surgeries

MDPI

Systematic Review

Prehabilitation in Patients Undergoing Cardiac Surgery: An Umbrella Review of Systematic Reviews and Meta-Analysis

Abubakar I. Sidik [1,*], Maxim L. Khavandeev [2], Malik K. Al-Ariki [1], Vladislav V. Dontsov [3], Ivan G. Karpenko [4], Anvar K. Djumanov [5], Alina V. Ogurchikova [1], Sergey A. Kurnosov [3] and Dadaev Shirin [5]

1 Medical Insitute, Peoples' Friendship University of Russia, Moscow 117198, Russia
2 Department of Cardiac Surgery, Gusak Institute of Emergency and Reconstructive Surgery, Donetsk 283045, Russia
3 Moscow Regional Research and Clinical Institute Named After M.F. Vladimirsky, Moscow 123592, Russia
4 Department of Cardiac Surgery, A.A. Vishnevskiy Hospital, Kranogorsk 143420, Russia
5 Department of Surgical Diseases No. 2, Tashkent State Medical University, Tashkent 100109, Uzbekistan
* Correspondence: abu.ibn.sidik@gmail.com

Abstract

Background/Objective: Prehabilitation aims to improve physiological reserve before surgery to enhance postoperative outcomes. Multiple systematic reviews have evaluated preoperative interventions in adult cardiac surgery; however, variability in scope, methodological quality, and overlap of primary trials complicates interpretation. The aim of this study is to synthesise and critically appraise evidence from systematic reviews and meta-analyses evaluating prehabilitation interventions in adults undergoing cardiac surgery. No funding was received for this study. **Methods**: We conducted an umbrella systematic review following a prospectively registered protocol (PROSPERO: CRD420261292354) and PRISMA 2020 guidance. PubMed, Web of Science, and Scopus were searched from inception to 31 December 2025. Eligible reviews included adults (≥18 years) undergoing cardiac surgery, evaluated and compared preoperative inspiratory muscle training (IMT), respiratory muscle training, and exercise-based, educational, or multimodal prehabilitation with usual care or sham intervention. Reviews focused solely on postoperative interventions or non-cardiac surgery were excluded. Methodological quality was assessed using AMSTAR-2. Certainty of evidence was evaluated using GRADE. Overlap of primary studies was quantified using the Corrected Covered Area (CCA). A structured narrative synthesis with a direction-of-effect framework was applied. **Results**: Eighteen systematic reviews (published 2012–2025) were included, comprising 46 unique primary studies and more than 6674 participants (exact totals unavailable due to incomplete reporting in at least one review). Overall overlap was high (CCA 12.5%). Respiratory-focused prehabilitation, particularly IMT, demonstrated consistent reductions in postoperative pulmonary complications (PPCs) (risk ratios approximately 0.42–0.53), pneumonia (RR ~0.44–0.45), and atelectasis (RR ~0.49–0.59), favouring prehabilitation over usual care. Hospital length of stay was reduced by approximately 1.5–3 days across multiple reviews. Inspiratory muscle strength improved consistently (mean difference ~+12 to +17 cmH_2O). Effects on ICU length of stay and mechanical ventilation duration were inconsistent or non-significant. Exercise-based programmes improved functional capacity (6 min walk distance increase ~50–75 m) and showed modest reductions in hospital stay, but heterogeneity was substantial. No intervention demonstrated a consistent reduction in postoperative mortality. Evidence was limited by clinical heterogeneity, performance bias in primary trials, inconsistent outcome definitions, and high overlap of key IMT trials across reviews. Mortality outcomes were underpowered. **Conclusions**: Preoperative IMT provides evidence for reducing pulmonary complications and shortening hospital stays

Check for updates

Academic Editors: Salomone Di Saverio and Paul Quax

Received: 14 February 2026
Revised: 30 March 2026
Accepted: 20 April 2026
Published: 23 April 2026

Copyright: © 2026 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license.

in adult cardiac surgery. Exercise-based prehabilitation improves functional capacity but requires further high-quality, standardised trials. Integration of respiratory prehabilitation into cardiac surgical pathways appears supported by the current evidence.

Keywords: prehabilitation; cardiac surgery; inspiratory muscle training; respiratory physiotherapy; systematic review; umbrella review; postoperative pulmonary complications; functional capacity

1. Introduction

Prehabilitation refers to interventions delivered in the preoperative period with the aim of enhancing functional capacity and physiological reserve in order to improve postoperative outcomes. In cardiac surgery, prehabilitation strategies have included inspiratory muscle training (IMT), breathing exercises and chest physiotherapy, structured exercise-based programmes (aerobic, resistance, or combined training), educational interventions, and multimodal approaches incorporating two or more components [1–8].

Evidence from randomised controlled trials (RCTs) and subsequent systematic reviews (SRs) suggests that prehabilitation may reduce postoperative pulmonary complications (PPCs), shorten hospital length of stay (LOS), and improve functional capacity following cardiac surgery, particularly when respiratory muscle training or structured exercise programmes are implemented preoperatively [1–3,7]. Recent meta-analyses (MAs) have also explored the potential for exercise-based prehabilitation to improve broader postoperative recovery and proposed models for clinical implementation in cardiac surgical pathways [8].

Over the past decade, growing interest in prehabilitation has led to a rapid increase in the number of systematic reviews and meta-analyses (SR + MA) evaluating preoperative interventions in cardiac surgery. These reviews vary substantially in scope, intervention content, surgical populations, and methodological quality. Some reviews focus exclusively on IMT [2,3,7], others on exercise-based or multimodal programmes [4,8,9], while several include mixed surgical populations or combine pre- and postoperative interventions [9–12].

This proliferation of reviews raises important concerns regarding redundancy, overlap of primary studies, and inconsistent interpretation of findings. As multiple reviews frequently include the same landmark trials, unrecognised overlap may inflate perceived certainty and complicate evidence-based decision-making for clinicians and guideline developers. Given the increasing number of SRs addressing prehabilitation in cardiac surgery, a review of reviews is warranted to provide a comprehensive and coherent synthesis of the existing evidence. Umbrella reviews enable comparison across SRs, appraisal of methodological quality, and identification of consistent and inconsistent findings, thereby offering a higher-level summary of the evidence base [13].

In the field of prehabilitation, prior reviews have differed markedly in inclusion criteria, intervention definitions, outcome reporting, and analytical approaches. Some have combined cardiac surgery with other surgical populations, while others have pooled preoperative and postoperative interventions, potentially introducing indirectness and clinical heterogeneity [9–12]. Furthermore, overlapping inclusion of primary trials across reviews may obscure true effect sizes if not explicitly assessed [14]. An umbrella review therefore provides an appropriate methodological framework to address these challenges by evaluating the overlap of primary studies, assessing methodological quality using validated tools, and synthesising outcome-specific effects across intervention domains in a structured and transparent manner.

The primary objective of this umbrella review was to synthesise and critically appraise evidence from SRs and MAs on the effects of prehabilitation interventions in adults undergoing cardiac surgery. Secondary aims included comparing different prehabilitation modalities such as inspiratory muscle training, exercise-based programmes, and multimodal approaches across key outcomes including PPCs, hospital and ICU LOS, functional capacity, and mortality. The review also evaluated the methodological quality of included reviews using the AMSTAR-2 tool to help contextualise the strength of evidence. Additionally, it quantified overlap between primary studies using the Corrected Covered Area to assess redundancy and avoid inflated certainty from repeated inclusion of the same trials. Finally, the umbrella review sought to identify heterogeneity, inconsistencies, and evidence gaps to guide future research and support the development of effective prehabilitation strategies in cardiac surgical care.

2. Methods

This umbrella review was conducted according to a prespecified protocol that was registered prospectively in the International Prospective Register of Systematic Reviews (https://www.crd.york.ac.uk/PROSPERO/view/CRD420261292354; accessed on 12 February 2026). The review was conducted and reported in accordance with the PRISMA 2020 statement [15], the Meta-Analysis of Observational Studies in Epidemiology (MOOSE) guidelines [16] and guidance for umbrella reviews.

2.1. Eligibility Criteria (PICOS)

Eligibility criteria for this umbrella review were defined a priori according to the Population, Intervention, Comparator, Outcomes, and Study design (PICOS) framework [17].

Population: Systematic reviews and meta-analyses were eligible if they included adult patients (≥18 years) undergoing cardiac surgery, including coronary artery bypass grafting (CABG), valve surgery, or mixed cardiac surgical procedures. Reviews focusing exclusively on paediatric populations or on non-cardiac surgical procedures were excluded. Reviews that included mixed surgical populations were eligible only if results for cardiac surgery patients were reported separately or if cardiac surgery constituted a substantial (≥50%) component of the included population.

Intervention: Eligible reviews evaluated prehabilitation interventions delivered before cardiac surgery, including but not limited to IMT, breathing or chest physiotherapy, exercise-based prehabilitation (aerobic, resistance, or combined exercise), educational interventions, or multimodal prehabilitation programmes combining two or more components. Reviews focusing solely on postoperative rehabilitation or intraoperative interventions were excluded.

Comparator: The comparator of interest was usual care, standard preoperative management, no intervention, or sham interventions, as defined by the authors of the included reviews.

Outcomes: Reviews were eligible if they reported at least one of the following outcomes: PPCs (composite outcomes as defined by review authors), pneumonia, atelectasis, hospital LOS, LOS in intensive care unit (ICU), postoperative mortality, or measures of functional or exercise capacity. Reviews reporting only physiological outcomes without clinical or functional relevance were excluded.

2.2. Information Sources and Search Strategy

A comprehensive and systematic literature search was conducted to identify relevant SRs and MAs evaluating prehabilitation interventions in adult patients undergoing cardiac surgery. The following electronic databases were searched: PubMed (MED-

LINE), Web of Science (WoS), and Scopus. Each database was searched from inception to 31 December 2025. No restrictions were applied with respect to language, publication status, or year of publication.

Search strategies were developed using a combination of controlled vocabulary terms, where applicable, and free-text keywords related to prehabilitation, cardiac surgery, and SR methodology. In the absence of a universally accepted definition of prehabilitation, we defined it a priori as either a unimodal intervention involving exercise, nutritional, or cognitive or psychological training, or a multimodal programme combining exercise, nutrition, and cognitive or psychological components, with or without additional elements such as risk factor management, implemented for at least seven days before cardiac surgical procedures, including CABG, valve surgery, and cardiothoracic surgery. Study design filters were used to identify SAs and MAs.

Database-specific search strings were tailored to the indexing systems and search functionalities of each platform. In PubMed, both Medical Subject Headings (MeSH) and title and abstract terms were used. In Web of Science (WoS) and Scopus, topic-based searches and title, abstract, and keyword fields were applied. The full electronic search strategies for all databases are provided in Supplementary Table S1.

The review included SRs and SRs with MAs that synthesised evidence from RCTs or quasi-RCTs. Narrative and scoping reviews, reviews focused on single medical risk factor management (such as smoking cessation, anaemia correction, or medication optimisation), primary research studies, editorials, conference abstracts, and clinical practice guidelines were excluded.

2.3. Study Selection Process

All records identified through the electronic database searches were imported into a Mendeley reference manager, and duplicate records were removed prior to screening. Study selection was conducted in two sequential stages. First, titles and abstracts were independently screened by two (A.I.S. and M.L.K.) reviewers to assess potential eligibility based on the predefined inclusion and exclusion criteria. Second, full-text articles of all potentially relevant records were retrieved and independently assessed by the same two reviewers for final inclusion. In addition to electronic database searching, the reference lists of all included SRs and MAs were manually screened to identify any additional eligible studies that may not have been captured through the initial search strategy.

Any disagreements between reviewers at either the title and abstract screening stage or the full-text assessment stage were resolved through discussion and consensus. When consensus could not be reached, a third reviewer was consulted to adjudicate and make the final decision. Reasons for exclusion at the full-text screening stage are given in Supplementary Table S2. The study selection process was conducted in accordance with established guidelines for SRs and umbrella reviews and is summarised in a PRISMA flow diagram.

2.4. Data Extraction

Data extraction was performed using a standardised and piloted data extraction form (Supplementary Table S3). The data extraction form was piloted on a subset of included reviews to ensure consistency. For each included SR or MA, the following information was extracted: first author and year of publication, type of review, databases searched and search end date, population characteristics and type of cardiac surgery, characteristics of the prehabilitation intervention, comparator, number and type of primary studies included, outcomes (related to health, experience, or costs (per the Institute for Healthcare Improvement (IHI) Triple Aim framework) [18] assessed, summary effect estimates and direction

of effect as reported by review authors, and authors' main conclusions. Information on methodological quality assessment tools used by review authors and any reported certainty of evidence was also extracted.

2.5. Methodological Quality Assessment

The methodological quality of the included SRs and MAs was assessed using the "A Measurement Tool to Assess Systematic Reviews 2" (AMSTAR-2) instrument. AMSTAR-2 is a validated tool designed to appraise the methodological rigour of SRs that include randomised and non-randomised studies of interventions [19].

Each included review was independently assessed by two reviewers across the AMSTAR-2 domains, including protocol registration, comprehensiveness of the literature search, justification for study selection, assessment and consideration of risk of bias, appropriateness of meta-analytical methods where applicable, and assessment of publication bias. Discrepancies in quality assessments were resolved through discussion, with involvement of a third reviewer when necessary.

Overall confidence in the results of each review was categorised according to AMSTAR-2 guidance as high, moderate, low, or critically low, based on the presence of critical and non-critical methodological weaknesses. Methodological quality ratings were not used as exclusion criteria. Instead, they were used to inform the interpretation and synthesis of findings, with greater emphasis placed on conclusions drawn from higher-quality and more recent reviews. Reviews judged to be of low or critically low confidence were interpreted cautiously and used to support, rather than determine, overarching conclusions.

2.6. Certainty of the Evidence (GRADE Assessment)

The certainty of evidence for each critical outcome was assessed using the GRADE framework (Standard version), following Pollock et al., 2016 [20]. In keeping with the umbrella review design, GRADE was applied at the outcome level based on findings reported in included SRs and MAs, rather than through re-analysis of primary studies. Evidence was initially rated according to study design, with RCT-derived evidence starting as high certainty. Certainty was then downgraded when concerns existed regarding risk of bias, inconsistency, indirectness, imprecision, or publication bias.

Downgrading decisions drew on AMSTAR-2 methodological ratings, consistency of effects, heterogeneity, and whether publication bias assessments were performed. When multiple reviews addressed the same outcome, certainty reflected the highest-quality evidence, prioritising reviews with higher AMSTAR-2 confidence, cardiac surgery-specific populations, and preoperative interventions. Critically low-quality reviews were retained but weighted less. No upgrading was applied. Final certainty ratings (high to very low) informed interpretation and were supported by evidence maps stratified by procedure and intervention type [20,21].

2.7. Assessment of Evidence Overlap

Overlap of primary studies across included SRs was assessed using the Corrected Covered Area (CCA) method, as recommended for umbrella reviews. The CCA quantifies the degree to which the same primary studies are repeatedly included across SRs and provides an objective measure of redundancy. A citation matrix was constructed in which rows represented unique primary studies (RCTs or quasi-RCTs) and columns represented included SRs. A cell was marked when a primary study was included in a given review [22,23].

For SRs that evaluated mixed surgical populations or combined pre- and postoperative interventions, only data from relevant subgroups were included in the citation matrix and overlap assessment. Specifically, only cardiac surgery and the preoperative IMT subgroups

were extracted. Non-cardiac surgery studies and postoperative-only intervention arms were excluded to avoid indirectness. The CCA was calculated using the formula:

$$CCA = \frac{N - r}{(r \times c) - r} \quad (1)$$

where N is the total number of study occurrences across reviews, r is the number of unique primary studies, and c is the number of systematic reviews. CCA values were interpreted using established thresholds, with values <5% indicating low overlap, 6–10% moderate overlap, 11–15% high overlap, and >15% very high overlap.

2.8. Data Synthesis

This review synthesised evidence from published SRs and MAs evaluating the effects of prehabilitation interventions in adult patients undergoing cardiac surgery. The unit of analysis was the SR rather than individual primary studies. No re-analysis or pooling of data from original RCTs was undertaken.

Data synthesis was conducted using a structured narrative approach, with findings organised according to predefined clinical outcomes. Outcomes of interest included PPCs, pneumonia, atelectasis, hospital LOS, ICU LOS, postoperative mortality, and functional capacity. Postoperative pulmonary complications were considered a composite outcome encompassing pneumonia, atelectasis, and other respiratory complications as defined by the authors of the included reviews. Where pneumonia and atelectasis were reported as separate outcomes, they were analysed independently to allow outcome-specific synthesis.

Given the heterogeneity in patient populations, prehabilitation modalities, outcome definitions, and effect measures across reviews, a quantitative re-synthesis was not attempted. Instead, a direction-of-effect approach was applied, whereby results were classified as favouring prehabilitation, showing no significant effect, or being inconclusive. Emphasis was placed on the consistency of findings across reviews rather than on the magnitude of reported effect sizes. The strength of evidence for each outcome was determined using a qualitative, rule-based framework that considered the number of SRs and MAs reporting the outcome, the consistency of the direction of effects, the methodological quality of the reviews, and the recency and comprehensiveness of the evidence base. Outcomes were categorised as having strong, moderate, limited, or no evidence of benefit.

Methodological quality of the included SRs was incorporated into the interpretation of findings. Greater weight was given to higher-quality and more recent reviews, including Cochrane reviews and large MAs. Reviews judged to be at high risk of bias were not excluded but were interpreted cautiously and used to support, rather than determine, overall conclusions.

Overlap of primary studies across SRs was assessed qualitatively. Given the substantial reuse of early randomised trials, particularly in reviews evaluating IMTs, findings were synthesised at the review level to minimise the risk of double counting. Where multiple reviews addressed the same outcome using overlapping primary studies, consistency of conclusions rather than redundancy of evidence was emphasised. Subgroup analyses were reported narratively where reviews provided stratified data, including analyses by type of prehabilitation intervention (IMT, exercise-based, or multimodal), type of cardiac surgery (CABG, valve surgery, or mixed procedures), and patient characteristics such as age or frailty status.

3. Results

3.1. Study Selection

The electronic database search identified 902 records in total, including 283 records from PubMed, 177 from WoS, and 442 from Scopus. After removal of duplicate records, 355 unique documents remained for screening.

During title and abstract screening, 232 records were excluded because they focused on postoperative rehabilitation, vascular surgery, or thoracic surgery, leaving 123 records for further assessment. Subsequent screening excluded 43 records that addressed non-surgical cardiac procedures, including percutaneous coronary intervention (PCI) and transcatheter aortic valve implantation (TAVI), resulting in 80 records.

Further exclusions were applied to studies evaluating non-physiological prehabilitation interventions, such as psychological education targeting depression or anxiety, pharmacological interventions (including aspirin, statins, or Levosimendan), or non-exercise-based educational interventions. After these exclusions, 18 records remained for full-text assessment.

At the full-text review stage, studies were excluded if they evaluated mixed preoperative and postoperative interventions, or if they included mixed surgical populations in which cardiac surgery accounted for less than 50% of cases and no separate subgroup analysis for cardiac surgery was reported. Following these exclusions, 18 SRs and MAs met the eligibility criteria and were included in the umbrella review. The study selection process is summarised in a PRISMA flow diagram (Figure 1).

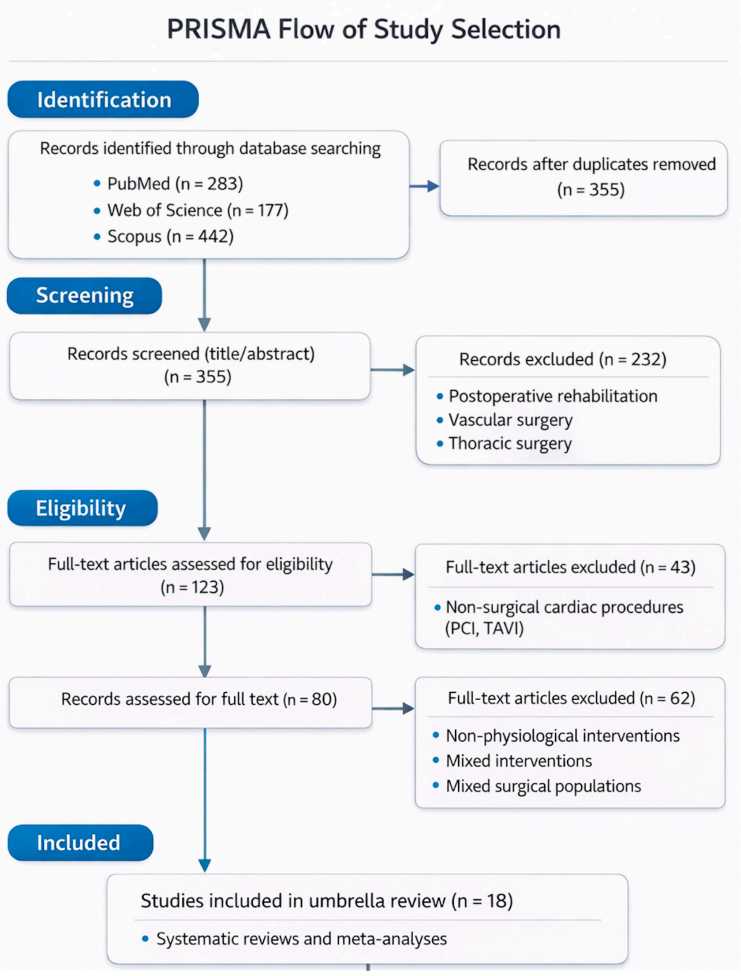

Figure 1. PRISMA flow diagram of study selection.

3.2. Characteristics of Included Reviews

A total of 18 SRs and MAs were included in this umbrella review, and their key characteristics are summarised in Table 1. These reviews were published between 2012 and 2025 and collectively synthesised evidence from adult patients undergoing elective cardiac surgery. Sample sizes varied considerably across reviews, with total participant numbers ranging from fewer than 200 to nearly 3000, reflecting both the heterogeneity of study designs and the expansion of the evidence base over time.

Review design and scope: The majority of included reviews (89%) conducted a quantitative synthesis through meta-analysis, while two were SRs without pooled-effect estimates. Several reviews focused exclusively on cardiac surgery populations, whereas others included mixed surgical cohorts but reported cardiac surgery data separately. As shown in Table 1, reviews differed in the breadth of their inclusion criteria, with earlier reviews tending to focus narrowly on respiratory interventions and more recent reviews adopting broader prehabilitation frameworks.

Prehabilitation intervention domains: Across the included reviews, respiratory muscle training (IMT/RMT) was the predominant prehabilitation modality. Approximately 72% of reviews evaluated IMT either as a standalone intervention or as part of a combined programme. These interventions most commonly employed threshold or resistive inspiratory loading devices. In contrast, exercise-based or multimodal programmes were evaluated in five reviews (28%), incorporating aerobic exercise, resistance or functional training, and, in some cases, educational or psychological components.

Study volume and participant characteristics: The number of primary studies included per review ranged from 4 to 21, with intervention group sizes varying from 91 to 1428 participants. Reviews centred on IMT typically included fewer, more homogeneous trials, whereas exercise-based or multimodal reviews incorporated larger and more diverse study populations. For example, Snowdon et al., 2014 [6] synthesised 17 trials (13 included in the meta-analysis) encompassing approximately 2689 patients, with intervention groups representing roughly 50% of the total sample. In contrast, Mans et al., 2015 [11], included four RCTs with a total of 180 participants, highlighting the smaller scale of early IMT-focused studies.

Settings and delivery of prehabilitation: Prehabilitation interventions were delivered across a range of settings, including hospital, outpatient, community, and home environments, with considerable variation between intervention types. Among reviews evaluating IMT or RMT, approximately two-thirds of programmes employed a hybrid delivery model, in which training was initiated in hospital or outpatient clinics and subsequently continued at home. Purely home-based IMT delivery was reported in approximately 25–40% of trials.

Supervision characteristics: The degree of supervision varied substantially across reviews and intervention modalities. Overall, fully supervised interventions accounted for approximately 30 to 40% of programmes, while partially supervised models, typically involving initial physiotherapist-led instruction followed by home-based training, were the most common, representing around half of all IMT interventions. Fully unsupervised programmes were uncommon, comprising less than 15% of reported interventions.

Duration of prehabilitation programmes: The duration of prehabilitation programmes ranged widely, from 5 days to 16 weeks, although most interventions clustered within shorter preoperative windows. IMT and RMT programmes were most commonly delivered over 2–4 weeks, a duration reported in over 70% of respiratory-focused reviews. Exercise-based and multimodal programmes tended to be longer, often spanning 2–8 weeks, with some extending up to 16 weeks, as reported by Yau et al., 2020 [5]. Short, intensive interventions lasting $\leq$7 days were described in approximately 15% of cardiac trials, including those synthesised by Assouline et al., 2021 [9].

Table 1. Characteristics of included systematic reviews and meta-analyses evaluating prehabilitation interventions in adult cardiac surgery.

First Author (Year)	Review Type	Prehabilitation Intervention(s)	No of Studies; Patients (IG/Total)	Settings for Prehabilitation (Home/Hospital; Counts)	With/Without Supervision and Type	Duration of Prehabilitation Programme (Preoperative)
Hulzebos et al., 2012 [24]	SR + MA	- IG: IMT, mixed interventions (aerobic exercise, breathing exercises ± education). - CG: Usual care or sham intervention.	8 RCTs; 434/856 patients	Not reported.	Predominantly supervised or partially supervised.	2–4 weeks
Snowdon et al., 2014 [6]	SR + MA	- IG: Education and counselling, IMT, chest physiotherapy. - CG: Usual care or sham intervention.	17 RCTs & quasi-RCTs overall (13 included in MA); ≈1345/2689 patients	Mixed settings; hospital/clinic settings and home-based settings; exact counts per setting not consistently reported at review level.	Predominantly supervised interventions; some education/counselling interventions delivered by nurses; degree of supervision variably reported.	5 days to several weeks preoperatively; IMT often short-term (≈1–2 weeks), while education or exercise programmes were sometimes longer
Katsura et al., 2015 [7] (Cardiac surgery subgroup)	SR + MA	- IG: IMT. - CG: Usual care or sham intervention.	5 RCTs; 226/448 patients	Typically initiated in hospital or outpatient clinic settings with subsequent home-based continuation; exact counts per setting not reported.	Predominantly supervised or partially supervised. Initial IMT instruction and load adjustment performed by physiotherapists or trained clinicians.	≥2 weeks preoperatively in all cardiac trials; most protocols used 5–7 sessions/week, 15–30 min per session, with IMT loads of 10–60% Pi-max
Mans et al., 2015 [11] (Cardiac subgroup)	SR + MA	- IG: IMT. - CG: Usual care or sham intervention.	4 RCTs; 91/180 patients	Primarily home-based; some outpatient/hospital elements (e.g., initial instruction or occasional sessions); ~4–5 cardiac trials home-dominant.	With supervision (varied, e.g., 1 session/week supervised by physiotherapist/physician; some fully unsupervised after initial training; overall moderate supervision across review); supervision type: physiotherapist-led (most common) or physician.	Typically 2–4 weeks
Gomes Neto et al., 2016 [3] (Preoperative subgroup)	SR + MA	- IG: IMT delivered preoperatively, postoperatively, or combined pre- and post-IMT. - CG: Usual care or none.	4 RCTs; 210/416 patients	Primarily home-based.	Mixed/partial supervision dominant; some fully unsupervised after training.	Typically, 2–4 weeks
Karanfil et al., 2018 [25]	SR + MA	- IG: IMT. - CG: Sham intervention or none.	5 RCTs; 226/451 patients	IMT commonly initiated in hospital or outpatient clinic settings, with predominant home-based continuation.	1 study fully supervised in hospital, 2 studies partially supervised (weekly supervision + home training), 2 studies primarily home-based with no regular supervision.	2 weeks to 4 weeks

Table 1. *Cont.*

First Author (Year)	Review Type	Prehabilitation Intervention(s)	No of Studies; Patients (IG/Total)	Settings for Prehabilitation (Home/Hospital; Counts)	With/Without Supervision and Type	Duration of Prehabilitation Programme (Preoperative)
Rodrigues et al., 2020 [26]	SR + MA	- IG: Breathing exercises, IMT. - CG: Usual care or sham intervention.	11 (10 RCTs, 1 observational cohort) studies; 542/1240 patients	Based on study descriptions: ~3 studies hospital-based/supervised, ~5 studies mixed hospital + home, ~3 studies primarily home-based. Exact counts per setting were not formally summarised by the review.	Predominantly supervised or partially supervised. Only one RCT used sham IMT, limiting participant blinding; outcome assessor blinding reported in 4 studies.	≥2 weeks preoperatively in most studies; range from 5 days to several weeks, depending on surgical waiting time. Training frequency commonly daily or twice daily, session duration 15–30 min, with IMT loads typically 15–40% of maximal inspiratory pressure, sometimes progressively increased
Yau et al., 2020 [5]	SR + MA	- IG: Exercise (aerobic exercise, resistance/functional training, and physical activity counselling); multimodal (education/psychological support but exercise component mandatory). - CG: Usual care or none.	7 RCTs; 726 (6 RCTs included in MA; 334/726-664) patients	Hospital (2 studies); outpatient/community (4 studies); home (1 study).	Predominantly supervised programmes (6/7 studies); 1 study primarily home-based with exercise diary and telephone follow-up.	5 days to 16 weeks
First Author (Year)	**Review Type**	**Prehabilitation Intervention(s)**	**No of Studies; Patients (IG/Total)**	**Settings for Prehabilitation (Home/Hospital; Counts)**	**With/Without Supervision and Type**	**Duration of Prehabilitation Programme (Preoperative)**
Zheng et al., 2020 [12]	SR + MA	- IG: Preoperative exercise interventions, including IMT, aerobic exercise, resistance training, and stretching. - CG: Usual care or none.	6 RCTs as reported; 275/752 patients	Across 6 included studies, preoperative exercise was delivered in mixed settings, including hospital-based physiotherapy programmes and home-based exercise regimens. Exact counts of home vs. hospital delivery were not provided by the review.	Variable and inconsistently reported. Some interventions involved supervised exercise sessions, while others relied on unsupervised or self-directed home exercise. The review did not stratify outcomes by supervision status.	Short-term preoperative programmes, generally ranging from 5 days to several weeks
Assouline et al., 2021 [9] (Cardiac surgery subgroup)	SR + MA + TSA	- IG: IMT/RMT, endurance exercise, or combined ET + RMT - CG: Usual care or sham intervention.	6 RCTs; 308/628 patients (meta-analysis: 5 RCTs used; 308/613 patients)	Hospital (3 out of the 6 RCTs); home (3 out of the 6 RCTs); mixed: not clearly reported for cardiac-only subgroup.	Supervised: most hospital-based cardiac programmes (physiotherapist-led IMT or ET); unsupervised/semi-supervised: common in home-based IMT programmes; training type: predominantly IMT/RMT; some endurance or combined programmes.	1–4 weeks preoperatively; short-course programmes common (5–7 days to 2 weeks) in cardiac trials

Table 1. *Cont.*

First Author (Year)	Review Type	Prehabilitation Intervention(s)	No of Studies; Patients (IG/Total)	Settings for Prehabilitation (Home/Hospital; Counts)	With/Without Supervision and Type	Duration of Prehabilitation Programme (Preoperative)
Shahood et al., 2022 [27]	SR + MA	- IG: Preoperative chest physiotherapy, including IMT, incentive spirometry, breathing exercises, and IMT devices. - IG: Usual care.	10 (9 RCTs, 1 observational cohort); 651/1458 patients	Mixed settings: hospital-based supervised programmes and home-based programmes; exact counts per setting not consistently reported.	Both supervised and unsupervised interventions included.	5 days to 10 weeks
Cook et al., 2022 [28]	SR	- IG: Threshold IMT - CG: Usual care or sham intervention.	7 RCTs; 308/642 patients (one post hoc analysis of an included trial)	Commonly initiated in hospital or outpatient clinic settings, with continuation at home.	3 studies fully supervised in hospital/clinic, 3 studies partially supervised (weekly supervision with home training), 1 study unsupervised home-based.	5 days to ≥2 weeks, most commonly 2–4 weeks
Steinmetz et al., 2023 [29]	SR + MA	- IG: Exercise (aerobic exercise ± resistance training; multimodal programmes including education/psychological support; limited respiratory training). - CG: Usual care.	6 RCTs & non-RCTs; 282/665 patients (5 RCTs included in MA; 119/665-337)	Predominantly hospital-/clinic-based; one study included additional home-based exercise; exact counts per setting not quantified at review level.	All intervention groups received supervised exercise training.	5 days to ~10 weeks
Wang et al., 2023 [30]	SR + MA	- IG: IMT; threshold IMT; MIP; often combined with breathing exercises or routine physiotherapy. - CG: Usual care or postoperative physiotherapy, or sham intervention.	6 RCTs; 471/925 patients	Home; hospital (exact counts per setting not explicitly quantified at review level).	Supervised IMT; supervision intensity varied, with some protocols transitioning to unsupervised home practice.	5 days to ≥2 weeks (most trials implemented 1–2 weeks of IMT before surgery)
Zhang et al., 2023 [2] (Preoperative only)	SR + MA	- IG: Preoperative IMT only using threshold/resistive devices; training initiated before CABG; postoperative-only and combined perioperative IMT excluded. - CG: Usual care or sham intervention.	4 RCTs; 315/624 patients	Mixed settings across included trials; IMT delivered in hospital/clinic settings (particularly postoperative phases) and home-based settings (mainly preoperative programmes after initial instruction); exact counts per setting not consistently reported at review level.	Primarily home-based IMT after initial instruction; some trials initiated IMT in hospital/clinic settings before discharge to home; exact counts per setting not explicitly reported.	Partially supervised: IMT typically prescribed and instructed by physiotherapists or trained staff, with ongoing unsupervised home training using threshold/resistive devices; supervision intensity varied across trials

Table 1. *Cont.*

First Author (Year)	Review Type	Prehabilitation Intervention(s)	No of Studies; Patients (IG/Total)	Settings for Prehabilitation (Home/Hospital; Counts)	With/Without Supervision and Type	Duration of Prehabilitation Programme (Preoperative)
Wang et al., 2024 [4]	SR + MA	- IG: IMT; exercise-based (breathing exercises, physiotherapy, aerobic training); health education; interventions analysed separately, not pooled together. - CG: None.	21 RCTs and quasi-RCT; 1428/2895 patients	Home; hospital; pre-admission clinic (counts per setting not explicitly quantified at review level).	Predominantly supervised interventions; some trials transitioned to unsupervised home practice after instruction; supervision intensity variably reported.	5 days to ≥8 weeks; IMT often short-term (≈5 days–2 weeks); exercise-based programmes generally longer (≈2–8 weeks); education interventions delivered shortly before surgery
Cursino de Moura et al., 2024 [1]	SR + MA	- IG: RMT using threshold inspiratory loading devices (15–40% MIP; 20–40 min/day; 5 days–4 weeks). - CG: Sham intervention or none.	8 RCTs; 350/696 patients	Mixed settings. Home-based RMT predominant; hospital-/clinic-based initiation reported in several trials. Exact counts per setting not consistently reported at review level.	Mixed supervision. Fully supervised in 3 trials; intermittent supervision (weekly or every 3 days) in 4 trials; supervision not reported in 1 trial. Training typically prescribed and instructed by physiotherapists; home-based self-training common thereafter.	5 days to 4 weeks preoperatively. Most trials implemented 2–4 weeks of RMT; one trial demonstrated benefit with a short 5-day intensive protocol. Sessions 20–40 min/day at 15–40% MIP
Hurtado-Borrego et al., 2025 [8]	SR + MA + meta-regression	- IG: Exercise-based ± IMT. - CG: CG: Usual care or sham intervention.	9 RCTs; 873 patients; IG number not available in review	Hospital-based and home-based programmes reported; exact counts per setting not quantified at review level.	Predominantly supervised; some partially supervised or home-based components; level of supervision variably reported.	5 days to 8 weeks

Table 1 summarises the design and characteristics of the systematic reviews (SRs) and meta-analyses (MAs) included in this umbrella review. AF, atrial fibrillation; CABG, coronary artery bypass grafting; CG, control group; ET, endurance training; FEV_1, forced expiratory volume in one second; FVC, forced vital capacity; IG, intervention group; IMT, inspiratory muscle training; LOS, length of stay; MA, meta-analysis; MIP, maximal inspiratory pressure; Pi-max, maximal inspiratory pressure; PPCs, postoperative pulmonary complications; QoL, quality of life; RCT, randomised controlled trial; RMT, respiratory muscle training; SR, systematic review; TSA, trial sequential analysis; 6 MWT, six-minute walk test.

Overall heterogeneity: Considerable heterogeneity was evident across reviews in terms of intervention content, delivery setting, supervision intensity, and programme duration. Even within individual reviews, substantial variability was observed. As illustrated in Table 1, Assouline et al., 2021 [9], included cardiac surgery trials ranging from short 5–7-day IMT protocols to longer 1–4-week endurance or combined respiratory–exercise programmes, underscoring the breadth of prehabilitation strategies evaluated. This heterogeneity has important implications for the interpretation of pooled estimates and is addressed further in the outcome-specific analyses. A full list of primary studies included in each SR, including publication years, number of databases searched, and surgical populations, is provided in Supplementary Table S4.

3.3. Comparator Characteristics, Intervention Delivery, and Programme Structure

Comparator characteristics, delivery setting, supervision, and programme duration varied substantially across reviews and intervention modalities, as summarised in Table 1.

Comparator characteristics: Across the included reviews, comparator groups were generally aligned with the type of prehabilitation intervention evaluated. In reviews of IMT/RMT, whether delivered alone or combined with breathing exercises or chest physiotherapy, comparators were most often usual perioperative care or sham interventions such as placebo respiratory training or sham IMT devices. The frequent use of sham comparators reflects attempts to control for device handling and participant engagement, as seen in key IMT reviews by Hulzebos et al., 2012 [24], and the cardiac surgery subgroup of the Cochrane review by Katsura et al., 2015 [7].

In contrast, reviews evaluating exercise-based prehabilitation, including aerobic exercise, resistance training, functional training, or structured activity counselling, typically used usual care or no structured prehabilitation as the comparator, without sham exercise controls. This approach was evident in exercise-focused and multimodal reviews such as Steinmetz et al., 2023 [29], where comparator groups received routine preoperative management without formal training or behavioural interventions. Similarly, multimodal programmes combining exercise with education, psychological support, or limited respiratory components predominantly used usual care or no intervention as the control. Reviews restricted to preoperative IMT consistently employed usual care or sham interventions, as illustrated in the CABG-specific meta-analysis by Zhang et al., 2023 [2].

Duration of prehabilitation programmes: Programme duration varied substantially across reviews and was closely related to intervention type and preoperative waiting times. Most reviews described short- to medium-term programmes lasting between 5 days and 4 weeks, although longer durations appeared in some exercise-based interventions.

IMT- and RMT-focused reviews commonly reported durations of 1–4 weeks, with several studies using shorter, intensive protocols. In the cardiac surgery subgroup analysed by Assouline et al., 2021 [9], IMT programmes ranged from 5–7 days to 4 weeks, reflecting adaptation to limited preoperative time. Cursino de Moura et al., 2024 [1], similarly reported that most RMT protocols spanned 2–4 weeks, although one intensive 5-day protocol also demonstrated benefit, highlighting the potential efficacy of brief respiratory interventions.

Exercise-based and multimodal programmes were generally longer than IMT-only programmes. Reviews assessing structured exercise interventions reported durations from 5 days to 8 weeks or longer, particularly when combining aerobic and resistance training. Hurtado-Borrego et al., 2025 [8], noted programme durations ranging from 5 days to 8 weeks, with longer durations more common in exercise-based approaches.

Location of prehabilitation delivery: Delivery settings varied across reviews and were influenced by modality, supervision requirements, and study design. Many reviews

described mixed models in which interventions began in hospital or outpatient clinics and continued at home, particularly for IMT and RMT.

IMT interventions were typically home-based after initial supervised instruction. Reviews by Gomes Neto et al., 2016 [3], and Zhang et al., 2023 [2], described protocols initiated under physiotherapist supervision and subsequently performed independently at home, reflecting the portability of IMT devices.

Exercise-based and multimodal programmes were more frequently delivered in hospital or clinic settings, particularly when direct supervision of aerobic or resistance training was required. Reviews such as Steinmetz et al., 2023 [29], and Hurtado-Borrego et al., 2025 [8], reported predominantly institution-based programmes, though some incorporated home-based components. Several reviews reported mixed delivery models, but many did not provide sufficient detail to allow precise classification.

Supervision of prehabilitation interventions: Supervision intensity varied widely and was closely related to intervention modality. IMT and RMT programmes were usually partially supervised, with physiotherapist-led instruction, load adjustment, and technique review at initiation followed by mostly unsupervised home-based training. This pattern was consistently reported in reviews such as Assouline et al., 2021 [9], and Gomes Neto et al., 2016 [3].

Exercise-based and multimodal programmes were more commonly fully supervised, especially when involving aerobic or resistance training delivered in clinical settings. Reviews by Hurtado-Borrego et al., 2025 [8], and Yau et al., 2020 [5], described predominantly supervised interventions designed to ensure safety and progression. Several reviews included mixed models, ranging from fully supervised programmes to minimally supervised home-based interventions supported by written materials or periodic follow-up. Figure 2 summarises the distribution of comparator types, prehabilitation duration, delivery settings, and supervision models across the 18 included SRs.

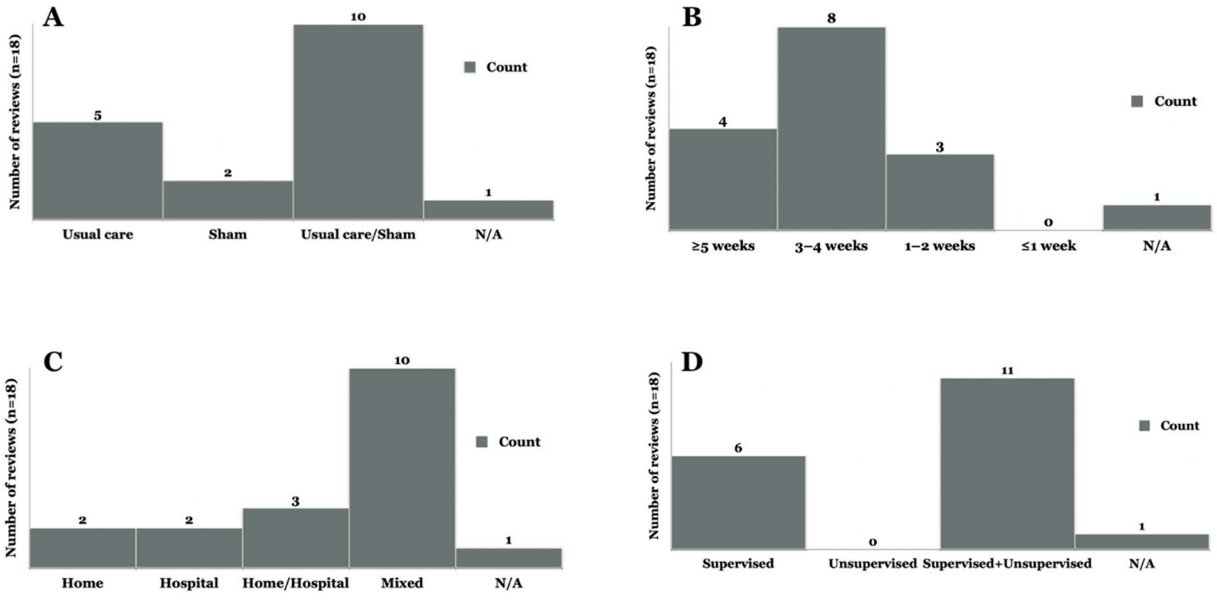

Figure 2. Bar charts illustrating key structural characteristics of prehabilitation interventions across the 18 included systematic reviews: (**A**) comparator characteristics; (**B**) predominant duration of prehabilitation; (**C**) location of delivery; (**D**) supervision model.

3.4. Effects of Interventions by Outcome

Across the included reviews, the most consistent evidence relates to reductions in PPCs, particularly when prehabilitation involves IMT or RMT. Multiple high-quality reviews, including those by Hulzebos et al., 2012 [24], and Cursino de Moura et al., 2024 [1], reported

a clear and reproducible reduction in pneumonia and atelectasis. This direction of benefit was also confirmed in cardiac-specific analyses such as Assouline et al., 2021 [9], indicating that targeted respiratory training improves pulmonary outcomes across a range of cardiac surgical procedures.

Reductions in hospital LOS were also consistently observed in reviews that evaluated respiratory-focused interventions and in several reviews assessing exercise-based programmes. Findings from Gomes Neto et al., 2016 [3], and Shahood et al., 2022 [27], support the conclusion that prehabilitation contributes to earlier postoperative recovery, although the size of the effect varied across studies. In contrast, the evidence for reductions in ICU LOS was mixed. Some exercise-focused reviews reported modest improvements, but IMT-only reviews generally found little to no effect, suggesting that shorter respiratory programmes may not influence the more intensive postoperative recovery period.

Improvements in respiratory muscle strength represented one of the most reproducible physiological effects. Nearly all IMT-focused reviews documented meaningful increases in inspiratory pressures. This pattern, observed in reviews such as Zhang et al., 2023 [2], provides a plausible mechanistic pathway for the reduction in PPCs and the enhanced postoperative respiratory performance seen across multiple analyses.

Functional capacity outcomes tended to improve most in reviews of structured exercise-based or multimodal programmes. These interventions often produced gains in walking distance and other physical performance measures. Although heterogeneity in training content and timing limited pooling across studies, the overall direction of improvement was consistent, particularly in reviews that focused on supervised or higher intensity exercise.

By contrast, effects on mechanical ventilation duration, mortality, and postoperative atrial fibrillation were inconsistent. Most reviews found no reliable evidence of benefit for these outcomes, and variations in sample size, outcome definitions, and study quality contributed to uncertainty. Isolated trials reported potential improvements, but these were not sufficiently consistent to alter the overall interpretation. Table 2 provides an overarching summary of the outcome-level evidence, indicating how consistently each clinical outcome was reported across reviews and the overall direction and certainty of effects.

Table 2. Summary of methodological characteristics, pooled outcomes, and key statistical findings of included systematic reviews and meta-analyses.

Review	Methodological Notes	Key Pooled Outcomes	Statistical Results (as Reported)
Hulzebos et al., 2012 [24]	RCTs and quasi-RCTs; meta-analysis performed; no protocol registration (pre-PROSPERO era); performance bias common due to limited blinding	Atelectasis (PPC grade 2); pneumonia (PPC grade 3); mechanical ventilation (>48 h); mortality; hospital LOS; 6 MWT; health-related QoL.	↓ Pneumonia: RR 0.45 (95% CI: 0.24–0.83); ↓ atelectasis: RR 0.52 (95% CI: 0.32–0.87); ↓ hospital LOS: MD −3.21 days (95% CI: −5.73 to −0.69); ↓ mechanical ventilation > 48 h: no significant difference (RR 0.55, 95% CI: 0.03–9.20); mortality: no significant difference (RR 0.66, 95% CI: 0.02–18.48)
Snowdon et al., 2014 [6]	RCTs and quasi-RCTs; substantial clinical heterogeneity across intervention types (IMT, exercise, education, relaxation); interventions often pooled broadly, with subgroup analyses by intervention type; inconsistent reporting of intervention dose, intensity, and supervision; no GRADE assessment; PPC definitions varied across trials	PPCs; time to extubation; ICU LOS; hospital LOS; mortality	↓ PPC: RR 0.39 (95% CI: 0.23–0.66; 6 trials, n = 661) ↓ Time to extubation; MD −0.14 days (≈3.4 h; 4 trials, n = 291); ICU LOS: no significant difference; Hospital LOS: overall non-significant; significant reduction in older patients (>63 yrs): MD −1.32 days (95% CI: −2.36 to −0.28); Mortality: no significant difference.
Katsura et al., 2015 [7] **Cardiac surgery subgroup**	High-quality systematic review; RCTs only. CABG-only and CABG ± valve surgery trials. IMT intervention and cardiac-specific pooled estimates were not reported; subgroup contributed to overall meta-analyses	PPCs (atelectasis, pneumonia), LOS; mechanical ventilation, mortality	No cardiac-only pooled-effect estimates reported. Cardiac surgery trials contributed to overall pooled analyses showing ↓ pneumonia (RR 0.45, 95% CI: 0.26–0.77) and ↓ atelectasis (RR 0.53, 95% CI: 0.34–0.82)
Mans et al., 2014 [11] **Cardiac surgery subgroup**	PEDro quality moderate (mean 5.9/10 overall); limitations: inadequate blinding (impossible for participants), small samples in some cardiac trials, potential bias in allocation/outcome assessment; benefits (reduced PPCs, improved MIP) consistent in cardiac-heavy studies but pooled data; no cardiac-specific subgroup pooling; evidence supports home-based IMT for high-risk cardiac patients with no adverse events reported	PPCs; MIP; lung function recovery; hospital LOS; mechanical ventilation > 24 h; adverse events; patient satisfaction	↓ PPCs: RR ~0.58 (95% CI: 0.22–1.55; 3 trials, 140 pts; not significant, $p \approx 0.28$); ↓ hospital stay: MD −1.99 days (95% CI: −5.41 to 1.43; 1 trial, 26 pts; not significant); ↑ MIP preop: MD 14.99 cmH_2O (95% CI: 9.01–20.98; 3 trials, 180 pts; $p < 0.00001$); ↑ MIP < 5 days postop: MD 4.68 cmH_2O (95% CI: −10.28 to 19.64; 1 trial); ↑ MIP 5–10 days postop: MD 22.10 cmH_2O (95% CI: 6.04–38.16; 1 trial); moderate PEDro quality; low heterogeneity
Gomes Neto et al., 2016 [3] (preoperative subgroup)	PEDro scale quality scores generally 4–8/10 for included studies; low heterogeneity in preoperative outcomes ($I^2 \approx 0\%$); PRISMA-compliant; focused on IMT alone (threshold-loading dominant); common limitations: small samples (416 total patients), variable protocols, potential blinding issues	Intervention vs. control: MIP; inspiratory muscle endurance (Pi-max); PPCs; hospital LOS; pulmonary function (FEV1, FVC, tidal volume)	↓ Hospital stay: MD = −2.04 days (95% CI: −3.37, −0.72; N ≈ 302; Z = 3.02, $p = 0.003$; $I^2 = 0\%$); ↑ MIP change: MD = 14.99 cmH_2O (95% CI: 9.01, 20.98; N = 542; Z = 4.91, $p < 0.00001$; $I^2 = 33\%$); ↑ endurance (Pmpeak/Pi-max) change: MD = 8.28% (95% CI: 4.71, 11.85; N ≈ 360; Z = 4.91, $p < 0.00001$; $I^2 = 33\%$); ↑ FEV1 change: MD = 3.06% predicted (95% CI: 0.09, 6.04; N = 140; Z = 2.02, $p = 0.04$; $I^2 = 0\%$); ↑ FVC change: MD = 4.64% predicted (95% CI: 1.90, 7.39; N = 140; Z = 2.02, $p = 0.04$; $I^2 = 0\%$); ↑ pulmonary complications: RR = 0.61 (95% CI: 0.46, 0.80; events 42/195 vs 69/191; Z = 3.51, $p = 0.0004$; $I^2 = 0\%$)
Karanfil et al., 2018 [25]	PROSPERO-registered protocol; PRISMA-compliant; meta-analysis performed; heterogeneity in IMT modality, intensity, supervision, and diagnostic criteria for pulmonary complications	Postoperative pneumonia and atelectasis	↓ Pneumonia: RR 0.44 (95% CI: 0.23–0.83), $p = 0.01$; $I^2 = 0\%$ ↓ Atelectasis: RR 0.59 (95% CI: 0.35–1.00), $p = 0.05$; $I^2 = 0\%$
Rodrigues et al., 2020 [26]	PRISMA and Cochrane guidance; included 10 RCTs and 1 observational cohort study, increasing clinical and methodological heterogeneity. Considerable variation in intervention type (IMT, diaphragmatic breathing, incentive spirometry, or combinations). Performance bias high due to lack of blinding; postoperative care protocols poorly reported, contributing to heterogeneity in pooled analyses	PPCs, hospital LOS, postoperative respiratory performance (spirometry, inspiratory muscle strength)	↓ PPCs: RR 0.47 (95% CI: 0.26–0.85; 8 studies, n = 1077); ↓ PPCs in older adults (≥65 y): ↓ RR 0.30 (95% CI: 0.19–0.49; 3 studies, n = 648); hospital LOS: ↓ MD −0.81 days (95% CI: −1.38 to −0.48; 7 studies, n = 1050; not statistically significant); postoperative respiratory performance: significant improvement (MD −25.36, 95% CI: −31.87 to −18.85; 4 studies, n = 219; high heterogeneity)

Table 2. *Cont.*

Review	Methodological Notes	Key Pooled Outcomes	Statistical Results (as Reported)
Yau et al., 2020 [5]	PROSPERO-registered; PRISMA-compliant; RCTs only; comprehensive search including trial registries; high clinical heterogeneity in setting, supervision, duration, and intervention content; all included trials at high risk of performance bias; adherence and fidelity variably reported; functional outcomes measured at differing postoperative time points, limiting pooling	Mortality; PPCs (atrial fibrillation, pneumonia, atelectasis, pleural effusion); functional capacity (6 MWT, gait speed); hospital LOS; ICU LOS; psychosocial outcomes; frailty; healthcare utilisation	↑ Mortality: Peto OR 1.30 (95% CI: 0.28–5.95; I^2 = 0%; low-certainty)—no significant effect. ↓ Postoperative AF: RR 0.75 (95% CI: 0.38–1.46; I^2 = 50%; very low-certainty). ↓ Pneumonia: RR 0.38 (95% CI: 0.01–14.64; I^2 = 67%; very low-certainty). ↓ Atelectasis: RR 0.74 (95% CI: 0.04–14.21; I^2 = 71%; very low-certainty). ↓ Pleural effusion: RR 0.43 (95% CI: 0.19–0.97; moderate-certainty; single study). ↓ Hospital LOS: MD −0.66 days (95% CI: −1.29 to −0.03; I^2 = 45%; low-certainty). ↓ ICU LOS: no significant difference. ↓ Functional capacity: pooled MA not consistently possible; individual trials showed postoperative 6 MWT improvements (e.g., +54 m at discharge; +123 m at 3 months).
Zheng et al., 2020 [12]	Systematic review with meta-analysis including 6 studies (randomised and case–control). High heterogeneity for ICU LOS (I^2 = 88%). Interventions were heterogeneous and grouped under a single "exercise" category. Risk of bias present across multiple domains, particularly performance bias and selection bias in non-randomised studies	ICU LOS, postoperative physical function	↓ ICU LOS: MD −1.35 days (95% CI: −2.64 to −0.06; p = 0.04; I^2 = 88%); ↑ postoperative physical function: significant improvement (MD 6.81; Z = 9.92; $p < 0.00001$; I^2 = 12%); WBC day 7: no significant difference (RR 0.43, 95% CI: 0.10–1.81; p = 0.25); mental health: no significant difference (MD −0.01, 95% CI: −1.55 to 1.52; p = 0.99)
Assouline et al., 2021 [9] (cardiac surgery subgroup)	Subgroup analysis for PPCs reported; other outcomes not pooled separately. Heterogeneity acceptable. Performance bias common (no participant blinding). Cardiac trials contributed substantially to IMT-driven effect. TSA deemed conclusive for PPC reduction in cardiac subgroup	PPCs	↓ PPCs: RR 0.53 (95% CI: 0.38–0.73); direction favours prehabilitation; TSA: conclusive for cardiac subgroup
Shahood et al., 2022 [27]	SR + MA; included mostly RCTs plus pilot RCTs and one observational cohort study; intervention protocols heterogeneous in type, intensity, and supervision; Cochrane Risk of Bias tool used; no GRADE assessment; substantial overlap with prior cardiac prehabilitation reviews	PPCs; hospital LOS; mechanical ventilation duration; ICU LOS; pulmonary function (FEV1% predicted, FVC% predicted, Pi-max)	↓ PPCs: RR 0.47 (95% CI: 0.36–0.62), I^2 = 0%; ↓ hospital LOS: MD −1.02 days ($p < 0.001$); Mechanical ventilation duration: ↓ MD −0.76 h ($p < 0.001$); ICU LOS: no significant difference (p = 0.92); ↑ pulmonary function improved (FEV1% +3.7%, FVC% +10.17%, Pi-max +17.25 cmH_2O; $p < 0.05$)
Cook et al., 2022 [28]	Systematic review of 7 single-centre RCTs; no meta-analysis performed due to heterogeneity in outcomes and protocols. High risk of performance bias unavoidable; allocation concealment and adherence reporting inconsistent. Outcomes (LOS, PPCs) defined heterogeneously. PROSPERO registration not undertaken, acknowledged as a limitation	Hospital LOS; PPCs; quality of life; mortality	Hospital LOS: ↓ in all 5 studies; statistically significant ↓ in 3 studies (mean reduction ~ 1.0–1.9 days); PPCs: significant ↓ reported in 3 studies (including reduced pneumonia and PPCs ≥ grade 2); quality of life: mixed results, no consistent between-group differences; mortality: no statistically significant differences reported
Steinmetz et al., 2023 [29]	PROSPERO-registered; PRISMA-compliant; random-effects MA; high clinical heterogeneity in exercise modality, intensity, frequency, and duration; all included studies at high risk of performance bias due to lack of blinding; limited standardisation and reporting of exercise intensity and progression; subgroup analyses by age (≤65 vs. >65) and surgery type performed	Functional capacity (6 MWD); hospital LOS; ICU LOS; postoperative AF; PPCs (pneumonia, atelectasis); mortality	↑ 6 MWD: Post-intervention MD +75.4 m (95% CI: 13.7–137.1; p = 0.02; I^2 = 78%); ↑ post-surgery MD +30.5 m (95% CI: 8.5–52.6; p = 0.007; I^2 = 0%). ↓ LOS: MD −1.00 day (95% CI: −1.78 to −0.23; p = 0.01; I^2 = 92%). ↓ ICU LOS: no significant difference (MD −265.7 min; 95% CI: −553.2 to 21.7; p = 0.07). ↓ Postoperative AF: overall no significant effect (RR 0.82; 95% CI: 0.52–1.29), but reduced in patients ≤65 years (RR 0.34; 95% CI: 0.14–0.83; p = 0.02). ↓ Atelectasis: RR 0.20 (95% CI: 0.06–0.73; p = 0.01). ↓ Pneumonia: borderline reduction (RR 0.12; 95% CI: 0.02–1.00; p = 0.05). ↓ Mortality: no significant difference (Peto OR 0.54; 95% CI: 0.14–2.06; p = 0.36).

Table 2. *Cont.*

Review	Methodological Notes	Key Pooled Outcomes	Statistical Results (as Reported)
Wang et al., 2023 [30]	RCT-only inclusion; random-effects MA; low statistical heterogeneity for pooled outcomes; substantial clinical heterogeneity in IMT intensity (15–40% MIP), frequency, supervision, and co-interventions; some outcomes required conversion of medians/IQRs to means/SDs; no GRADE summary reported; focus limited to IMT excludes broader multimodal or exercise-based prehabilitation	Mechanical ventilation time, ICU and hospital LOS	↔ Mechanical ventilation time or ICU stay; significant ↓ LOS (MD −1.77 days, 95% CI: −2.41 to −1.12) ↓ Hospital LOS: MD −1.77 days (95% CI: −2.41 to −1.12; $p < 0.001$; $I^2 = 17\%$). ↓ ICU LOS: MD 0.44 h (95% CI: −0.58 to 1.45; $p = 0.40$; $I^2 = 0\%$)—no significant difference. ↑ Mechanical ventilation duration: MD −0.45 h (95% CI: −1.59 to 0.69; $p = 0.44$; $I^2 = 0\%$)—no significant difference
Zhang et al., 2023 [2] (Preoperative only)	Short- to medium-term preoperative programmes, ranging from 5 days to ~4 weeks before CABG; most trials implemented 2–4 weeks of IMT prior to surgery	PPCs; hospital LOS; inspiratory muscle strength (MIP); pulmonary function (FEV_1, FVC)	↓ PPCs: RR 0.42 (95% CI: 0.25–0.71; $I^2 = 0\%$). ↓ Hospital LOS: reduced by approximately 1.9–2.0 days. ↑ Inspiratory muscle strength (MIP): MD +16.55 cmH_2O (95% CI: 13.86–19.25). ↑ Pulmonary function: modest improvements in FEV_1 (~+7% predicted) and FVC (~+4% predicted; limited trials)
Wang et al., 2024 [30]	RCTs and quasi-RCTs; interventions analysed separately by type (IMT, exercise, education); substantial clinical heterogeneity in content, duration, intensity, and supervision; risk of bias assessed using PEDro scale rather than Cochrane RoB; no protocol registration reported; no GRADE assessment; pooling avoided across dissimilar intervention types	IMT & exercise ↓ PPCs & LOS PPCs (atelectasis, pneumonia, composite PPCs); hospital LOS; ICU LOS	↓ Pneumonia (OR ≈ 0.41); ↓ atelectasis (OR ≈ 0.49); ↓ LOS (~1.6 days); ↓ ICU LOS (~2.2 h); ↓ LOS (~1.8 days). IMT: ↓ Atelectasis OR 0.49 (95% CI: 0.28–0.86); ↓ pneumonia OR 0.41 (95% CI: 0.25–0.67); ↓ hospital LOS MD −1.57 days (95% CI: −2.33 to −0.81); ↓ ICU LOS no significant effect. Exercise-based: Composite ↓ PPCs OR 0.15 (95% CI: 0.06–0.38); ↓ hospital LOS MD −1.82 days (95% CI: −3.38 to −0.27); ↓ ICU LOS MD −2.22 h (95% CI: −3.05 to −1.38). Health education: No significant reduction in PPCs or LOS
Cursino de Moura et al., 2024 [1]	PROSPERO-registered; PRISMA-compliant; RCTs only. Risk of bias assessed with PEDro scale (median score 6/10). Random-effects meta-analysis with very low heterogeneity for key outcomes. Prediction intervals reported. GRADE applied at outcome level; high certainty for pneumonia, LOS, and MIP. PPC definitions varied across trials; performance bias common due to lack of blinding	PPCs, pneumonia, hospital LOS, MIP, mechanical ventilation duration, pulmonary function, mortality	↓ PPCs: RR 0.51 (95% CI: 0.38–0.70; $I^2 = 2\%$; moderate-certainty); ↓ pneumonia: RR 0.44 (95% CI: 0.25–0.78; $I^2 = 0\%$; high-certainty); ↓ hospital LOS: MD −1.7 days (≈ −1.1 to −2.4 days; $I^2 = 0\%$; high-certainty); ↑ MIP: MD +12 cmH_2O (95% CI: 8–16; $I^2 = 0\%$; high-certainty); ↔ duration of mechanical ventilation (MD −0.2 h; $I^2 = 70\%$; moderate-certainty); ↔ mortality (RR 0.63; 95% CI: 0.17–2.33; low-certainty)
Hurtado-Borrego et al., 2025 [8]	PROSPERO-registered; PRISMA 2020-compliant; RCTs only; meta-analysis, subgroup analysis, and meta-regression conducted; substantial clinical heterogeneity in exercise modality, intensity, supervision, and surgical type; heterogeneity high for some outcomes (e.g., 6 MWT, hospital LOS); RoB 2 used; GRADE applied; exercise-only focus excludes nutrition/psychological components	Functional capacity (6 MWT); PPCs (atelectasis, pneumonia); hospital LOS; ICU LOS; arrhythmias; mortality; frailty	↑ Functional capacity: Δ6 MWT +52.4 m (95% CI: 22.4–82.1; $p < 0.001$; $I^2 = 76\%$); ↓ atelectasis: OR 0.41 (95% CI: 0.18–0.91; $p = 0.03$; $I^2 = 0\%$); ↓ Hospital LOS: MD −15.2 h (95% CI: −34.6 to 4.22; $p < 0.001$; $I^2 = 84\%$); ↓ ICU LOS: MD −0.76 h (95% CI: −1.52 to −0.01; $p = 0.05$; $I^2 = 0\%$); ↔ arrhythmias: OR 0.54 (95% CI: 0.20–1.49); ↔ mortality: OR 0.67 (95% CI: 0.25–1.77). Frailty scores (CFS, EFT) improved in individual trials

Table 2 summarises methodological characteristics and pooled statistical outcomes of included systematic reviews and meta-analyses. AF, atrial fibrillation; CABG, coronary artery bypass grafting; CG, control group; CI, confidence interval; FEV_1, forced expiratory volume in one second; FVC, forced vital capacity; ICU, intensive care unit; IG, intervention group; IMT, inspiratory muscle training; LOS, length of stay; MA, meta-analysis; MD, mean difference; MIP, maximal inspiratory pressure; OR, odds ratio; Peto OR, Peto odds ratio (fixed-effect method for rare events); PEDro, Physiotherapy Evidence Database scale; PPCs, postoperative pulmonary complications; QoL, quality of life; RCT, randomised controlled trial; RR, risk ratio; RMT, respiratory muscle training; SR, systematic review; TSA, trial sequential analysis; 6 MWT, six-minute walk test; I^2, I-squared statistic (measure of statistical heterogeneity); ↓, statistically significant reduction; ↑, statistically significant increase; ↔, no statistically significant difference.

3.5. Evidence from Included Systematic Reviews and Meta-Analyses

Overall, the most consistent and robust evidence supports preoperative IMT/RMT, particularly for reducing PPCs and hospital LOS. Early IMT-focused reviews, such as Hulzebos et al., 2012 [24], reported significant reductions in pneumonia and atelectasis and a clinically meaningful reduction in LOS, despite methodological limitations inherent to pre-PROSPERO trials. Snowdon et al., 2014 [6], broadened the intervention scope and similarly demonstrated reductions in PPCs, though interpretation was constrained by substantial clinical heterogeneity.

Cardiac-focused analyses reinforced these findings. Katsura et al., 2015 [7], showed that cardiac trials contributed meaningfully to overall pooled reductions in pneumonia and atelectasis, and Karanfil et al., 2018 [25], reported consistent reductions in both complications with no statistical heterogeneity. Reviews centred on IMT also demonstrated improvements in inspiratory muscle strength and pulmonary function. Mans et al., 2014 [11], and Gomes Neto et al., 2016 [3], found significant increases in maximal inspiratory pressure and reductions in LOS, although effects on PPCs were less consistent in smaller cardiac-only datasets.

Recent high-quality reviews strengthened the certainty of evidence. Assouline et al., 2021 [9], demonstrated a significant PPC reduction in cardiac surgery, supported by conclusive trial sequential analysis. Cursino de Moura et al., 2024 [1], provided high-certainty evidence for reductions in PPCs, pneumonia, and LOS, alongside consistent improvements in inspiratory muscle strength.

Findings for exercise-based and multimodal prehabilitation were more variable. Yau et al., 2020 [5], Steinmetz et al., 2023 [29], and Hurtado-Borrego et al., 2025 [8], reported improvements in functional capacity and modest LOS reductions, but effects on PPCs, ICU LOS, and mortality were inconsistent due to heterogeneity, performance bias, and non-standardised protocols. Across reviews, no consistent mortality reduction was observed, and effects on ICU LOS and ventilation duration were small or non-significant. No review reported increased adverse events, supporting the overall safety of prehabilitation. Supplementary Table S5 summarises outcome-specific findings across all reviews.

3.6. Methodological Quality of Included Reviews

In total, 18 SRs were included in this umbrella review. Of these, six reviews [1,7–9,11,24] were rated as high confidence, ten as moderate confidence, and two as low confidence according to AMSTAR-2 criteria. Reviews rated as high confidence were characterised by prospective protocol registration, comprehensive searches without language restriction, duplicate processes throughout, formal risk-of-bias assessment integrated into interpretation using frameworks such as GRADE, and robust meta-analytic methods. These reviews therefore carry the greatest evidential weight in the synthesis and primarily underpin the conclusions of the umbrella review.

Several reviews, including Shahood et al., 2022 [27], Karanfil et al., 2018 [25], and Steinmetz et al., 2023 [29], fulfilled all assessed AMSTAR-2 domains but were rated as moderate confidence. This downgrading reflects the presence of important non-critical limitations rather than deficiencies in methodological conduct. Common issues included small numbers of included trials and participants leading to imprecision, substantial clinical heterogeneity in intervention characteristics and outcome definitions, reliance on surrogate or short-term outcomes, absence of formal certainty-of-evidence grading in some reviews, and residual high risk of bias in the underlying primary studies. For example, Steinmetz et al., 2023 [29], included only six studies with high heterogeneity and mixed study designs, Yau et al., 2020 [5], included seven trials all at high risk of bias, and Wang et al., 2024 [30], focused primarily on short-term outcomes without applying a formal

GRADE framework. As a result, these reviews contribute supportive and complementary evidence but are interpreted with greater caution than high-confidence reviews.

Two reviews were rated as low confidence due to one or more critical AMSTAR-2 flaws, most notably lack of protocol registration and substantial methodological limitations in synthesis. These reviews are retained in the umbrella review to provide historical context and illustrate the evolution of the evidence base but are not used to drive primary conclusions. A full breakdown of AMSTAR-2 compliance across all included reviews is provided in Supplementary Table S6, enabling transparent comparison of methodological strengths and limitations.

3.7. Overlap of Primary Studies

Assessment of overlap demonstrated a moderate degree of redundancy among the primary studies included across the SRs and MAs. A citation matrix comprising 18 SRs (c = 18) and 46 unique primary studies (r = 46) identified 144 study occurrences across reviews (N = 144). Using the CCA method, the overall CCA was 12.5%, indicating a high degree of overlap among included reviews (Supplementary Table S7).

The observed overlap was largely driven by repeated inclusion of a small number of landmark RCTs evaluating IMT and respiratory-focused prehabilitation in cardiac surgery. In particular, the parallel trials by Hulzebos et al. (2006 A and B) [24,31] and the early trial by Weiner et al., 1998 [32], were consistently included across most IMT-focused reviews [1–4,7,11,25,30]. Similarly, Ferreira et al., 2009 [33], and Carvalho et al., 2011 [34], appeared repeatedly across multiple reviews evaluating PPCs and hospital LOS.

Additional overlap arose from later respiratory physiotherapy trials, such as those by Savci et al., 2011 [35], Sobrinho et al., 2014 [36], Valkenet et al., 2013 [37], Chen et al., 2019 [38], and Shakuri et al., 2015 [39], which were commonly shared among more recent MAs. These studies contributed to overlap particularly in reviews by Rodrigues et al., 2020 [26], Shahood et al., 2022 [27], Wang et al., 2023 [30], Wang et al., 2024 [4], and Cursino de Moura et al., 2024 [1].

In contrast, reviews focusing on exercise-based or multimodal prehabilitation demonstrated less overlap and a more heterogeneous primary study base. Exercise-oriented reviews, including those by Hurtado-Borrego et al., 2025 [8], Steinmetz et al., 2023 [29], and Yau et al., 2020 [5], incorporated a broader range of trials spanning different intervention modalities, populations, and outcome priorities, thereby reducing redundancy with the respiratory training literature.

Cardiac surgery subgroup analyses extracted from broader surgical reviews predominantly relied on the same core IMT trials and therefore contributed to overlap across reviews. However, these subgroup analyses did not introduce new primary studies but instead re-analysed overlapping trials within more narrowly defined clinical contexts.

To minimise the risk of double counting and overestimation of certainty arising from overlapping primary studies, the unit of analysis in this umbrella review was the SR rather than individual trials. Synthesis therefore prioritised consistency in the direction and strength of effects across independent reviews, rather than the frequency of study inclusion. The observed overlap reflects reliance on a shared foundational evidence base rather than inappropriate duplication and underscores both the robustness and the current limitations of the evidence supporting prehabilitation in cardiac surgery.

3.8. Narrative Evidence Map

The evidence map demonstrates a clear gradient in both the volume and maturity of evidence across prehabilitation intervention types in adult cardiac surgery. Respiratory-focused interventions, particularly IMT and RMT, represent the most extensively studied

and quantitatively synthesised domain, with consistent signals of benefit across multiple outcomes and reviews. In contrast, exercise-based and multimodal prehabilitation programmes show greater heterogeneity in intervention design, outcome reporting, and effect estimates, resulting in lower overall certainty.

Across respiratory-focused reviews [1,7,9,12,27,30,31] IMT was consistently associated with reductions in PPCs, particularly pneumonia and atelectasis. Pooled risk reductions were remarkably concordant (RR range ≈ 0.42–0.53), with minimal heterogeneity in several MAs and moderate-to-high certainty ratings in the most recent syntheses. Reductions in hospital LOS of approximately 1.5–3 days were also frequently observed. Improvements in inspiratory muscle strength were consistent and robust across reviews. In contrast, effects on ICU LOS, mechanical ventilation duration, and mortality were largely null or inconsistent.

Exercise-based prehabilitation programmes, synthesised in reviews by Hurtado-Borrego et al., 2025 [8], Steinmetz et al., 2023 [29], Yau et al., 2020 [5], Zheng et al., 2020 [12] and Wang et al., 2024 [4], demonstrated consistent improvements in preoperative and early postoperative functional capacity, particularly 6 MWD. Some reviews also reported reductions in hospital LOS and selected complications (e.g., atelectasis, POAF in younger patients). However, effect estimates were heterogeneous, and pooled analyses frequently showed substantial statistical heterogeneity. ICU LOS and mortality outcomes were inconsistently affected, resulting in predominantly low-certainty evidence.

Multimodal prehabilitation programmes combining exercise, respiratory training, education, and psychosocial components were evaluated in several mixed-intervention reviews but were rarely pooled as discrete intervention categories. While some benefit was observed for functional capacity and LOS, findings were inconsistent and difficult to attribute to individual components. Health education-only interventions, when analysed separately, showed no consistent benefit for PPCs or LOS.

Across all intervention categories, mortality was a rare and underpowered outcome. No review demonstrated a statistically significant reduction in postoperative mortality attributable to prehabilitation, and certainty remained low or very low. Overall, the evidence map indicates that respiratory prehabilitation has reached the highest level of evidentiary maturity, whereas exercise-based and multimodal programmes require further well-designed, adequately powered trials with standardised outcome reporting (Table 3; Supplementary Table S8).

Table 3. Evidence map of prehabilitation interventions in cardiac surgery.

Intervention Domain	PPCs (Composite)	Pneumonia	Atelectasis	Hospital LOS	ICU LOS	Functional Capacity	MIP/Resp Strength	Mortality
Inspiratory muscle training (IMT/RMT)	↓ (Moderate–High)	↓ (Moderate–Hig)	↓ (Moderate)	↓ (Moderate)	↔ (Low)	↑ (Low–Moderate)	↑ (High)	↔ (Very Low)
Exercise-based prehabilitation	↓ (Low–Moderate)	↓ (Low–Moderate)	↓ (Low)	↓ (Low–Moderate)	↔ (Low)	↑ (Low)	↑ (Low)	↔ (Very Low)
Multimodal prehabilitation	↓ (Low)	↓ (Low)	↔ (Very Low)	↓ (Low)	↔ (Very Low)	↑ (Low)	↑ (Very Low)	↔ (Very Low)
Education/counselling-only	↔ (Very Low)	↔ (Very Low)	↔ (Very Low)	↔ (Very Low)	↔ (Very Low)	↔ (Very Low)	↔ (Very Low)	↔ (Very Low)

Symbol guide: ↓ = reduction/improvement; ↑ = increase/improvement; ↔ = no consistent effect; Certainty categories follow GRADE: High, Moderate, Low, Very Low.

3.9. GRADE Certainty of Evidence

Certainty of evidence was rated using GRADE across key outcomes. As this was an umbrella review, certainty ratings were derived from the included SRs and MAs (n = 18), with greatest weight given to reviews of higher methodological confidence (AMSTAR-2 high or moderate), cardiac surgery-specific populations and preoperative-only interven-

tions, consistency of effect direction, and consideration of heterogeneity and publication bias. Certainty was downgraded for risk of bias (limitations of primary trials and review methods), inconsistency (heterogeneity and discordant findings), indirectness (where evidence derived from mixed populations, which was mitigated here by subgroup-only extraction), imprecision (small samples, wide confidence intervals, low event rates), and suspected publication bias.

Using GRADE, certainty of evidence was moderate for reductions in composite PPCs and pneumonia, reflecting consistent effects across multiple reviews but downgrading for risk of bias in underlying trials. Certainty was low for atelectasis and hospital LOS due to heterogeneity in outcome definitions and care pathways, and very low for ICU LOS because findings were inconsistent and context-dependent. Functional capacity improvements showed moderate certainty, primarily supported by exercise-based programmes. Evidence for mortality was low certainty and showed no clear effect, largely limited by imprecision and low event rates as shown in Table 4

Table 4. GRADE summary of findings table.

Outcome	Reviews Reporting (n = 18)	Overall Direction of Effect	Consistency Across Reviews	Certainty of Evidence (GRADE)	Main Reasons for Downgrading
Postoperative Pulmonary Complications (PPCs)	18	Beneficial (reduction in PPCs, especially with IMT)	Generally consistent across most reviews	**Moderate** ●●●○	Risk of bias in primary trials; heterogeneity in PPC definitions; variation in intervention protocols
Length of Hospital Stay (LOS)	18	Probably beneficial (small reductions)	Inconsistent; several reviews show minimal or no effect	**Low** ●●○○	Inconsistency across studies; imprecision (wide CIs, small samples); methodological limitations
Length of ICU Stay	14	Uncertain effect	Highly inconsistent; limited and sparse data	**Very low** ●○○○	Imprecision; heterogeneity in ICU endpoints; small sample sizes
Functional Capacity (Peak VO_2, 6 MWT, IMT strength)	17	Beneficial preoperative improvement	Mixed consistency; effects not always maintained postoperatively	**Low** ●●○○	Indirectness (surrogate outcomes); risk of bias; imprecision
Quality of Life (QoL)	10	Uncertain	Inconsistent across instruments and timepoints	**Very low** ●○○○	Sparse evidence; inconsistency of measures; imprecision
Postoperative Mortality	16	Uncertain (no clear reduction)	Consistently null across reviews, but highly imprecise	**Very low** ●○○○	Very low event rates; wide CIs; indirectness (secondary outcome)

Certainty of evidence was rated using the GRADE framework, considering risk of bias, inconsistency, indirectness, imprecision, and publication bias. Ratings reflect the overall body of evidence across systematic reviews rather than individual trials. "High" indicates very high confidence in the effect estimate; "Moderate" indicates moderate confidence; "Low" indicates limited confidence; and "Very low" indicates very little confidence in the estimate. Downgrading was applied where primary studies showed methodological limitations, where results were heterogeneous or imprecise, or where evidence was indirect or sparse. Key to GRADE: High certainty, ●●●●; Moderate certainty, ●●●○; Low certainty, ●●○○; Very low certainty, ●○○○.

4. Discussion

This umbrella review synthesised evidence from 18 SRs and MAs evaluating prehabilitation interventions in adults undergoing cardiac surgery. Across these reviews, three major themes emerged. Respiratory muscle training, particularly IMT, demonstrated the most consistent benefit across clinical outcomes. Exercise-based and multimodal programmes

showed promising effects on functional capacity but were limited by heterogeneity and methodological weaknesses. Several outcomes such as mortality and ICU LOS remained inconsistent or underpowered across the included evidence base.

Summary of principal findings: Respiratory-focused interventions represented the most studied prehabilitation domain, appearing in 72% of included reviews. Across these reviews, IMT was consistently associated with reductions in PPCs, including pneumonia and atelectasis, with most pooled estimates converging around RR between 0.42 and 0.53. Recent reviews contributed to certainty in these findings. Assouline et al., 2021 [9], reported a significant reduction in PPCs with a RR of 0.53 and a conclusive trial sequential analysis for the cardiac subgroup. Cursino de Moura et al., 2024 [1], similarly demonstrated certainty reductions in PPCs, pneumonia and hospital LOS, as well as improvements in inspiratory muscle strength.

These clinical effects were supported by improvements in physiological markers. Gomes Neto et al., 2016 [3], reported increases in FEV1 and FVC. Shahood et al., 2022 [27], additionally demonstrated improvements in FEV1 percent, FVC percent and maximal inspiratory pressure. These changes offer a sound physiological explanation for the reduction in pulmonary morbidity reported across reviews.

Exercise-based programmes also demonstrated improvements in functional capacity. Steinmetz et al., 2023 [29], reported increases in 6 MWD of more than 75 m preoperatively and more than 30 m postoperatively. Hurtado-Borrego et al., 2025 [8], found a pooled improvement of 52 m. Yau et al., 2020 [5], reported postoperative gains of up to 123 m at three months, although heterogeneity in follow-up time points prevented pooling. These improvements did not reliably translate to reductions in pulmonary complications, ICU LOS or mortality. Across exercise-based reviews, effects on these clinical outcomes were variable and frequently imprecise.

The narrative evidence map also indicated that exercise-based interventions provided low to moderate certainty evidence because of heterogeneity in intervention characteristics and inconsistent outcome reporting.

Multimodal programmes that combined exercise, respiratory muscle training and educational or psychological components demonstrated potential benefits in hospital LOS and functional capacity. However, these interventions were inconsistently described and rarely synthesised as a discrete category, which limited the interpretability of their effects across reviews. Mortality outcomes were largely unchanged across all intervention types. No review demonstrated a statistically significant reduction in postoperative mortality. Certainty remained low because of low event rates and wide confidence intervals.

Similarly, effects on ICU LOS were inconsistent. Some exercise-based reviews reported modest reductions. For example, Zheng et al., 2020 [12], found a reduction of 1.35 days. In contrast, most reviews of IMT found no significant difference. Mechanical ventilation duration showed small reductions in selected reviews such as Snowdon et al., 2014 [6], and Shahood et al., 2022 [27], but these findings were not universal.

Methodological strengths and limitations of the evidence base: A major strength of the included evidence is the direction of effect across numerous independent reviews. Interventions such as IMT demonstrated reductions in pulmonary complications across time, across surgical subgroups and across different modes of delivery. Several reviews incorporated protocol registration, comprehensive searches, duplicate study selection and risk of bias assessment using validated tools such as GRADE. These reviews enhanced the reliability of outcome-specific conclusions and formed the evidential backbone of this umbrella review.

Despite these strengths, several limitations were evident. Substantial clinical heterogeneity was present across studies. Programmes varied in setting, duration, supervision

and intensity. Inspiratory muscle training programmes ranged from five-day intensive protocols to four-week preoperative interventions. Exercise-based programmes spanned hospital, outpatient and home environments with inconsistent levels of supervision. Such heterogeneity complicates interpretation and may obscure true effect sizes.

Another limitation was the considerable overlap of primary studies, particularly within IMT reviews. Many reviews relied on a small number of foundational trials. Although this umbrella review synthesised results at the level of the SR to mitigate double counting, the underlying redundancy indicates that more contemporary trials are required.

Exercise-focused reviews frequently suffered from methodological weaknesses. These included small sample sizes, single-centre study designs, lack of blinding, and inconsistent reporting of exercise intensity, progression and adherence. These limitations contributed to downgrades in certainty of evidence and likely contributed to the inconsistent findings across reviews. Outcome reporting also varied substantially across studies. Definitions of PPCs differed between reviews and often combined pneumonia, atelectasis, pleural effusion and other respiratory events into broad composite outcomes. Hospital LOS is influenced by institutional discharge practices and may not directly reflect physiological recovery.

Comparison with the prior literature: The findings of this umbrella review are similar to prehabilitation research in other surgical fields, where respiratory muscle training often provides the clearest and most reproducible benefit [40,41]. Similar to abdominal, thoracic and oncological surgery, the strongest effects relate to pulmonary outcomes rather than mortality. Improvements in functional capacity seen with exercise-based prehabilitation mirror trends in non-cardiac surgery, although the magnitude of benefit varies. The particularly strong performance of IMT in cardiac surgery may reflect the respiratory challenges associated with cardiopulmonary bypass and postoperative chest discomfort [10,40,41].

Implications for clinical practice: Given the evidence supporting IMT, its incorporation into preoperative care for elective cardiac surgery appears justified. Inspiratory muscle training is low cost, safe and feasible across a variety of clinical and home-based settings. The consistent reductions in PPCs, pneumonia and hospital LOS without reported adverse events support its practical implementation. Exercise-based prehabilitation may be especially beneficial for improving functional capacity, particularly in frail or deconditioned patients. However, its adoption into standard care should be guided by available resources, patient characteristics and the current uncertainty around its effects on pulmonary and intensive care outcomes. Multimodal programmes may hold additional promise, although further research is required before widespread implementation.

Implications for future research: Future research should prioritise large multicentre RCTs that examine inspiratory muscle training, exercise-based programmes and multimodal interventions using standardised and transparent protocols. Standardised definitions of PPCs in hospitals and ICU LOS and functional capacity need to be adopted across studies. Researchers should also explore the differential effects of prehabilitation by age, frailty and surgical complexity. Comparative effectiveness studies that directly contrast IMT, exercise and multimodal programmes are needed. Long-term outcomes related to quality of life and readmission remain insufficiently reported and deserve greater attention.

5. Conclusions

This umbrella review shows that prehabilitation, particularly respiratory-focused interventions such as inspiratory muscle training, provides benefit for adults undergoing cardiac surgery. Across 18 systematic reviews and meta-analyses, evidence demonstrates reductions in postoperative pulmonary complications, including pneumonia and atelectasis, as well as modest decreases in hospital length of stay and improvements in inspiratory muscle strength. These effects were observed across multiple reviews, indicating that

respiratory prehabilitation is a relevant strategy to support perioperative recovery. Exercise-based programmes also improved functional capacity, although findings were more variable due to differences in intervention design, supervision, and duration.

In contrast, evidence for exercise-based and multimodal prehabilitation remains less certain. Heterogeneity in programme structure and methodological limitations contribute to inconsistent effects on outcomes such as ICU stay, postoperative atrial fibrillation, and mortality. Further high-quality cardiac-specific trials with standardised outcome reporting are required to clarify the role of broader prehabilitation strategies and guide their integration into cardiac surgical care.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/surgeries7020049/s1, Table S1: Full search strategies for all databases; Table S2: Excluded studies with reasons for exclusion; Table S3: Data extraction template for included systematic reviews; Table S4: Characteristics of included reviews; Table S5: Summary of findings across outcomes from included systematic reviews; Table S6: Methodological quality assessment of included reviews; Table S7: Matrix across included reviews; Table S8: Summary of intervention categories, representative reviews, outcomes, effect direction, certainty, and limitations.

Author Contributions: Conceptualisation; A.I.S.; methodology, M.L.K.; software, S.A.K.; validation, A.V.O. and D.S.; formal analysis. M.K.A.-A.; investigation, V.V.D.; resources, I.G.K.; data curation, A.I.S.; writing—original draft preparation, A.I.S. and V.V.D.; writing—review and editing, A.I.S. and M.L.K.; visualisation, I.G.K.; supervision, A.K.D.; project administration, A.V.O. and A.K.D.; funding acquisition, M.L.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The original contributions presented in this study are included in the article/Supplementary Materials. Further inquiries can be directed to the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

SR	Systematic Review
MA	Meta-analysis
RCT	Randomised Controlled Trial
PICOS	Population, Intervention, Comparator, Outcomes, Study design
AMSTAR-2	A Measurement Tool to Assess Systematic Reviews, version 2
GRADE	Grading of Recommendations Assessment, Development and Evaluation
CCA	Corrected Covered Area
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
MOOSE	Meta-analysis of Observational Studies in Epidemiology
CABG	Coronary Artery Bypass Grafting
PPCs	Postoperative Pulmonary Complications
LOS	Length of Stay
ICU	Intensive Care Unit
IMT	Inspiratory Muscle Training
RMT	Respiratory Muscle Training
6 MWD	Six-Minute Walk Distance
CPET	Cardiopulmonary Exercise Testing
Pi-max	Maximal Inspiratory Pressure
CENTRAL	Cochrane Central Register of Controlled Trials

MEDLINE	Medical Literature Analysis and Retrieval System Online
WoS	Web of Science
CINAHL	Cumulative Index to Nursing and Allied Health Literature
PEDro	Physiotherapy Evidence Database
LILACS	Latin American and Caribbean Health Sciences Literature
PCI	Percutaneous Coronary Intervention
TAVI	Transcatheter Aortic Valve Implantation

References

1. de Moura, J.F.C.; Oliveira, C.B.; Coelho Figueira Freire, A.P.; Elkins, M.R.; Pacagnelli, F.L. Preoperative respiratory muscle training reduces the risk of pulmonary complications and the length of hospital stay after cardiac surgery: A systematic review. *J. Physiother.* **2023**, *70*, 16–24. [CrossRef] [PubMed]
2. Zhang, S.; Li, B.; Meng, X.; Zuo, H.; Hu, D. The Effects of Inspiratory Muscle Training (IMT) on Patients Undergoing Coronary Artery Bypass Graft (CABG) Surgery: A Systematic Review and Meta-Analysis. *Rev. Cardiovasc. Med.* **2023**, *24*, 16. [CrossRef] [PubMed]
3. Neto, M.G.; Martinez, B.P.; Reis, H.F.C.; Carvalho, V.O. Pre- and postoperative inspiratory muscle training in patients undergoing cardiac surgery: Systematic review and meta-analysis. *Clin. Rehabil.* **2017**, *31*, 454–464. [CrossRef] [PubMed]
4. Wang, J.; Li, H.; Yan, W.; Xue, N.; Yin, J.; Nawsherwan; Yin, S. Prehabilitation Interventions for Cardiac Surgery to Prevent Postoperative Pulmonary Complications: Systematic Review and Meta-Analysis. *Iran. J. Public Health* **2024**, *53*, 2167–2179. [CrossRef]
5. Yau, D.K.W.; Underwood, M.J.; Joynt, G.M.; Lee, A. Effect of preparative rehabilitation on recovery after cardiac surgery: A systematic review. *Ann. Phys. Rehabil. Med.* **2021**, *64*, 101391. [CrossRef]
6. Snowdon, D.; Haines, T.P.; Skinner, E.H. Preoperative intervention reduces postoperative pulmonary complications but not length of stay in cardiac surgical patients: A systematic review. *J. Physiother.* **2014**, *60*, 66–77. [CrossRef]
7. Katsura, M.; Kuriyama, A.; Takeshima, T.; Fukuhara, S.; Furukawa, T.A. Preoperative inspiratory muscle training for postoperative pulmonary complications in adults undergoing cardiac and major abdominal surgery. *Cochrane Database Syst. Rev.* **2015**, *2015*, CD010356. [CrossRef]
8. Hurtado-Borrego, J.C.; Bayonas-Ruiz, A.; Bonacasa, B. Exercise-Based Prehabilitation Before Cardiac Surgery: A Systematic Review, Meta-Analysis, Meta-Regression, and Proposal for a Clinical Implementation Model. *J. Clin. Med.* **2025**, *14*, 8195. [CrossRef]
9. Assouline, B.; Cools, E.; Schorer, R.; Kayser, B.; Elia, N.; Licker, M. Preoperative exercise training to prevent postoperative pulmonary complications in adults undergoing major surgery: A systematic review and meta-analysis with trial sequential analysis. *Ann. Am. Thorac. Soc.* **2021**, *18*, 678–688. [CrossRef]
10. Kamarajah, S.K.; Bundred, J.; Weblin, J.; Tan, B.H.L. Critical appraisal on the impact of preoperative rehabilitation and outcomes after major abdominal and cardiothoracic surgery: A systematic review and meta-analysis. *Surgery* **2020**, *167*, 540–549. [CrossRef]
11. Mans, C.M.; Reeve, J.C.; Elkins, M.R. Postoperative outcomes following preoperative inspiratory muscle training in patients undergoing cardiothoracic or upper abdominal surgery: A systematic review and meta analysis. *Clin. Rehabil.* **2015**, *29*, 426–438. [CrossRef] [PubMed]
12. Zheng, Y.T.; Zhang, J.X. Preoperative exercise and recovery after cardiac surgery: A meta-analysis. *BMC Cardiovasc. Disord.* **2020**, *20*, 2. [CrossRef] [PubMed]
13. Ioannidis, J.P.A. Integration of evidence from multiple meta-analyses: A primer on umbrella reviews, treatment networks and multiple treatments meta-analyses. *CMAJ Can. Med. Assoc. J.* **2009**, *181*, 488–493. [CrossRef] [PubMed]
14. Lunny, C.; Pieper, D.; Thabet, P.; Kanji, S. Managing overlap of primary study results across systematic reviews: Practical considerations for authors of overviews of reviews. *BMC Med. Res. Methodol.* **2021**, *21*, 140. [CrossRef]
15. Page, M.J.; McKenzie, J.E.; Bossuyt, P.M.; Boutron, I.; Hoffmann, T.C.; Mulrow, C.D.; Shamseer, L.; Tetzlaff, J.M.; Akl, E.A.; Brennan, S.E.; et al. The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ* **2021**, *372*, 71. [CrossRef]
16. Stroup, D.F.; Berlin, J.A.; Morton, S.C.; Olkin, I.; Williamson, G.D.; Rennie, D.; Moher, D.; Becker, B.J.; Sipe, T.A.; Thacker, S.B. Meta-analysis of Observational Studies in Epidemiology: A Proposal for Reporting—Meta-analysis Of Observational Studies in Epidemiology (MOOSE) Group B. *JAMA Neurol.* **2000**, *283*, 2008–2012.
17. Schiavenato, M.; Chu, F. PICO: What it is and what it is not. *Nurse Educ. Pract.* **2021**, *56*, 103194. [CrossRef]
18. Stiefel, M.; Nolan, K. Measuring the Triple Aim: A Call for Action. *Popul. Health Manag.* **2013**, *16*, 219–220. [CrossRef]
19. Shea, B.J.; Reeves, B.C.; Wells, G.; Thuku, M.; Hamel, C.; Moran, J.; Moher, D.; Tugwell, P.; Welch, V.; Kristjansson, E.; et al. AMSTAR 2: A critical appraisal tool for systematic reviews that include randomised or non-randomised studies of healthcare interventions, or both. *BMJ* **2017**, *358*, j4008. [CrossRef]

20. Pollock, A.; Farmer, S.E.; Brady, M.C.; Langhorne, P.; Mead, G.E.; Mehrholz, J.; van Wijck, F.; Wiffen, P.J. An algorithm was developed to assign GRADE levels of evidence to comparisons within systematic reviews. *J. Clin. Epidemiol.* **2016**, *70*, 106–110. [CrossRef]
21. Schünemann, H.; Brożek, J.; Guyatt, G.; Oxman, A. *GRADE Handbook for Grading Quality of Evidence and Strength of Recommendations*; Updated October 2013; The GRADE Working Group: Hamilton, ON, Canada, 2013.
22. Ying, X.; Bougioukas, K.I.; Pieper, D.; Mayo-Wilson, E. Weighted corrected covered area (wCCA): A measure of informational overlap among reviews. *Res. Synth. Methods* **2025**, *16*, 701–708. [CrossRef] [PubMed]
23. Hennessy, E.A.; Johnson, B.T. Examining overlap of included studies in meta-reviews: Guidance for using the corrected covered area index. *Res. Synth. Methods* **2020**, *11*, 134–145. [CrossRef] [PubMed]
24. Hulzebos, E.H.J.; Smit, Y.; Helders, P.P.J.M.; van Meeteren, N.L.U. Preoperative physical therapy for elective cardiac surgery patients. *Cochrane Database Syst. Rev.* **2012**, *11*, CD010118. [CrossRef] [PubMed]
25. Karanfil, E.O.T.; Møller, A.M. Preoperative inspiratory muscle training prevents pulmonary complications after cardiac surgery—A systematic review. *Dan. Med. J.* **2018**, *65*, A5450.
26. Rodrigues, S.N.; Henriques, H.R.; Henriques, M.A. Effectiveness of preoperative breathing exercise interventions in patients undergoing cardiac surgery: A systematic review. *Rev. Port. Cardiol.* **2021**, *40*, 229–244. [CrossRef]
27. Shahood, H.; Pakai, A.; Kiss, R.; Eva, B.; Szilagyi, N.; Sandor, A.; Verzar, Z. Effectiveness of Preoperative Chest Physiotherapy in Patients Undergoing Elective Cardiac Surgery, a Systematic Review and Meta-Analysis. *Medicina* **2022**, *58*, 911. [CrossRef]
28. Cook, A.; Smith, L.; Anderson, C.; Ewing, N.; Gammack, A.; Pecover, M.; Sime, N.; Galley, H.F. The effect of Preoperative threshold inspiratory muscle training in adults undergoing cardiac surgery on postoperative hospital stay: A systematic review. *Physiother. Theory Pract.* **2023**, *39*, 690–703. [CrossRef]
29. Steinmetz, C.; Bjarnason-Wehrens, B.; Walther, T.; Schaffland, T.F.; Walther, C. Efficacy of Prehabilitation before Cardiac Surgery: A Systematic Review and Meta-analysis. *Am. J. Phys. Med. Rehabil.* **2023**, *102*, 323–330. [CrossRef]
30. Wang, J.; Wang, Y.-Q.; Shi, J.; Yu, P.-M.; Guo, Y.-Q. Effect of preoperative inspiratory muscle training on postoperative outcomes in patients undergoing cardiac surgery: A systematic review and meta-analysis. *World J. Clin. Cases* **2023**, *11*, 2981–2991. [CrossRef]
31. Hulzebos, E.H.J.; Helders, P.J.M.; Favié, N.J.; De Bie, R.A.; De La Riviere, A.B.; Van Meeteren, N.L.U. Preoperative intensive inspiratory muscle training to prevent postoperative pulmonary complications in high-risk patients undergoing CABG surgery: A randomized clinical trial. *JAMA* **2006**, *296*, 1851–1857. [CrossRef]
32. Weiner, P.; Zeidan, F.; Zamir, D.; Pelled, B.; Waizman, J.; Beckerman, M.; Weiner, M. Prophylactic inspiratory muscle training in patients undergoing coronary artery bypass graft. *World J. Surg.* **1998**, *22*, 427–431. [CrossRef]
33. Ferreira, P.E.G.; Rodrigues, A.J.; Évora, P.R.B. Effects of an inspiratory muscle rehabilitation program in the postoperative period of cardiac surgery. *Arq. Bras. Cardiol.* **2009**, *92*, 275–282. [CrossRef] [PubMed]
34. Carvalho, T.; Bonorino, K.C.; Panigas, T.F. Preoperative respiratory muscle training reduces complications in coronary artery bypass surgery. *Eur. Heart J.* **2011**, *32*, 382.
35. Savci, S.; Degirmenci, B.; Saglam, M.; Arikan, H.; Inal-Ince, D.; Turan, H.N.; Demircin, M. Short-term effects of inspiratory muscle training in coronary artery bypass graft surgery: A randomized controlled trial. *Scand. Cardiovasc. J.* **2011**, *45*, 286–293. [CrossRef] [PubMed]
36. Sobrinho, M.T.; Guirado, G.N.; Silva, M.A.d.M. Preoperative therapy restores ventilatory parameters and reduces length of stay in patients undergoing myocardial revascularization. *Rev. Bras. Cir. Cardiovasc.* **2014**, *29*, 221–228. [CrossRef]
37. Valkenet, K.; de Heer, F.; Backx, F.J.; Trappenburg, J.C.; Hulzebos, E.H.; Kwant, S.; van Herwerden, L.A.; van de Port, I.G. Effect of inspiratory muscle training before cardiac surgery in routine care. *Phys. Ther.* **2013**, *93*, 611–619. [CrossRef]
38. Chen, X.; Hou, L.; Zhang, Y.; Liu, X.; Shao, B.; Yuan, B.; Li, J.; Li, M.; Cheng, H.; Teng, L.; et al. The effects of five days of intensive preoperative inspiratory muscle training on postoperative complications and outcome in patients having cardiac surgery: A randomized controlled trial. *Clin. Rehabil.* **2019**, *33*, 913–922. [CrossRef]
39. Shakuri, S.K.; Salekzamani, Y.; Taghizadieh, A.; Sabbagh-Jadid, H.; Soleymani, J.; Sahebi, L.; Sahebi, R. Effect of Respiratory Rehabilitation before Open Cardiac Surgery on Respiratory Function: A Randomized Clinical Trial. *J. Cardiovasc. Thorac. Res.* **2015**, *7*, 13–17. [CrossRef]
40. Sandhu, M.S.; Akowuah, E.F. Does prehabilitation improve outcomes in cardiac surgical patients? *Interact. Cardiovasc. Thorac. Surg.* **2019**, *29*, 608–611. [CrossRef]
41. Ettema, R.G.A.; Van Koeven, H.; Peelen, L.M.; Kalkman, C.J.; Schuurmans, M.J. Preadmission interventions to prevent postoperative complications in older cardiac surgery patients: A systematic review. *Int. J. Nurs. Stud.* **2014**, *51*, 251–260. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.