA 84.1%), open (SUCRA 63.5%), patch (SUCRA 55.5%), InSpace Implant (SUCRA 52.0%), bridging (SUCRA 47.8%), arthroscopic RCR (SUCRA 42.9%), SCR (SUCRA 36.4%), debridement (SUCRA 16.6%) and LDT (SUCRA 15.3%). The results showed that there were no significant differences among these interventions. Combining the results from Figure 4b, mini-open appears to be a promising intervention for achieving better long-term surgical effects.

#### Assessment of publication bias

Funnel plots were constructed using STATA software based on the extracted data to assess the presence of publication bias

(Figure 5). In terms of the efficacy of surgical interventions, we created funnel plots for both short-term and long-term effects. The colored dots in the funnel plot represent various comparisons between different intervention measures. We found no significant asymmetry in the adjusted comparison funnel plot, indicating that publication bias in our study can be considered negligible (Figure 5a and b).

#### Quantitative analysis of imaging assessment

Of the 15 studies analysed, 6 studies utilized MRI to evaluate the efficacy of surgical interventions for patients with mRCTs. A total of 313 individuals underwent MRI examinations, with the follow-up period ranging from 9 months to 2 years. We conducted a meta-analysis of 5 studies to assess the

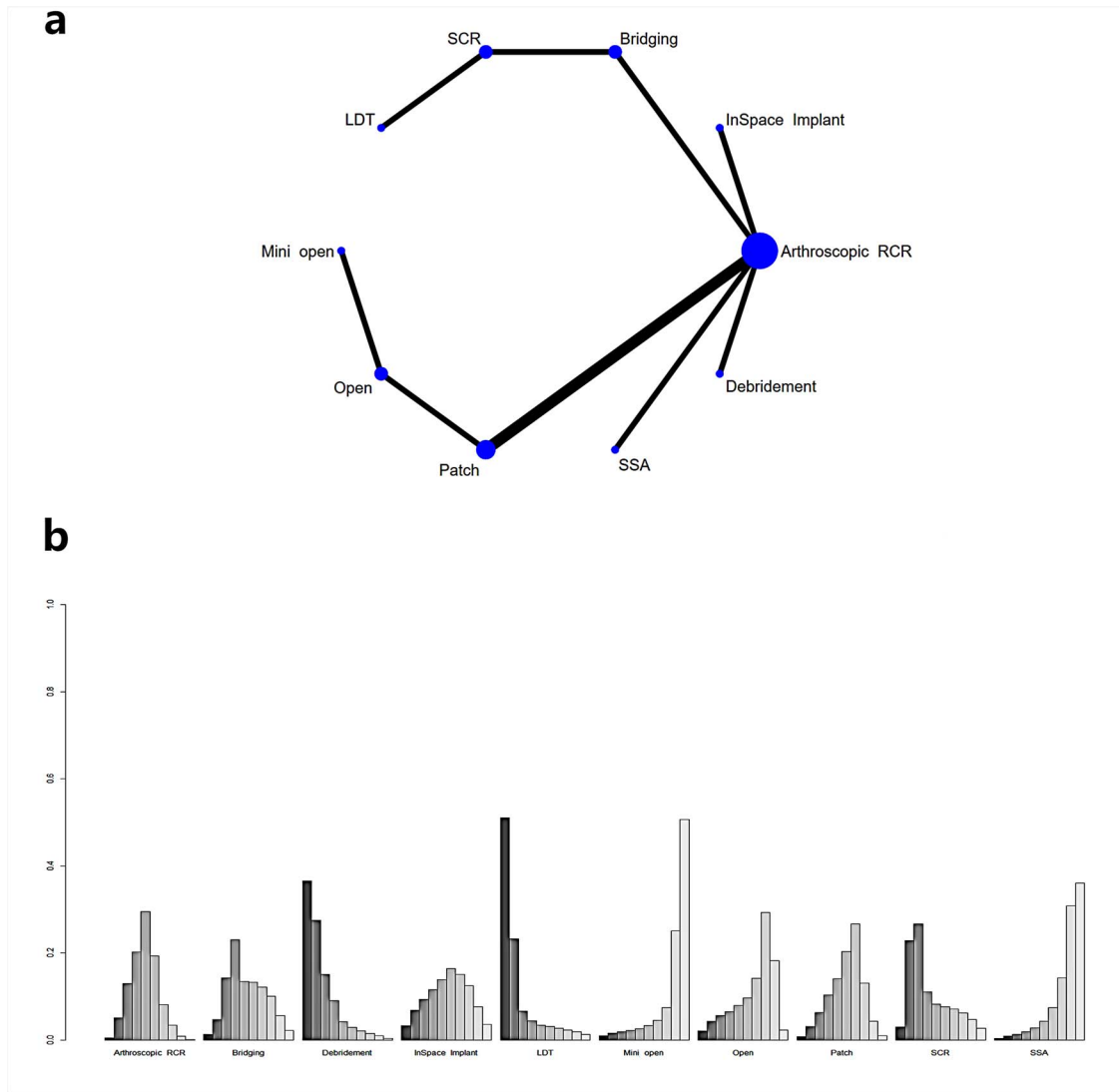


**Figure 4.** Network analysis of surgical interventions on long-term effects. (a) Network map of surgical interventions for massive rotator cuff tears. (b) Probability rankings of long-term surgical effects across different interventions. *LDT* latissimus dorsi tendon transfer, *SCR* superior capsular reconstruction, *SSA* arthroscopic suture-spanning augmented repair

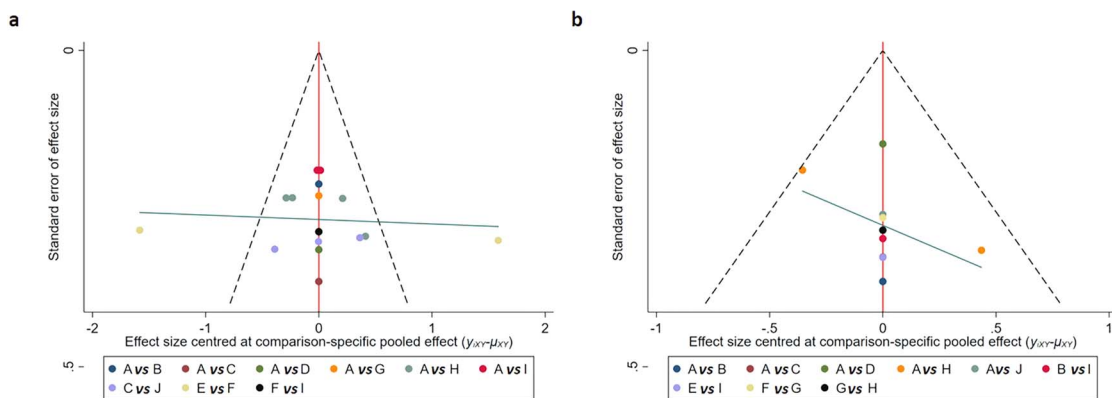


**Figure 5.** Assessment of publication bias. (a) Funnel plots for short-term surgical effects: A (reference), arthroscopic rotator cuff repair; B, bridging; C, debridement; D, mini open; E, open; F, platelet-leukocyte membrane; G, platelet-rich plasma; H, patch; and I, superior capsular reconstruction. (b) Funnel plots for long-term surgical effects: A (reference), arthroscopic rotator cuff repair; B, bridging; C, debridement; D, InSpace Implant; E, latissimus dorsi tendon transfer; F, mini open; G, open; H, patch; I, superior capsular reconstruction; and J, arthroscopic suture-spanning augmented repair

Table 3. Net-league of surgical management for massive rotator cuff tears that reported long-term surgical effect

| Arthroscopic RCR    | Bridging            | Debridement         | InSpace Implant     | LDT                 | Mini-open          | Open               | Patch             | SCR                 | SSA                |
|---------------------|---------------------|---------------------|---------------------|---------------------|--------------------|--------------------|-------------------|---------------------|--------------------|
| -0.02 (-1.65, 1.61) | 0.95 (-1.34, 3.24)  | -1.11 (-3.29, 1.1)  | 1.33 (-1.85, 4.49)  | -2.55 (-6.32, 1.15) | 0.86 (-0.71, 2.42) | 0.27 (-1.29, 1.85) | 0.59 (-1.9, 3.16) | -0.67 (-3.09, 1.84) | -1.53 (-4.3, 1.22) |
| 0.93 (-0.67, 2.51)  | -0.15 (-2.38, 2.07) | 0.22 (-2.99, 3.44)  | -1.22 (-4.17, 1.64) | -1.69 (-5.12, 1.65) | 1.14 (-1.1, 3.36)  | 0.86 (-2.06, 3.89) | 0.59 (-2.81, 1)   | -0.95 (-2.81, 1)    | -1.53 (-4.3, 1.22) |
| -0.18 (-1.69, 1.34) | 1.17 (-1.09, 3.42)  | -2.32 (-5.3, 0.6)   | -0.35 (-2.87, 2.04) | -1.42 (-4.46, 1.55) | 1.72 (-1.6, 5.13)  | 0.86 (-2.06, 3.89) | 0.59 (-2.81, 1)   | -0.95 (-2.81, 1)    | -1.53 (-4.3, 1.22) |
| 1.15 (-1.63, 3.96)  | -1.37 (-4.39, 1.57) | -1.47 (-4.01, 0.99) | -0.08 (-2.01, 1.73) | -0.83 (-2.42, 0.78) | 1.72 (-1.6, 5.13)  | 0.86 (-2.06, 3.89) | 0.59 (-2.81, 1)   | -0.95 (-2.81, 1)    | -1.53 (-4.3, 1.22) |
| -1.4 (-3.93, 1.05)  | -0.32 (-3.08, 1.96) | -1.2 (-3.17, 0.7)   | 0.5 (-2.22, 3.22)   | -2.36 (-5.57, 0.83) | 0.19 (-2.69, 3.15) | 0.86 (-2.06, 3.89) | 0.59 (-2.81, 1)   | -0.95 (-2.81, 1)    | -1.53 (-4.3, 1.22) |
| -0.54 (-2.5, 1.33)  | -0.24 (-2.25, 1.69) | -0.61 (-3.4, 2.18)  | -1.03 (-3.21, 1.13) | -2.36 (-5.57, 0.83) | 0.19 (-2.69, 3.15) | 0.86 (-2.06, 3.89) | 0.59 (-2.81, 1)   | -0.95 (-2.81, 1)    | -1.53 (-4.3, 1.22) |
| -0.26 (-1.41, 0.78) | 0.35 (-1.24, 1.92)  | -2.14 (-4.35, 0.1)  | -1.03 (-3.21, 1.13) | -2.36 (-5.57, 0.83) | 0.19 (-2.69, 3.15) | 0.86 (-2.06, 3.89) | 0.59 (-2.81, 1)   | -0.95 (-2.81, 1)    | -1.53 (-4.3, 1.22) |
| 0.33 (-1.95, 2.6)   | -1.19 (-3.44, 1.06) | -2.14 (-4.35, 0.1)  | -1.03 (-3.21, 1.13) | -2.36 (-5.57, 0.83) | 0.19 (-2.69, 3.15) | 0.86 (-2.06, 3.89) | 0.59 (-2.81, 1)   | -0.95 (-2.81, 1)    | -1.53 (-4.3, 1.22) |
| -1.21 (-2.76, 0.36) | -1.19 (-3.44, 1.06) | -2.14 (-4.35, 0.1)  | -1.03 (-3.21, 1.13) | -2.36 (-5.57, 0.83) | 0.19 (-2.69, 3.15) | 0.86 (-2.06, 3.89) | 0.59 (-2.81, 1)   | -0.95 (-2.81, 1)    | -1.53 (-4.3, 1.22) |

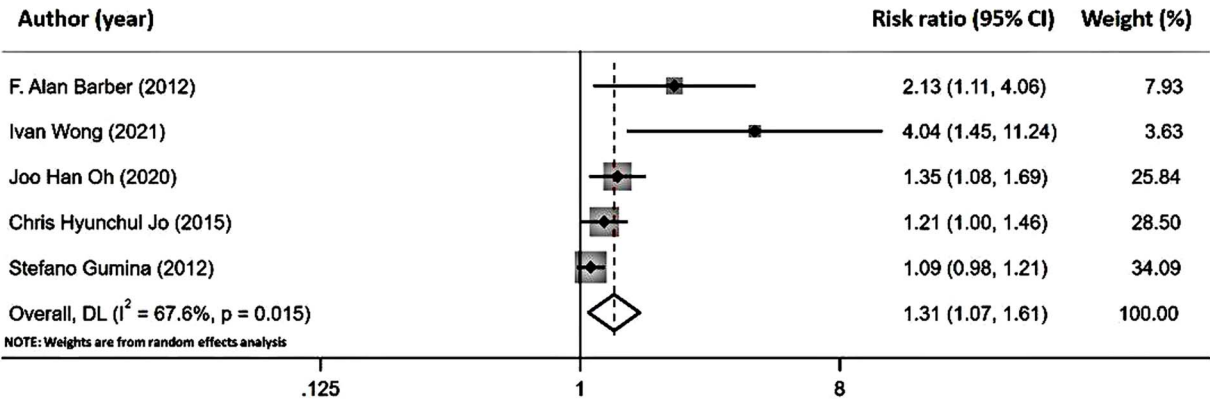
The data was presented in terms of Standardized Mean Difference (SMD) with a 95% Confidence Interval (CI). RCR rotatory cuff repair, LDT latissimus dorsi tendon transfer, SCR superior capsular reconstruction, SSA suture-spanning augmented repair

efficacy of surgical interventions in improving the healing rate of the RC, and the results are presented in Figure 6. Figure 6a demonstrates that combining arthroscopic RCR with PRP, PLM and other techniques significantly enhanced the imaging outcomes (intact cuffs) with a relative risk of 1.31 (95% CI: 1.07–1.61). We conducted a sensitivity analysis of the included studies, which is presented in Figure 6b. This result implies that the outcomes of our synthesized analysis exhibit a high degree of stability. The asymmetric shape of the funnel plot in Figure 6c indicates the presence of publication bias in the meta-analysis. The results of Begg’s test and Egger’s test showed  $p < 0.05$ , indicating significant publication bias. To address this bias, we attempted to utilize trim-and-fill analysis. However, the results showed that the publication bias was not effectively resolved.

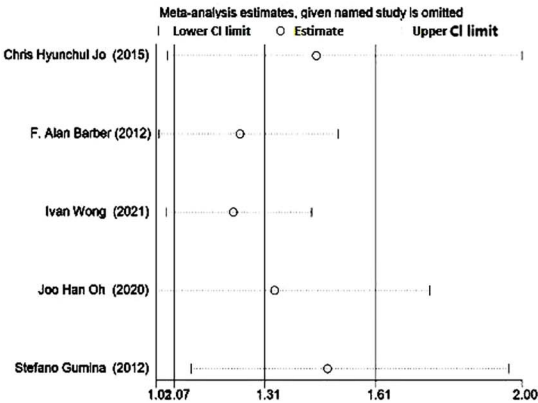
Discussion

mRCTs can lead to structural damage and poor outcomes, and the rate of retearing after surgical management is higher than that of other RC lesions, making it a matter of particular concern for surgeons [7]. Multiple surgical interventions have been developed to increase RC excursion and humeral head coverage, as well as to reconstruct the transverse force couple [8, 9]. However, there is a limited number of systematic reviews available on this topic, and the existing ones also suffer from deficiencies. A systematic review by Kovacevic *et al.* found that the outcomes of physical therapy may be inferior to those of surgical treatment [30]. However, due to the lack of high-quality clinical studies available, they did not make any recommendations or oppositions on the treatment strategies to guide the management of irreparable mRCTs. Maillot *et al.* conducted a network meta-analysis of various interventions for mRCTs based on the literature published up to 1 May 2016. However, their study also had certain limitations, as it included both prospective and retrospective studies, which could affect the synthesis analysis of the best evidence [31]. Davies *et al.* conducted a systematic review to investigate the efficacy of surgical techniques, including superior capsule reconstruction, partial RCR, graft insertion, arthroscopic debridement or balloon spacers, for the treatment of mRCTs. All these surgical interventions could potentially improve patient-reported outcomes and functional scores in the early and midterm periods. However, due to the heterogeneity in the quality of the studies included, no definitive conclusions could be drawn on the comparative effectiveness of each intervention [32]. To date, our study is the first to conduct a network meta-analysis of high-quality randomized controlled trials on surgical treatment for mRCTs to compare the surgical efficacy of multiple surgical options, even though no direct comparisons exist in the primary studies. The study thus provides a comprehensive overview of the current evidence on surgical interventions for mRCTs and help with the making of evidence-based decisions [33].

a



b



c

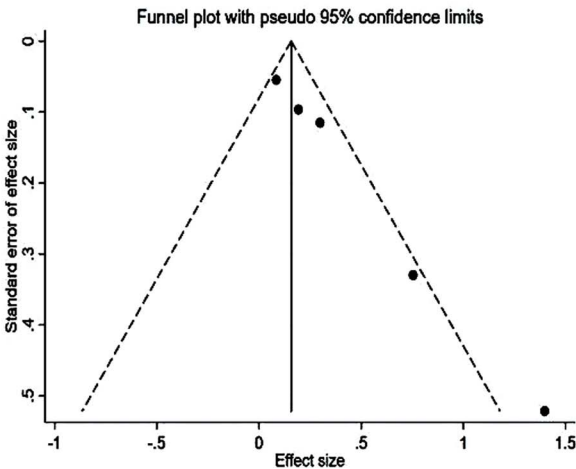


**Figure 6.** Quantitative analysis of imaging assessment outcomes. (a) Forest plots of the 5 included studies. (b) Sensitivity analysis of the 5 included studies. (c) Funnel plots for imaging assessment of surgical interventions for massive rotator cuff tears

The present study included 15 randomized controlled trials and extracted data on the effectiveness of multiple surgical interventions for mRCTs. Due to the lack of direct comparisons among most interventions, a network meta-analysis was conducted to comprehensively evaluate the efficacy of multiple surgical interventions by extracting shoulder function metrics from the included studies. The UCLA score, a prevalent metric for evaluating shoulder function, encompasses various aspects such as pain, strength, ROM and activity level in patients with shoulder disorders [34]. DASH score is a commonly used outcome measure for assessing functional disability and symptoms in individuals with upper extremity musculoskeletal disorders and provides a comprehensive and standardized assessment of upper extremity function and disability, which is widely used in clinical practice and research to evaluate the effectiveness of interventions and compare outcomes between different interventions. The ASES score is a widely acknowledged and validated metric employed for evaluating shoulder function and pain. It serves as a dependable and validated instrument that aids

clinicians and researchers in comprehending the ramifications of shoulder disorders and gauging the efficacy of interventions [35]. Our results shows no statistically significant differences in the pairwise comparisons between various interventions reported in the included studies in both short-term and long-term effect assessment, indicating that the determination of the most efficacious intervention measure remains uncertain, necessitating further research to gain insight into the optimal surgical interventions.

In addition, we obtained probability rankings through network analysis, which can help to provide further information regarding multiple surgical interventions. The patch augmentation technique is the most highly ranked surgical intervention that tends to achieve better short-term surgical outcomes. It is used to strengthen and envelop the degenerated or torn RC tendons, which can attain static shoulder joint stability, curtail upwards migration of the humeral head, act as a cushion between the humeral head and the acromion to minimize downwards pressure on the acromion, and synergize with the deltoid muscle to facilitate movement. Multiple patch

augmentation techniques were reported in the included studies, including small intestine submucosa-augmented repair, augmented repair, and 3D biological collagen graft augmented repair [25–27]. The patch can be made of synthetic materials, allografts or autografts. Villatte *et al.* conducted a systematic review and meta-analysis of studies that investigated the use of autografts and allografts for the treatment of mRCTs. Their analysis revealed that there was no statistically significant difference in the retear rate and clinical outcomes between the two treatment options in the short- to medium-term [36]. Cobb *et al.* conducted a systematic review of patch augmentation techniques for repairing RCTs. Short-term studies have yielded promising results, indicating that patch augmentation holds great potential for enhancing the success rate of mRCTs [37]. de Andrade *et al.* conducted a meta-analysis and systematic review on patch augmentation in RCR, which showed that patch augmentation could benefit RCR and significantly reduce the rate of retears [38]. The patch augmentation technique presents a relatively definitive advantage in the management of mRCTs. However, it will be necessary for future studies to obtain evidence from large-scale randomized controlled trials to consolidate this conclusion. There has been interest in enhancing patch augmentation techniques through the application of biological therapies [39]. There are many biological therapies to augment RCR in patients with large and massive tears. PRP contains a concentrated amount of growth factors, which can potentially stimulate tissue repair and regeneration. Combined with patches, PRP can improve clinical outcomes by promoting angiogenesis, enhancing tissue integration and accelerating the healing process, which is useful in smaller RCTs [40]. However, its efficacy in mRCTs is not confirmed yet. There has been growing interest in the use of biological patches to augment repairs in RCR. Extracellular matrices are frequently used as adjuvants in RCR. The primary role of extracellular matrices is to provide mechanical support and enhance the healing process in cases where the tissue is stiffer and mechanically inferior. Researchers and clinicians have been studying the effectiveness of these patches in enhancing the healing process and improving patient outcomes [41]. Furthermore, the use of mesenchymal stem cells, cytokines and biologics in patch augmentation techniques has garnered considerable interest. However, additional research is necessary to determine the effectiveness of these biological therapies in the treatment of mRCTs [42].

According to the cumulative probability ranking of long-term surgical effects among various intervention measures, arthroscopic-associated mini-open RCR is ranked as the highest surgical intervention in terms of achieving better long-term surgical outcomes. Among the 15 randomized controlled trials included in our analysis, Mohtadi *et al.* found no statistically significant difference between arthroscopic-assisted mini-open and open procedures in the long-term follow-up [28]. No randomized controlled trials that directly compared arthroscopic and mini-open RCR were included in our network analysis. However, the net-league based on the

data available from the included studies suggested that there was no statistically significant difference in surgical outcomes between mini-open and arthroscopic RCR. Ozcan *et al.* conducted a long-term follow-up study exceeding 2 years to evaluate the clinical outcomes of patients who underwent either arthroscopic or mini-open RCR. The study findings showed no significant differences in clinical outcomes between the two groups. Regrettably, their study did not include patients with mRCTs (>5 cm) [43]. Musil *et al.* demonstrated that to achieve excellent outcomes for the repair of mRCTs by the mini-open technique, early indication, appropriate surgical techniques and high-quality postoperative care are essential. Furthermore, this technique allows for assessing potential coexisting pathologies in the glenohumeral joint. With the development of arthroscopic technology, total arthroscopic RCR is increasingly favored by surgeons. More high-quality studies are needed to further compare the differences in efficacy among these interventions [44].

### Strengths and limitations

Our network meta-analysis is a comprehensive and systematic study of the surgical management of mRCTs. Only randomized controlled trials of a high standard were included, thus ensuring the accuracy and validity of the results and conclusions. Our study provides a more comprehensive overview of the current evidence than traditional meta-analysis, allowing healthcare professionals to make informed decisions about the best surgical options for patients with mRCTs. There are also limitations to our study. Given the difficulty of conducting randomized controlled trials in this research field, only a limited number of high-quality randomized controlled trials were included. Some interventions for mRCTs were not included in the analysis, which may limit the scope of our study conclusions. We acknowledge the importance and value of including studies from different languages to ensure a more comprehensive review. We have also highlighted the significance of future research to include studies in multiple languages to provide a more holistic understanding of the surgical management of mRCTs. Moreover, only prominent or representative outcome indicators were extracted and analysed in the process of data extraction, while other outcome indicators, such as pain evaluation and quality of life, were discarded, which may have an impact on the final results to some extent. There was an absence of screening the reference lists of included studies and searching grey literature, which is one of the limitations of our study. We expect better relevant studies in the future to compensate for the shortcomings of the existing study.

### Conclusions

Based on the available data from the included studies, similar surgical efficacies were observed among the reported intervention measures for mRCTs. The patch augmentation technique was found to potentially achieve better short-term

surgical outcomes, which is consistent with previous reports. However, the best surgical interventions for achieving long-term surgical outcomes remain unknown. Therefore, when making clinical decisions, individual factors such as clinical experience, patient factors, patient expectations and tear characteristics should be considered. Although the existing studies provide some evidence to support the surgical management of mRCTs, more high-quality research is needed to evaluate the efficacy and safety of these interventions and to guide clinical practice.

## Abbreviations

CI: Confidence interval; DIC: Deviance information criterion; MRI: Magnetic resonance imaging; mRCTs: Massive rotator cuff tears; LDT: Latissimus dorsi tendon transfer; PLM: Platelet-leukocyte membrane; PRP: Platelet-rich plasma; RC: Rotator cuff; RCR: Rotator cuff repair; ROM: Range of motion; SCR: Superior capsular reconstruction; SMD: Standardized mean difference; SSA: Suture-spanning augmented repair; SUCRA: Surface under the cumulative ranking.

## Authors' contributions

HFJ and ZHD wrote the manuscript. DTAV revised the manuscript. HFJ and JFS conducted the study selection, data extraction and risk of bias evaluation. WFX prepared the tables. YSL conceptualized this research and decided on the content. All authors approved the final version of the manuscript and agreed to be accountable for all aspects of the work.

## Conflict of interest

The authors declare that the research was conducted without any commercial or financial relationships construed as a potential conflict of interest.

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## Data availability

The datasets used and/or analyzed during the research are available from the corresponding author upon reasonable request.

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