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Rhinoplasty

Review Article

Fresh Frozen vs Autologous Costal Cartilage in Rhinoplasty: A Meta-Analysis of Complication Rates

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Aesthetic Surgery Journal Open Forum 2026, ojag072
Accepted date: March 26, 2026; online publish-ahead-of-print April 28, 2026.

https://doi.org/10.1093/asjof/ojag072
www.asjopenforum.com

OXFORD UNIVERSITY PRESS

Abstract

Background: Fresh frozen costal cartilage (FFCC) has emerged as a promising alternative to autologous costal cartilage (ACC) in structural rhinoplasty, offering advantages such as elimination of donor site morbidity and reduced operative time. However, concerns remain regarding its complication profile compared with ACC.

Objectives: This meta-analysis compares postoperative complication rates between FFCC and ACC in rhinoplasty, focusing on infection, warping, resorption, and revision surgery.

Methods: A systematic review was performed according to PRISMA guidelines. MEDLINE, Embase, Web of Science, and Scopus were searched for studies published between January 1990 and March 2025. Eligible studies reported outcomes of rhinoplasty using FFCC or ACC in cohorts of ≥5 patients. Data were extracted on complication rates, patient demographics, follow-up duration, and study characteristics. Risk of bias was assessed using the ROBINS-I tool. Pooled complication rates and 95% CIs were calculated. Differences between graft types were assessed using unpaired 2-proportion *z*-tests.

Results: Twenty-seven studies met inclusion criteria, encompassing 2137 patients in the ACC group and 766 in the FFCC group. The weighted mean follow-up was 18.4 months for ACC and 23.0 months for FFCC. Fresh frozen costal cartilage was associated with significantly lower rates of warping (1.2% vs 3.9%; $P = .00038$) and revision surgery (1.3% vs 3.4%; $P = .0029$). Infection (1.7% vs 2.3%; $P = .34$) and resorption rates (1.2% vs 1.9%; $P = .25$) were not significantly different between groups.

Conclusions: Fresh frozen costal cartilage demonstrates significantly lower rates of warping and revision surgery compared with ACC, with no increase in infection or resorption. Despite limitations related to study design and follow-up duration, these findings support FFCC as a safe and effective alternative to autologous grafts in rhinoplasty. Further prospective, controlled studies are needed to confirm these results and evaluate long-term outcomes.

Level of Evidence: 3 (Risk)

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Costal cartilage remains a critical material in structural rhinoplasty, particularly in cases requiring substantial dorsal augmentation, major revision procedures, or reconstruction following trauma or congenital deformity.[1,2] Among grafting options, autologous costal cartilage (ACC) has long been regarded as the gold standard due to its favorable mechanical strength, low immunogenicity, and robust long-term outcomes.[3,4] However, its use is not without drawbacks. Harvesting ACC increases operative time and is associated with donor site morbidity, including postoperative pain, chest wall scarring, and, in rare cases, pneumothorax.[5-7] In addition, ACC is prone to warping, particularly when carved from costal segments under tension, posing a significant challenge to surgical predictability and aesthetic durability.[7,8]

In an effort to preserve the structural reliability of costal cartilage while eliminating the morbidity of autologous harvest, surgeons and tissue engineers have explored allogeneic alternatives. Early attempts to utilize irradiated homologous costal cartilage (IHCC) were limited by concerns over high resorption rates and mechanical weakening caused by terminal sterilization.[9-12] To overcome these limitations, fresh frozen costal cartilage (FFCC) was developed as a novel graft material.[13] Fresh frozen costal cartilage is harvested from rigorously screened cadaveric donors and processed without terminal irradiation or chemical sterilization, preserving the native collagen architecture and biomechanical integrity of the tissue.[13,14] The cartilage is then cryopreserved via a fresh-freezing technique that maintains viability for reconstructive use while minimizing immunogenicity. Since its introduction, FFCC has since gained increasing popularity among rhinoplasty surgeons as an off-the-shelf graft option for both primary and revision rhinoplasty.[15]

Fresh frozen costal cartilage offers several theoretical advantages over ACC, including elimination of donor site morbidity, decreased operative time, and potential reduction of warping due to centralized processing and freezing.[13,14,16] However, despite growing clinical use, concerns remain regarding its long-term safety and reliability, particularly with respect to infection, resorption, and the need for revision. Additionally, the cost and availability of FFCC remain limiting factors in some practice settings.

While several case series and retrospective analyses have reported favorable outcomes using FFCC, there is currently no comprehensive meta-analytic comparison of complication rates between FFCC and ACC in rhinoplasty.[14,16] A recent meta-analysis by Mrad et al[17] sought to evaluate complication rates associated with frozen cadaveric costal cartilage grafts in rhinoplasty. However, that study included overlapping patient cohorts, heterogeneous graft types (including lyophilized and minimally irradiated cartilage), and inconsistent definitions of "fresh frozen" processing, all of which likely confounded its pooled estimates, thereby limiting the study's validity. These methodological issues were subsequently highlighted in a published correspondence to the editor, underscoring the need for a more rigorous and narrowly defined synthesis of true fresh-frozen graft outcomes.[18] Given these limitations, the present study aims to provide a methodologically robust re-analysis to more accurately characterize the safety profile and complication rates of fresh-frozen costal cartilage in rhinoplasty. To accomplish this, our study aims to address this gap by pooling data across published studies and comparing the rates of 4 key postoperative complications: infection, warping, resorption, and revision surgery. By providing a direct complication profile comparison between FFCC and ACC, this meta-analysis seeks to clarify the safety and reliability of FFCC and better inform graft selection in both aesthetic and reconstructive nasal surgery.

METHODS

Search Strategy and Study Selection

This meta-analysis followed the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) reporting guideline (Supplemental Table 1, available online at https://doi.org/10.1093/asjof/ojag072).[19] A comprehensive systematic search of the literature was conducted using 4 electronic databases: MEDLINE, Embase, Web of Science, and Scopus, covering studies published between January 1990 to March 2025. The complete search strategy is detailed in Supplemental Table 2, available online at https://doi.org/10.1093/asjof/ojag072.

Studies were imported into Covidence (Veritas Health Innovation, Melbourne, Australia) for further refinement.[20] After removing duplicates in Covidence, all studies were screened in 2 phases: first by title and abstract, then by full-text review. Screening was conducted independently by 2 reviewers (F.B. and E.D.). Discrepancies in study inclusion were resolved through discussion until consensus was reached.

Studies were eligible for inclusion if they were prospective or retrospective human studies reporting on adult rhinoplasty procedures using either ACC or FFCC. Eligible studies included randomized controlled trials, cohort studies, case–control studies, or case series with a minimum of 5 patients. Only articles published in English and reporting on at least one surgical complication outcome (infection, warping, resorption, or revision surgery) were included. Studies were excluded if they were animal or cadaveric studies, review articles, commentaries, editorials, or case reports, and/or if they failed to report any complication outcomes or had a sample size below 5 patients. When multiple studies from the same author group reported on overlapping patient cohorts during similar time frames, only the most recent and comprehensive study was included to minimize the risk of patient duplication.

This systematic review and meta-analysis was not prospectively registered, and no formal protocol was developed. However, all eligibility criteria and analytic methods were defined a priori.

Data Extraction and Risk of Bias Assessment

From each included study, data were extracted into a structured Microsoft Excel (Microsoft Corp., Redmond, WA) spreadsheet by the primary author and included information on publication year, study design, sample size, patient age, graft type (ACC or FFCC), duration of follow-up, and the number of complications observed. In addition, data relevant for bias assessment were collected, including whether studies adjusted for confounding, reported loss to follow-up, and whether complication assessment was blinded or independently adjudicated.

To assess the quality of the included studies, the Risk of Bias in Non-Randomized Studies—of Interventions (ROBINS-I) tool was used.[21] Each study was rated across 7 domains including confounding, selection bias, classification of interventions, deviations from intended interventions, missing data, measurement of outcomes, and selection of reported results by the screeners of this study (F.B.

and E.D.). Any discrepancies in bias assessment were discussed and resolved by consensus.

Statistical Analysis

Complication rates for infection, warping, resorption, and revision surgery were pooled separately for patients who received FFCC and ACC. Studies were weighted proportionally to the number of patients reported for each complication group. Because most included studies reported outcomes for only one graft type, complication rates were calculated as raw proportions (events per total number of patients) and pooled descriptively using Microsoft Excel. For each outcome, the total number of events and total number of patients were aggregated across all studies reporting that complication for the respective graft type.

To assess whether complication rates differed significantly between FFCC and ACC, unpaired 2-proportion *z*-tests were conducted using IBM SPSS Statistics Version 30. This test compared the incidence of each complication between groups under the null hypothesis that the proportions were equal. For each outcome, the z-statistic, 2-tailed *P*-value, and 95% CI for the absolute difference in proportions were calculated. A *P*-value <.05 was considered statistically significant.

Heterogeneity across included studies was assessed using the I^2 statistic, which quantifies the proportion of variability in effect estimates that is due to true differences between studies rather than chance.

Extracted data were later transferred to IBM SPSS Statistics (IBM Corp., Armonk, NY) for quantitative analysis and descriptive synthesis. Prism GraphPad (Version 10.6.0) was utilized for figure generation.

RESULTS

Demographics

A total of 1068 unique citations were screened, and 27 studies were selected for inclusion based on the predefined inclusion and exclusion criteria (Figure 1 and Supplemental Table 3, available at https://doi.org/10.1093/asjof/ojag072). Most studies identified for full-text review were excluded due to not reporting on at least one of the preidentified complications, not evaluating ACC or FFCC graft material, or being of wrong study design that did not include primary data. One study, Mohan et al,[16] which reported on 50 patients in the FFCC group, was excluded due to concerns of patient duplication. Results from this cohort were collected at the same institution and within the same time frame as the larger Rohrich et al's (2022) study, with overlapping authorship, raising the likelihood that the Mohan cohort was fully encompassed within the Rohrich population.[14,16] Of the included studies, 22 reported on ACC,[22-43] 3 on FFCC,[14,44,45] and 2 studies reported on both graft types.[46,47] Across these studies, 2137 patients were included in the ACC group and 766 patients in the FFCC group. The number of studies and total patients reporting each specific complication is summarized in Table 1.

The publication dates for studies investigating ACC ranged from July 1990 to March 2025, while those reporting on FFCC were published more recently, between July 2022 and August 2024.[14,25,33,45] The mean sample size of FFCC groups was 153 patients (range: 21-282), whereas ACC studies had a mean sample size of 89 patients (range: 12-611).

Among the ACC studies, 19 of 24 reported follow-up time. The weighted mean follow-up duration for ACC was 18.4 months (95% CI: 13.7-23.0). All FFCC studies reported follow-up, with a weighted mean of 23.0 months (95% CI: 13.4-32.7). Although the FFCC group had a longer mean follow-up, this difference was not statistically significant ($P = .4$). Full details regarding each study's reported follow-up time can be found in Supplemental Table 4, available online at https://doi.org/10.1093/asjof/ojag072.

Seventeen of the 24 ACC studies reported patient age. The weighted mean patient age in the ACC group was 32.1 years (95% CI: 29.4-34.8), whereas the FFCC group, based on 4 of 5 studies, had a weighted mean age of 38.0 years (95% CI: 35.8-40.3). This represents a statistically significant difference in baseline age between graft groups, with FFCC patients being older ($P = .001$).

Heterogeneity for studies reporting on FFCC varied by outcome. Infection rates demonstrated no observed heterogeneity among FFCC studies ($I^2 = 0\%$). In contrast, substantial heterogeneity was observed for warping ($I^2 = 73.2\%$), resorption ($I^2 = 80.8\%$), and revision surgery ($I^2 = 78.3\%$) (Table 1).

All included FFCC studies used grafts sourced from accredited tissue banks, most commonly the Musculoskeletal Transplant Foundation (MTF), ensuring consistency in processing and preservation.[48] Using the ROBINS-I tool, the risk of bias was assessed for all included studies: 4 studies were rated as having moderate risk, while 23 were rated as serious (Figure 2).

Complications

A comparison of rates of infection, warping, resorption, and revision surgery between FFCC and ACC are shown in Figure 3. Across included studies, the pooled infection rate was 1.7% (13/766) in the FFCC group compared with 2.3% (48/2113) in the ACC group (Table 1 and Figure 4). This difference was not statistically significant ($P = .34$) (Figure 3). In contrast, warping occurred significantly less frequently in FFCC grafts (1.2%; 9/766) than in ACC (3.9%; 56/1455), with an absolute risk reduction of 2.7% ($P = .00038$) (Table 1 and Figures 2, 5).

Similarly, the rate of revision surgery was significantly lower in the FFCC group (1.3%; 10/766) compared to ACC (3.4%; 67/1968), corresponding to a risk difference of −2.1% ($P = .0029$) (Table 1 and Figures 2, 6). Resorption rates did not significantly differ: 1.2% (9/766) in FFCC vs 1.9% (20/1083) in ACC ($P = .25$) (Table 1 and Figures 2, 7).

DISCUSSION

This meta-analysis provides the first comprehensive synthesis of postoperative complication rates associated with FFCC compared to ACC in rhinoplasty. The results demonstrate that FFCC is associated with significantly lower rates of warping and revision surgery, while infection and resorption rates did not differ significantly between the 2 graft types. These findings suggest that FFCC may represent a viable, and in some cases, advantageous alternative to autologous rib grafts in nasal reconstruction and augmentation.

Warping has historically been one of the most common and frustrating complications associated with ACC.[7,8] Its etiology is

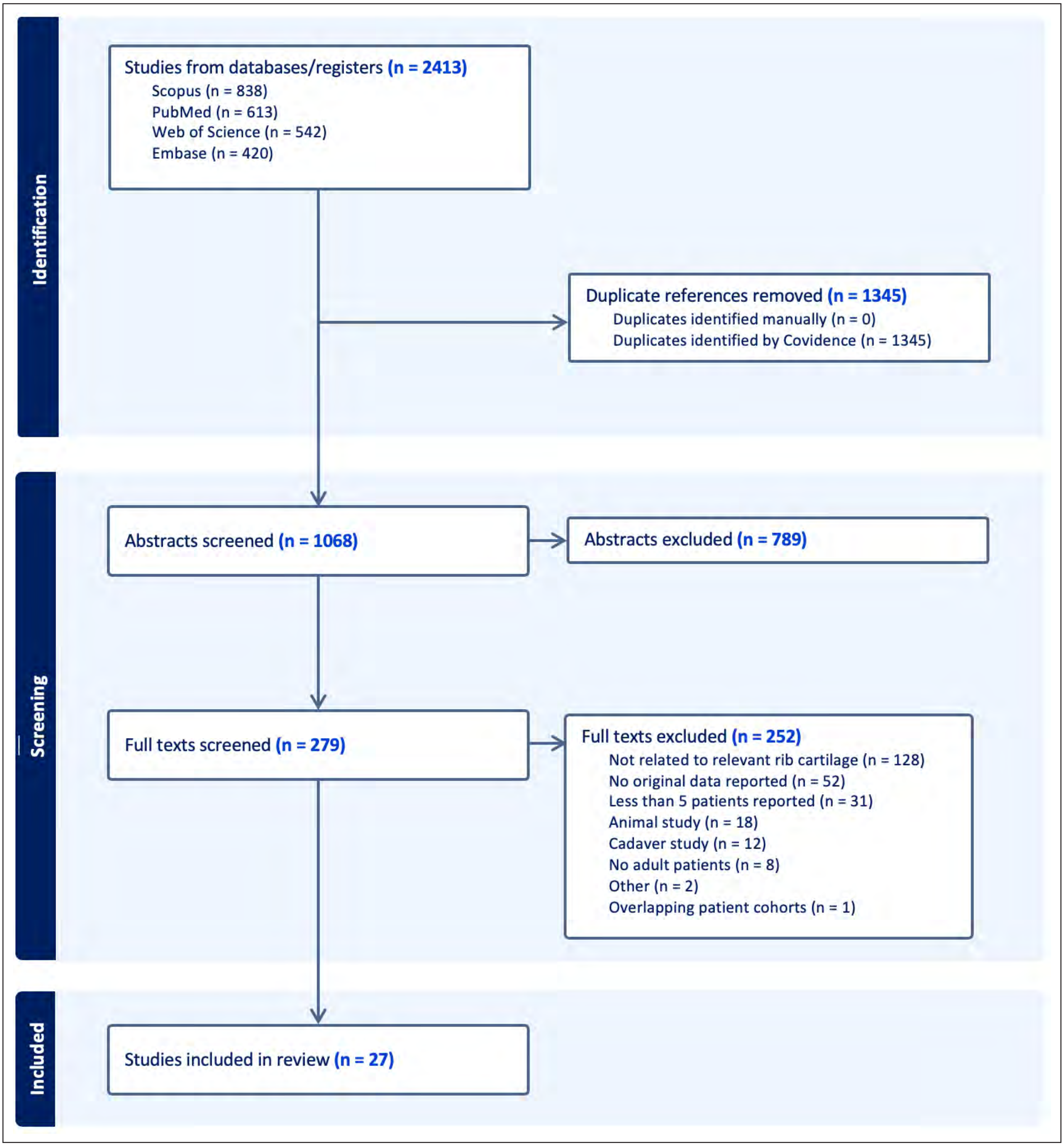

Figure 1. PRISMA diagram.

multifactorial, driven largely by residual intrinsic stress within the harvested cartilage and imperfect shaping techniques.[49,50] In this study, the warping rate among ACC grafts was over 3-fold higher than that of FFCC (3.9% vs 1.2%, $P = .00038$). This difference may reflect effects of centralized processing and freezing in FFCC; however, warping remains multifactorial and is influenced by carving technique, graft geometry, and postoperative forces. These results are consistent with prior series that reported favorable stability profiles for FFCC, but they do not establish a mechanistic guarantee of dimensional stability.

Table 1. Summary of Complications by Graft Material

Outcome, graft type	Studies	Patients	Events	Pooled event rate, % (95% CI)	Heterogeneity (I^2)
Infection					
ACC	23	2113	48	2.3 (1.7-3.0)	54.6
FFCC	5	766	13	1.7 (0.9-2.9)	0
Total	26	2877	61	2.1 (1.6-2.7)	50.9
Warping					
ACC	21	1455	56	3.9 (3.0-5.0)	63.1
FFCC	5	766	9	1.2 (0.6-2.2)	73.2
Total	24	2219	65	2.9 (2.3-3.7)	70.7
Resorption					
ACC	20	1083	20	1.9 (1.2-2.8)	37
FFCC	5	766	9	1.2 (0.6-2.2)	80.8
Total	21	1847	29	1.6 (1.1-2.2)	59.2
Revision surgery					
ACC	21	1357	67	3.4 (2.7-4.3)	60.6
FFCC	5	766	10	1.3 (0.7-2.4)	78.3
Total	24	2732	77	2.8 (2.3-3.5)	72

Similarly, the rate of revision surgery was significantly lower among patients receiving FFCC (1.3%) compared to those receiving ACC (3.4%, $P = .0029$). Although revision may result from numerous factors including aesthetic dissatisfaction, functional compromise, or graft-related complications, the lack of significant differences in infection (1.7% vs 2.3%, $P = .34$) and resorption rates (1.2% vs 1.9%, $P = .25$) suggests that warping may have played a role in some revision cases, but this relationship cannot be inferred directly. Because individual studies rarely specified the indication for revision, the present analysis cannot determine whether reduced warping directly accounts for the lower revision rate observed in the FFCC group. Therefore, the association between graft type and revision should be interpreted as descriptive rather than causal. Future studies should stratify revision etiology to clarify the relative contribution of graft-related factors vs aesthetic or functional concerns. This could reflect the increased technical variability associated with harvesting and shaping autologous costal cartilage.

An important limitation is the lack of uniformity in how complications were defined and measured across included studies. Within both the FFCC and ACC literature, outcomes such as warping, resorption, and infection were assessed using a variety of methods, ranging from retrospective chart review and unblinded clinical examination to prospective follow-up with standardized photography or anthropometric measurements.[14,44,46,47] These differences in measurement approach and follow-up rigor could influence the reported incidence of complications and make direct comparison between graft types less precise. For example, studies employing standardized imaging protocols may be more likely to detect subtle degrees of warping or resorption than those

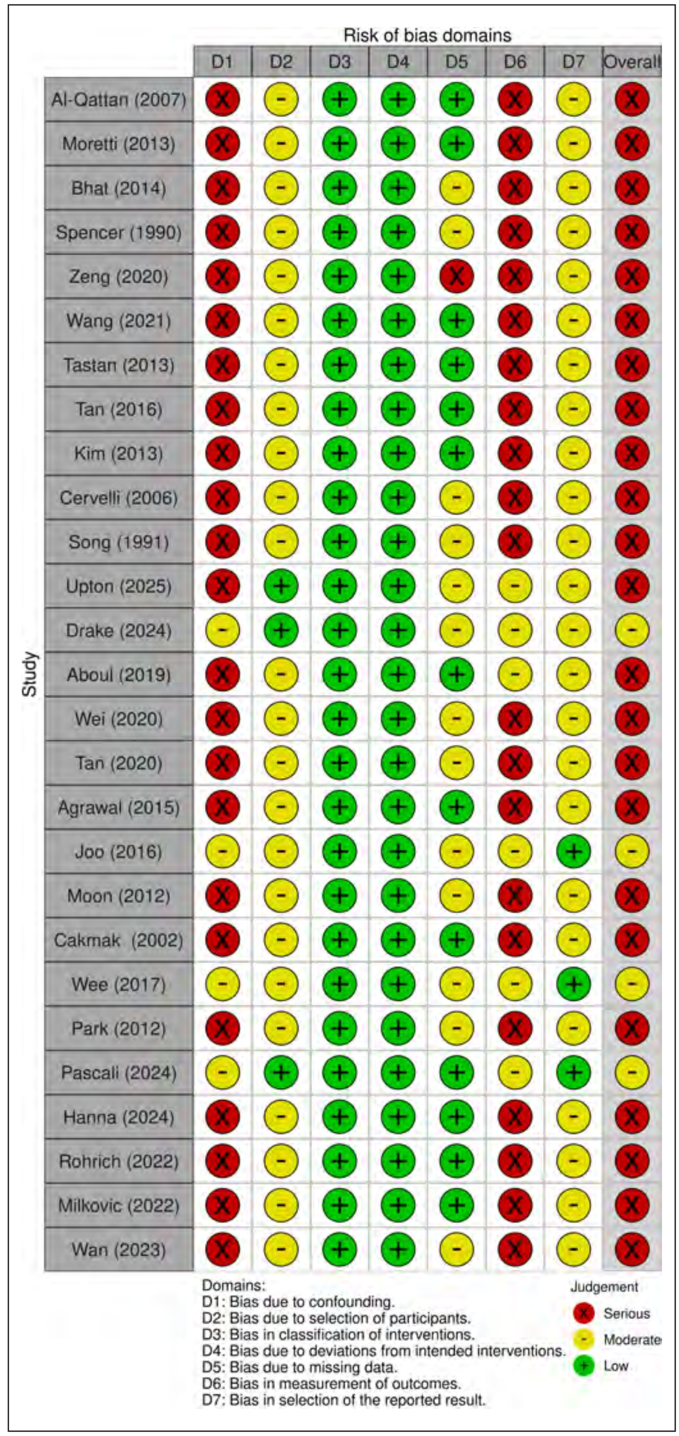

Figure 2. ROBINS-I risk of bias assessment.

relying solely on subjective surgeon assessment. This variability underscores the need for future research to use standardized, validated definitions and objective measurement techniques ideally with blinded assessment to ensure consistent reporting and allow for more accurate cross-study comparisons.

Patients in the FFCC group were statistically older than those in the ACC group (38.0 vs 32.1 years, $P = .001$). While statistically significant,

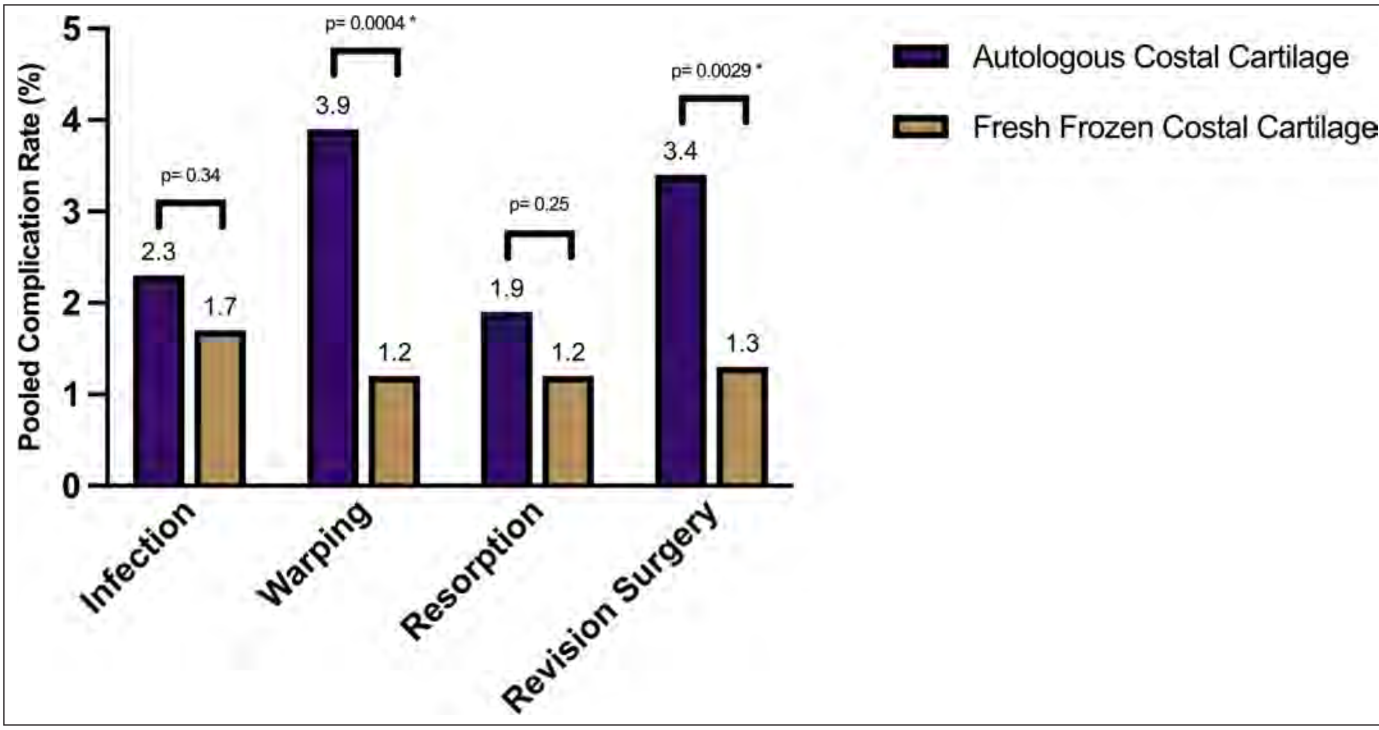

Figure 3. Comparison of pooled statistics for infection, warping, resorption, and revision surgery between autologous costal cartilage (purple) and fresh frozen costal cartilage (gold).

this difference is small and both groups fall within the typical adult age range for rhinoplasty, making it unlikely to be clinically meaningful. Nonetheless, age-related differences in cartilage properties could theoretically influence graft behavior. Older cartilage may be more calcified and dimensionally stable, which could reduce the risk of postoperative warping and may partially contribute to the lower warping rates observed in the FFCC cohort.

The findings of this paper suggest that FFCC demonstrates comparable short-term safety to ACC, with potential advantages in reducing warping and revision rates. Fresh frozen costal cartilage eliminates the need for donor site harvest, thereby reducing operative time, postoperative pain, and chest wall morbidity. For patients who are poor candidates for autologous rib harvest due to body habitus, prior thoracic surgery, or preference to avoid additional scarring, FFCC represents a promising alternative that can provide structurally reliable support. However, given that available data derive from a limited number of retrospective studies with relatively short follow-up, conclusions regarding long-term equivalence or superiority to ACC cannot be made. These findings should therefore be interpreted as preliminary and hypothesis-generating rather than definitive.

Limitations

However, despite its utility, FFCC is not without limitations. Fresh frozen costal cartilage lacks certain biologic properties inherent to autologous grafts. Autologous costal cartilage can be harvested and implanted with its perichondrium intact, which may enhance graft vascularization, lower resorption risk, and promote long-term integration with surrounding tissue.[51-53] In contrast, FFCC cannot be transplanted with perichondrium because of antigenicity concerns during tissue banking and processing.[13] This absence may partially limit biologic incorporation and represents a potential disadvantage compared with autologous cartilage, particularly in cases requiring extensive graft-host integration or long-term structural remodeling. Moreover, cost and availability may remain a barrier, as FFCC grafts may not be universally covered by insurance or available at all institutions. Additionally, while the overall follow-up duration across FFCC studies was adequate to capture early and intermediate complications, long-term outcome data remain limited, and further studies with extended surveillance are warranted.

This study also has methodological limitations. Most included studies were retrospective in design and subject to selection bias. Because few studies directly compared ACC and FFCC within the same patient cohort, complication rates were pooled from single-arm observational data and analyzed using unpaired statistical comparisons. While this approach is consistent with standard practice in surgical meta-analysis, it limits control over potential confounding factors, such as surgeon experience or operative setting. Subgroup analyses were not possible due to inconsistent reporting across studies. Although risk of bias was serious in the majority of included studies, the consistency of findings across multiple independent cohorts lends credibility to the observed differences. These variations likely reflect differences in study populations, surgical techniques, and outcome definitions across studies. Given the clinical and methodological diversity inherent in multi-institutional surgical literature, this degree of heterogeneity is expected as seen in similar analyses investigating rhinoplasty complications.[4]

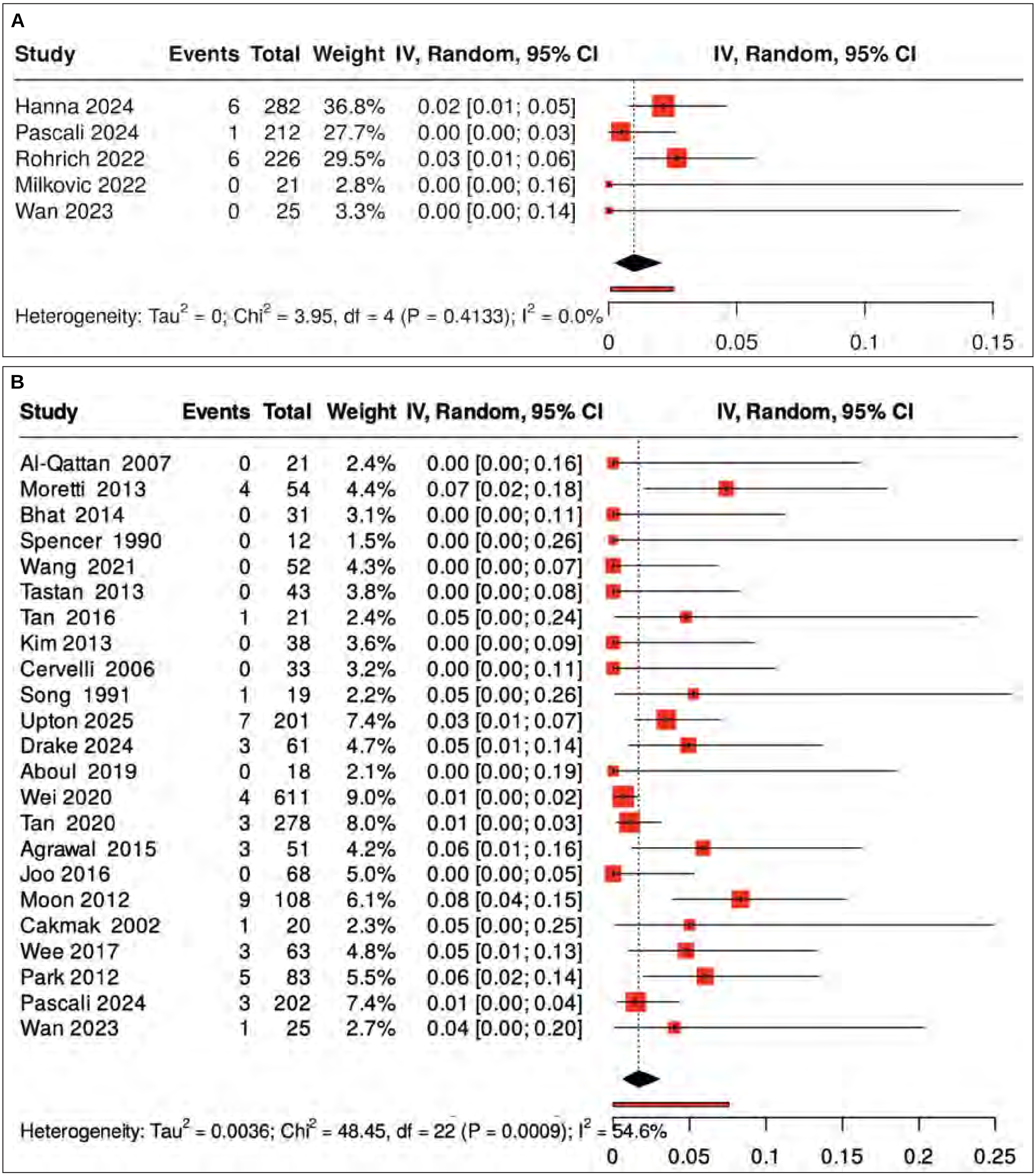

Figure 4. Meta-analysis of studies on infections by (A) fresh frozen costal cartilage and (B) autologous costal cartilage (B) graft material.

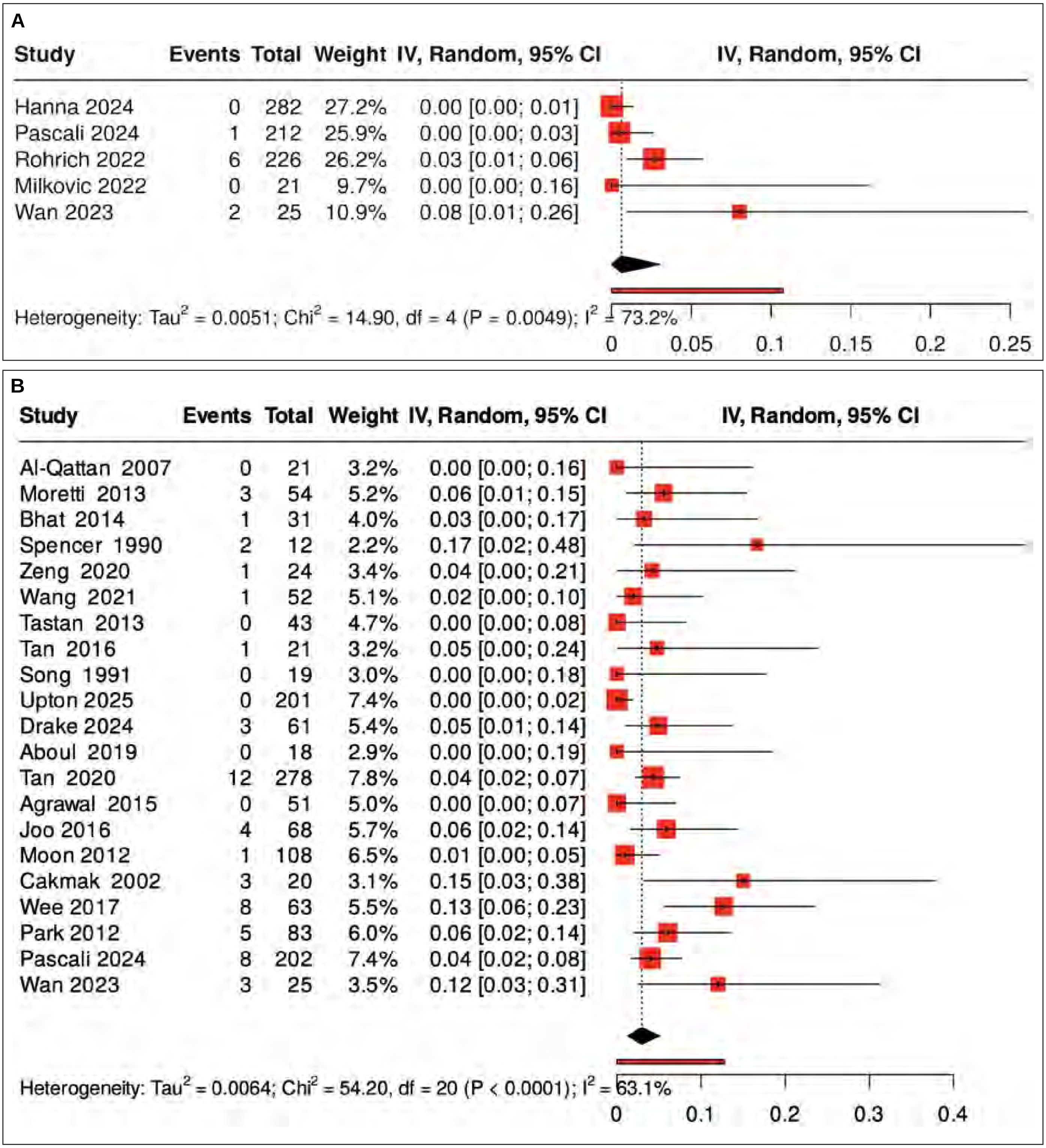

Figure 5. Meta-analysis of studies on warping by (A) fresh frozen costal cartilage and (B) autologous costal cartilage graft material.

Further, adequate duration and consistency of follow-up are essential for valid interpretation of revision outcomes. However, many included studies did not report mean follow-up length or rates of loss to follow-up, and only a minority described how revisions were captured. Patients who undergo revision surgery may seek care from a different surgeon or institution, leading to

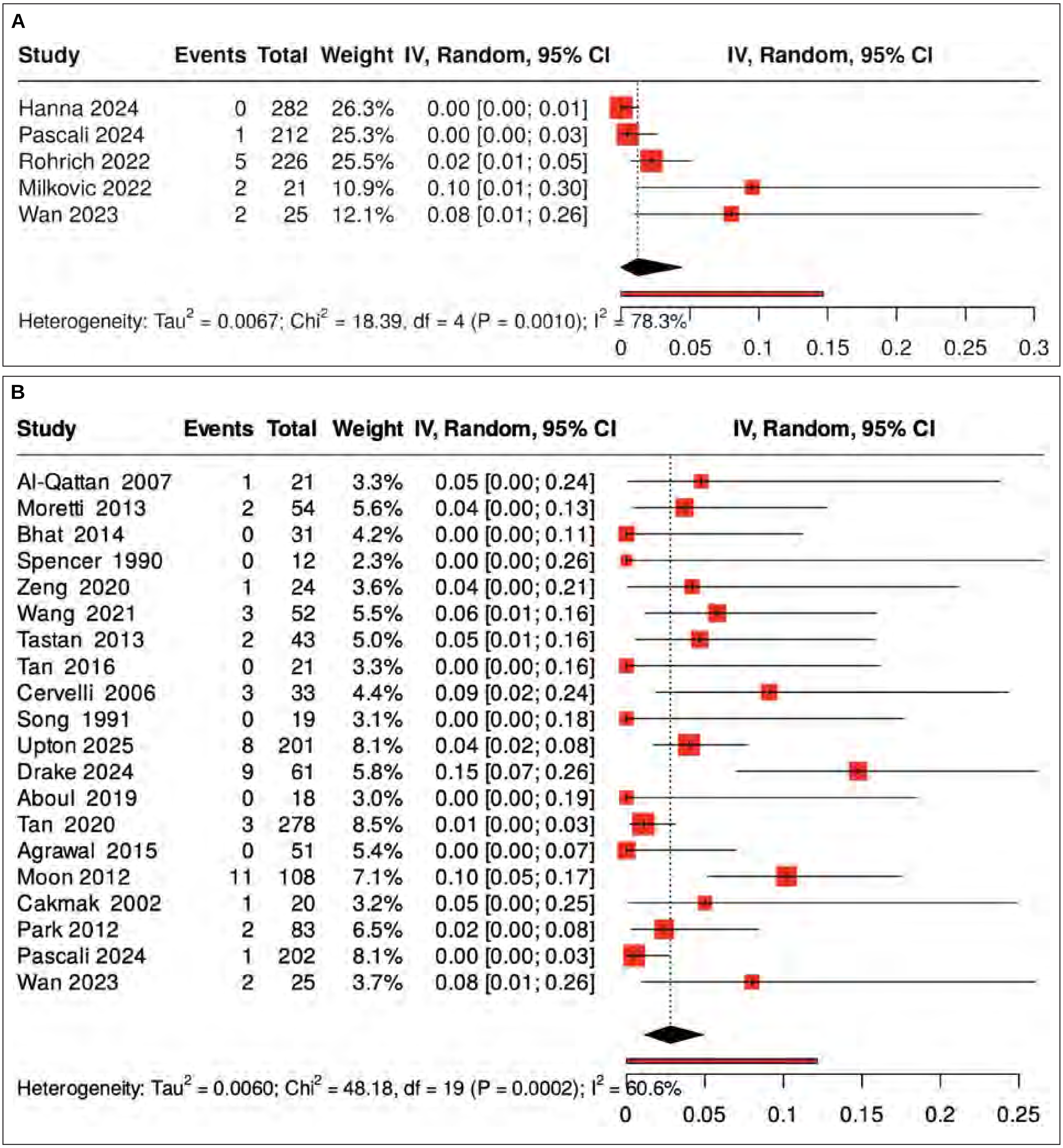

Figure 6. Meta-analysis of studies on revision surgery by (A) fresh frozen costal cartilage and (B) autologous costal cartilage graft material.

underreporting in single-center series. Consequently, the true incidence of revision is likely higher than observed. This limitation should be considered when interpreting the apparent differences between graft types, as incomplete follow-up may disproportionately affect one cohort depending on study design and reporting rigor. Future studies should standardize follow-up duration and explicitly track late revisions to allow for more reliable comparative assessment.

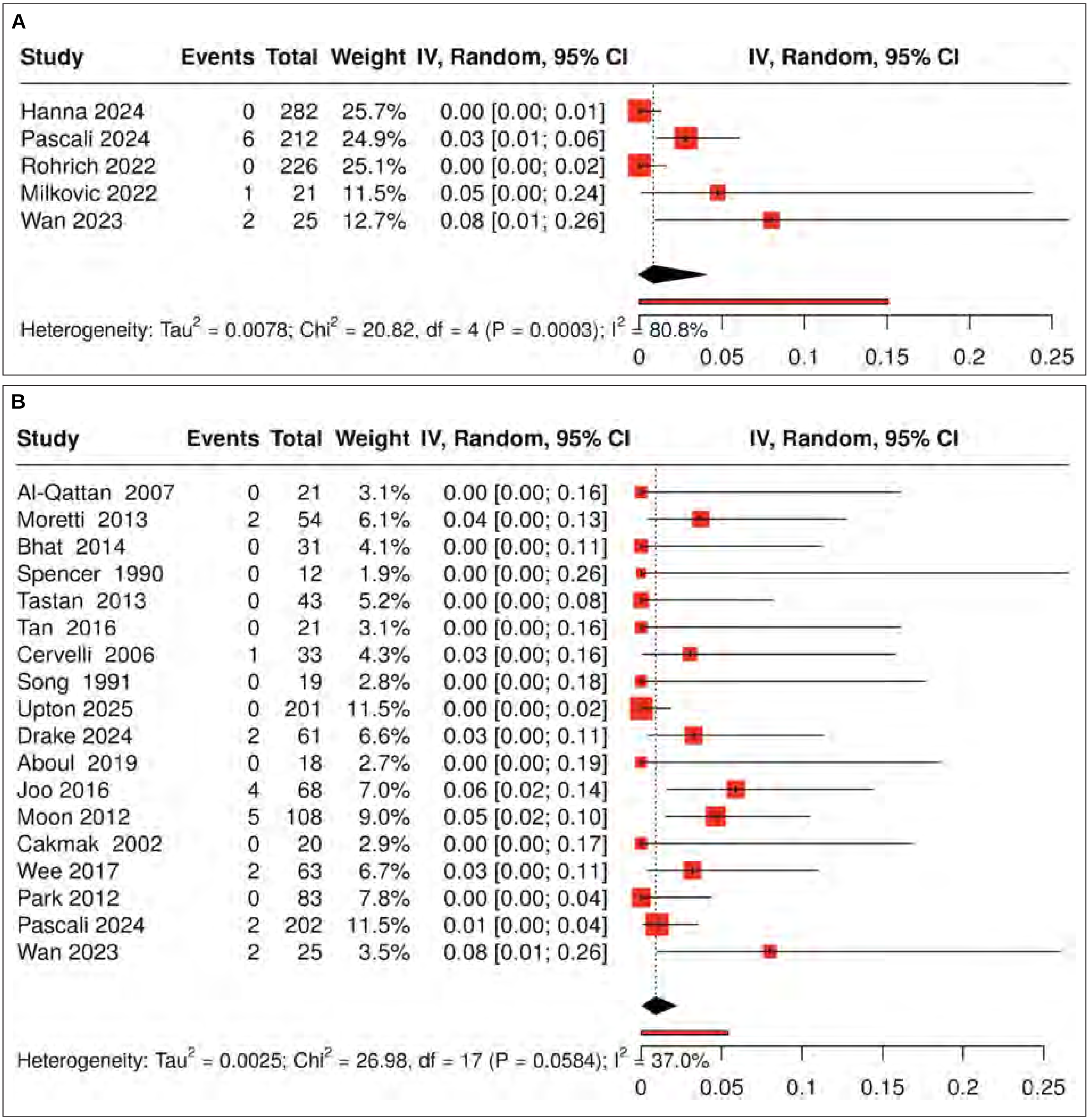

Figure 7. Meta-analysis of studies on resorption by (A) fresh frozen costal cartilage and (B) autologous costal cartilage graft material.

Despite these limitations, this meta-analysis provides meaningful and clinically actionable insights. The findings support the growing clinical adoption of FFCC as a safe and effective alternative to ACC, particularly in cases where donor site morbidity is a concern. As interest in off-the-shelf biologic grafts continues to expand, future prospective and randomized studies are needed to confirm these outcomes, assess cost-effectiveness, and define long-term durability.

CONCLUSIONS

This meta-analysis demonstrates that FFCC is associated with lower observed rates of warping and revision surgery compared to ACC, with no significant differences in infection or resorption. However, given the limited number of available FFCC studies, their retrospective design, and the relatively short follow-up duration, these findings should be interpreted cautiously. Fresh frozen costal cartilage appears to be a promising alternative that may offer practical and structural advantages in selected patients particularly when donor site morbidity is a concern, but its long-term safety and efficacy relative to ACC remain to be established. Prospective, comparative studies with standardized definitions and extended follow-up are needed to confirm these early observations and define FFCC's role in aesthetic and reconstructive rhinoplasty.

Supplemental material

This article contains supplemental material located online at https://doi.org/10.1093/asjof/ojag072.

Disclosures

Dr Reish is a consultant for the MTF Biologics (Edison, NJ). The other authors declared no potential conflicts of interest with respect to the research, authorship, and publication of this article.

Funding

The authors received no financial support for the research, authorship, and publication of this article.

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