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SYSTEMATIC REVIEW

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Different extubation protocols for adult cardiac surgery: a systematic review and pairwise and network meta-analysis

Ruo yu Luo[1,2], Ying Ying Fan[1,2], Meng Tian Wang[1], Chao Yun Yuan[1], Yuan Yuan Sun[1], Tian cha Huang[3] and Ji yong Jing[1*]

Abstract

Background With the advancement of ultra-fast track anesthesia, early extubation following cardiac surgery has become a prevailing trend. While there are significant benefits associated with early extubation, its high failure rate warrants further investigation, and the effectiveness of various extubation strategies in cardiac surgery still requires validation.

Methods An extensive literature search was performed in the PubMed, Scopus, Embase, and Web of Science databases, encompassing studies without language restrictions. Eligible studies were those that compared the outcomes of various extubation strategies.

Results Primary outcome was the success rate of the extubation protocol. Secondary outcomes were time to extubation, intensive care unit (ICU) length of stay (LOS), complications and mortality rate. Data from 12 studies, which included a total of 1454 participants, were included in the analysis. The pairwise meta-analysis revealed that late extubation was significantly more effective than immediate extubation strategies (relative risk [RR] = 1.52, 95% confidence interval [CI] = 1.21–1.91, P = 0.0001). In the network meta-analysis (NMA), the late extubation protocol was associated with a significantly lower risk of extubation failure compared to early extubation and extubation on the table (RR = 0.76, 95% CI: 0.5–1.16; RR = 0.22, 95% CI: 0.05–0.91). Furthermore, according to the SUCRA plot, late extubation was ranked as the most effective strategy for reducing extubation failure (94%).

Conclusions Our findings indicate that a late extubation strategy, as opposed to early (within a specified time frame) or immediate extubation, is correlate with a substantially higher rate of successful extubation. Despite this, the early extubation strategy seems to offer better cost-effectiveness and safety profiles. The selection of an appropriate extubation strategy should be personalized, taking into account the patient's preoperative characteristics and the circumstances encountered during surgery.

Trial registration The study protocol adheres to the PRISMA statement and checklist. The protocol was registered at PROSPERO (CRD42024529051).

Keywords Cardiac surgical procedures, Tracheal intubation, Anesthesia, General

*Correspondence:
Ji yong Jing
jiyong_jing@126.com
Full list of author information is available at the end of the article

Introduction

With the application of Ultra-Fast-Track Anesthesia (UFTA) in cardiac surgery, early extubation of patients following cardiac procedures has become a prevailing trend [1]. A wealth of research [2–4] has underscored the potential of early extubation in reducing the duration of intensive care unit stays and potentially decreasing the costs associated with cardiac surgeries. As the philosophy of Enhanced Recovery After Surgery (ERAS) continues to advance and be widely implemented, the expeditious recovery to autonomous breathing and the early extubation in cardiac surgery patients have emerged as focal points of research.

Although early ventilator weaning offers notable benefits, its high failure rates remain underexplored. Evidence [5] reveals a significant correlation between unsuccessful weaning and adverse outcomes post-cardiac surgery, such as extended hospitalization and escalated medical expenses, thereby hindering patient recovery. The failure rates of early ventilator weaning exhibit considerable variance among patients post-cardiac surgery, with rates spanning 11% [6] to 16% [7]. Despite progress in early weaning protocols, a significant 24% [8] of patients in the present study did not achieve successful weaning within the specified period. Moreover, the incidence of reintubation remains high, impacting between 32.1% [9] to 42.8% [10] of patients. Research [11] indicates that tracheal intubation, along with its accompanying laryngoscopic examination, may instigate unnecessary responses in the cardiovascular, respiratory, and other physiological systems.

The most recent expert consensus [12] suggests that the best strategies and management for early post-cardiac surgery extubation have yet to be systematically addressed, making the safety of various early extubation approaches a subject of ongoing debate. A study [13] that compared immediate extubation with extubation within 6 h post-surgery found an elevated risk of re-intubation due to bleeding, as well as a heightened need for subsequent surgery, in patients who underwent immediate extubation. Glossop et al.'s research [14] discovered that patients scheduled for extubation immediately after cardiac surgery or within a few hours post-surgery encountered significantly higher mortality rates, increased utilization of intensive care services, elevated hospital resource usage, and higher costs if postoperative respiratory complications necessitated re-intubation. Conversely, research conducted by Totonchi and colleagues [15] posits that immediate extubation could effectively reduce the expenses related to intensive care during cardiovascular surgeries while concurrently ensuring patient safety and mitigating adverse outcomes.

Thus, we performed a paired and network meta-analysis of high-quality Randomized Controlled Trials (RCTs) to compare clinical outcomes between delayed and early extubation, as well as across diverse extubation strategies. Our primary focus was on the failure rate of these strategies. We sought to determine which extubation approach is superior in terms of both cost-effectiveness and patient safety.

Materials & methods

We report our results following the Preferred Reporting Items for Systematic Reviews and Meta- Analyses (PRISMA) guidelines [16]. The study protocol adheres to the PRISMA statement and checklist. The protocol was registered at PROSPERO (CRD42024529051).

Information sources and search strategy

We implemented a search strategy in accordance with the PICO approach. We searched the PubMed, EMBASE, Web of Science, and Cochrane Library databases from their inception through to January 2025. The search parameters were: (P, population) Cardiac Surgical Procedures; (I, intervention) Immediate and early extubation; (C, control) Late extubation; (O, outcome) Incidence of extubation protocol failure. We used the following search blocks, translated into the appropriate search terms for each database: ("Cardiac Surgical Procedures " OR "Thoracic Surgery" OR "Coronary Artery Bypass" OR "coronary artery bypass graft" OR "valvular heart procedures" OR "heart transplantation" OR "Left ventricular assist device") AND ("Ultra-fast track anesthesia" OR "Extubating immediately" OR "intratracheal extubation" OR "tracheal extubation") (full search strategy per database is reported in Supplementary).

Eligibility criteria

A minimum of two reviewers (Luo and Fan) independently evaluated the search outcomes, accessed the full-text articles, and scrutinized the inclusion standards. In cases of ambiguity, a third reviewer (Jing) was consulted. We incorporated: (1) all randomized controlled trials involving adults (aged $\geq$ 18 years) who underwent cardiothoracic surgery; (2) studies that mandatorily incorporated a form of comparison between varying extubation strategies; (3) studies where outcome measures encompassed extubation failure rate (comprising failure to extubate within the stipulated timeframe and re-intubation), re-intubation rate, extubation duration, length of ICU stay, and incidence of complications; (4) studies without any linguistic constraints.

Study selection, data extraction, and outcome measures

Two independent researchers (Luo and Fan) screened the abstract and full-text articles for inclusion criteria using EndNote 20. Disagreements were resolved by the third author (Jing). Data extraction was performed by Luo using a structured Excel sheet and checked by Jing. The following data were extracted from each study: (1) study characteristics: publication year, first author, country, sample size; (2) participants characteristics: type of surgery, age, gender, smoking and lung disease); (3) interventions characteristics: extubation protocol, cardiopulmonary bypass (CPB) time, aortic clamping time, and opioid dosage; Currently, a standardized definition for early extubation is not established [3, 12]. For the purpose of our study, we delineate the following extubation protocols: immediate extubation, defined as extubation within the first hour post-operation; early extubation, defined as extubation between 1 to 8 h post-operation; and late extubation, defined as extubation occurring beyond 8 h post-operation;(4) outcome data: outcome measures and required outcome measures. In cases where means and standard deviations were not available, we calculated them from the available data according to the guidance of [17].

Risk-of-bias assessment

To assess the potential for bias in the studies, two reviewers conducted independent evaluations, while a third reviewer conducted assessments of randomized trials with the Cochrane Risk of Bias tool. This tool considers factors such as randomized sequence generation, allocation concealment, blinding (participant, person, and outcome), missing outcome data, selective outcome reporting, and other possible sources of bias. Ratings provided for each domain were categorized as "low risk of bias," "unclear," or "high risk of bias." The specific risk of bias is detailed in Fig S1 (located in the appendix).

Data synthesis and analyses

Pairwise meta-analyses

Review Manager (v5.4.0) software was used to perform the pairwise meta-analysis and assess the risk of bias of the included studies. We performed a paired meta-analysis of early ((including on-table extubation) and Late extubation strategies to compare the effects of different decannulation regimens in patients after cardiac surgery. We decided to use two effect sizes, Weighted mean difference (WMD) for the continuous outcomes of extubation time and length of stay in the ICU, and Relative risk (RR) for the binary outcomes of protocol failure and complication rates. Each effect size was accompanied by a 95% confidence interval, where a statistically significant result was indicated by a 95% CI excluding 1 for RR or excluding 0 for SMD and WMD [18].

Network meta-analysis

To further explore our primary outcome (the effect of different extubation protocols on patients after cardiac surgery), we performed a series of network meta-analyses using the mvmeta and network packages of Stata (v17.0). We compared three groups of extubation protocols: on-table extubation; Early extubation; Late extubation. We used network plots to compare different extubation protocols, with lines between dots representing direct comparisons and lines of different thicknesses representing comparisons between interventions of different sample sizes. Pairwise comparisons were visualized by forest plots and league plots, with a surface under the cumulative ranking (SUCRA) value used to estimate ranking probability, where higher SUCRA values indicate a higher likelihood of a superior ranking. Publication bias was assessed by egger test using Stata (v17.0). $P < 0.05$ was considered statistically significant publication bias. Simultaneously, we utilized the PRISMA 2020 Checklist to minimize bias [19].

Heterogeneity of the network was assessed using the I^2 statistic. Within- and between-network inconsistency was evaluated using the Q statistic. To reduce the heterogeneity of this study, we ensured consistency in the definitions of various indicators during the data extraction process. Additionally, for network meta-analysis, we employed a random effects model; for traditional meta-analysis, we used a fixed effects model when $I^2 > 50\%$, and a random effects model when $I^2 < 50\%$.

Subgroup analyses

To mitigate heterogeneity in our study, we ensured consistency in defining various indicators during data extraction. Additionally, we employed a random-effects model.

To investigate the sources of heterogeneity, we also performed the following subgroup analyses of pairwise and network meta-analyses:(1) studies with and without reporting lung diseases; (2) whether there were studies reporting smoking status; (3) age > 60 and ≤ 60; (4) whether the CBP time was more than 80 min; (5) whether the aortic clamping time was > 55 min; (6) dose of opioids(We divided opioid doses into low versus high doses according to Rong's study [20]).

Finally, to assess the robustness of our findings, we performed a sensitivity analysis, excluding one study with significantly longer extubation time and ICU length of stay.

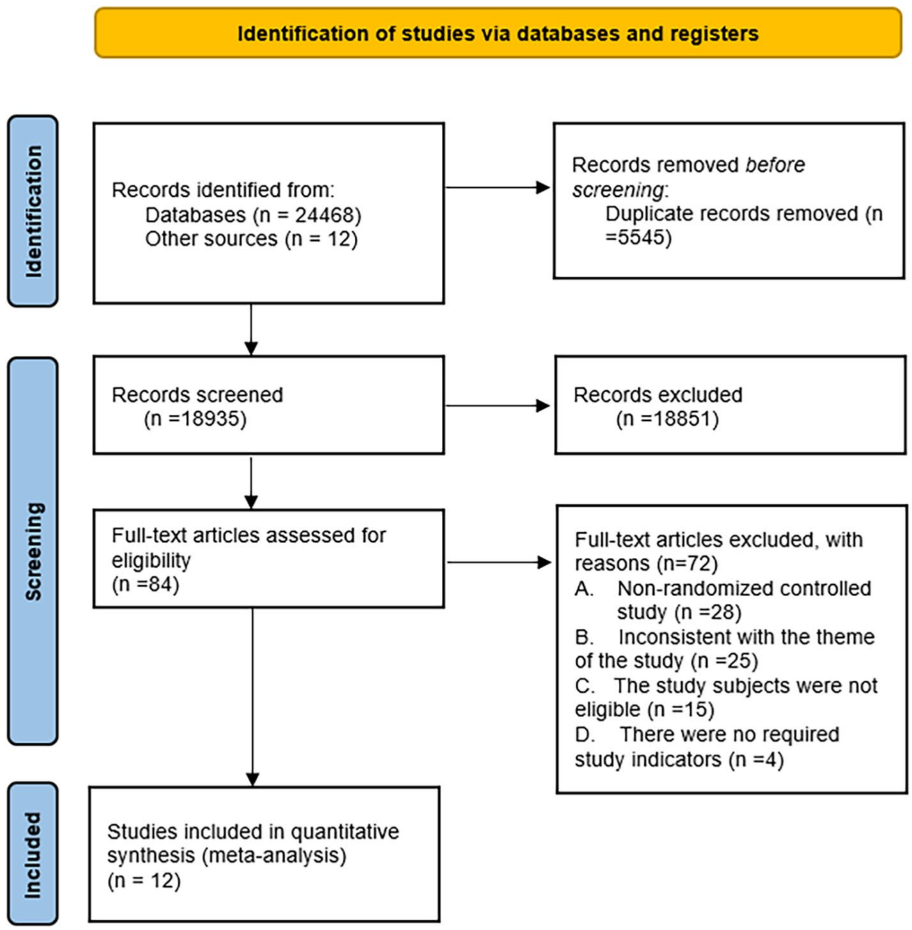

Fig. 1 PRISMA 2020 flow diagram for selecting the articles in this systematic review

Assessment of evidence certainty

We employed the Grading of Recommendations, Assessment, Development, and Evaluations (GRADE) method to assess the certainty of the evidence pertaining to direct, indirect, and network estimates, categorizing it as having high, moderate, low, or very low certainty. Seven critical factors were taken into account for downgrading the certainty, encompassing the risk of bias, inconsistencies, indirectness, potential publication bias, intransitivity, incoherence, and imprecision [21, 22]. Detailed results are provided in Table S3 in the Appendix.

Results

Characteristics of included studies

Among the 24,480 articles we retrieved, 12 full-text articles were included in this study [9, 10, 15, 23–31], and the specific screening process is shown in Fig. 1. 12 studies involving 1454 patients (immediate extubation group, $n=148$; Early extubation group, $n=625$; Conventional group, $n=681$). Most trials (8/12) compared early versus late extubation, two studies compared immediate versus usual decannulation, and two studies compared immediate versus early decannulation protocols. Supplementary Table 2 summarizes the characteristics of the included studies.

Primary outcome: the incidence of extubation protocol failure

Pairwise meta-analysis

Eight articles reported on the incidence of extubation failure in a total of 1270 patients (late extubation group, $n=635$; early extubation group, $n=635$). As depicted in Fig. 2, a forest plot of the results, early extubation indicated a statistically significant advantage over late extubation (RR = 1.52, 95% CI = 1.21—1.91, $p<0.001$), and no substantial heterogeneity was observed among the studies included (I^2 = 0%). Similarly, Fig. 3 presents the evidence of publication bias, as revealed by the Egger regression test ($P=0.042$, $P<0.05$). It should be noted, however, that our review included fewer than ten studies, a factor that may limit the comprehensiveness of our findings.

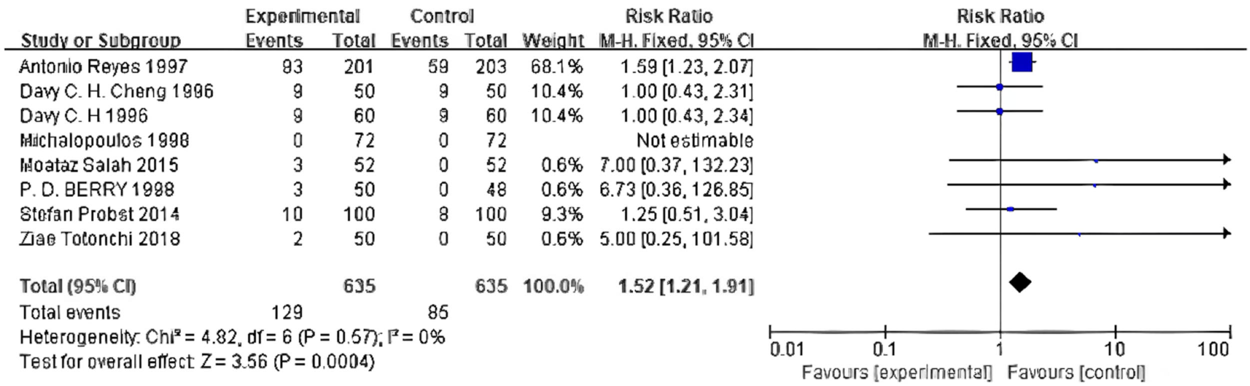

Fig. 2 Incidence of extubation protocol failure (primary outcome) from pairwise meta-analyses of forest plots

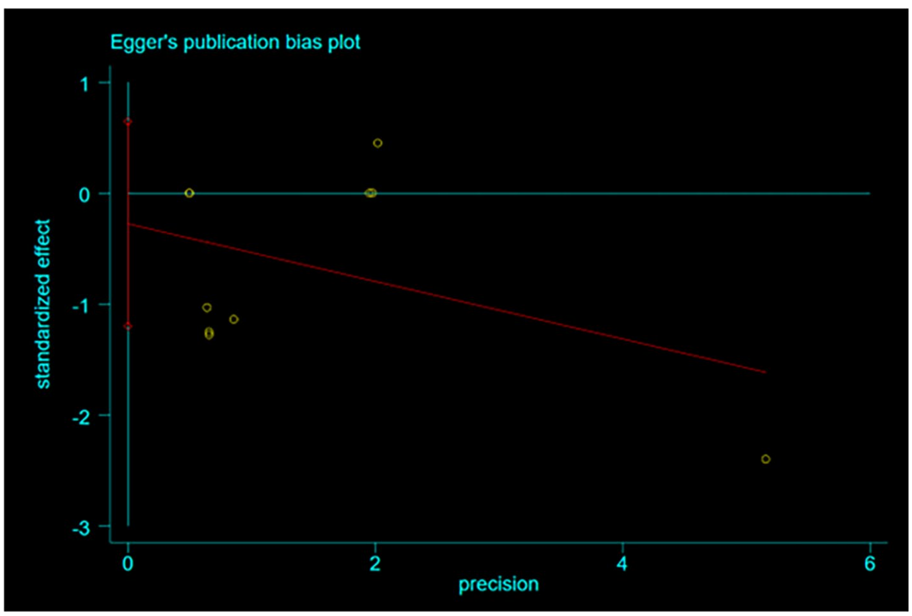

Fig. 3 The egger's test of the incidence of extubation protocol failure (primary outcome)

Network meta-analyses

As depicted in the Network Plot (Fig. 4), three extubation strategies are interconnected within a closed loop. Two studies conducted a direct comparison between late extubation and immediate extubation, another two studies compared early extubation with immediate extubation, and six studies compared late extubation with early extubation. The failure rates of the three extubation strategies were as follows: for late extubation, 13.7% (87 out of 635); for early extubation, 21.2% (123 out of 580); and for immediate extubation, 6% (9 out of 150). According to our Forest Plot (Fig. 5) and League Plot (Fig. 6), in terms of the extubation strategy failure rate, late extubation outperforms both early and immediate extubation (RR = 0.76, 95% CI: 0.5–1.16; RR = 0.22, 95% CI: 0.05—0.91). The SCURA ranking plot (Fig. 7) shows that late extubation is the most effective strategy in minimizing extubation failure rates, with an effectiveness rate of 94.0%. The results across different segments are generally consistent, with P-values all exceeding 0.05.

Secondary outcomes

Time to extubation

Eight studies, involving a total of 1,117 patients, reported on the timing of extubation. Our forest plot (Supplementary Fig. S2) demonstrates that early extubation significantly reduces the time to extubation compared to late extubation (MD = −11.33, 95% CI: −15.25 ~ −7.41,

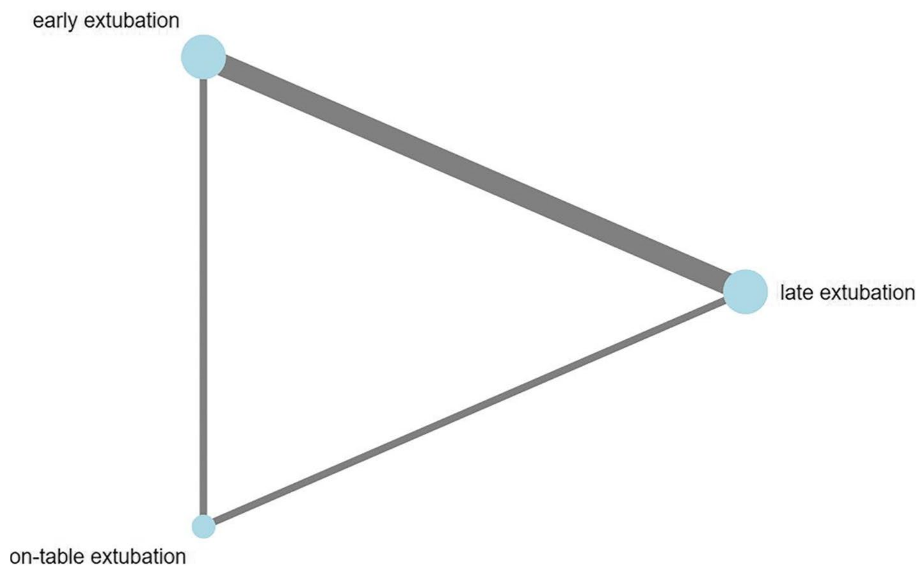

Fig. 4 Network plots of the incidence of extubation protocol failure (primary outcome). Each node represents the different extubation protocols in the trial, the size of the node is proportional to the number of patients receiving that start time, and the thickness of the edge is proportional to the number of trials

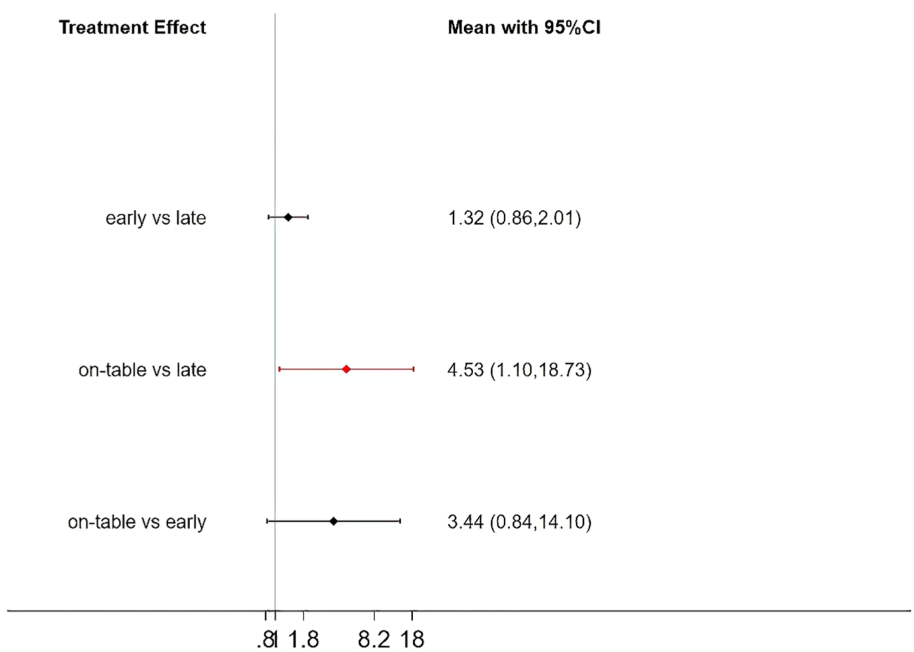

Fig. 5 Forest plot for the incidence of extubation protocol failure (primary outcome). CI- confidence interval

$p < 0.001$). There was notable heterogeneity among the included studies (I2 = 100%). In the network meta-analysis, three extubation strategies formed a closed loop, facilitating nine comparisons. The network meta-analysis further indicated that, in terms of extubation time, early extubation was the most beneficial strategy compared to late extubation and immediate extubation (MD = −17.66, 95% CI: −34.21 ~ −1.11;Md = 1.29, 95% CI: −3 0.19 ~ 32.78;SCURA = 75.6%), as revealed by our forest plot (Supplementary Fig. S4) and SCURA ranking (Supplementary Fig. S5). The segmented results were overall consistent, with all p-values > 0.05. Furthermore,

late extubation	1.32 (0.86,2.01)	4.53 (1.10,18.73)
0.76 (0.50,1.16)	early extubation	3.44 (0.84,14.10)
0.22 (0.05,0.91)	**0.29 (0.07,1.19)**	on-table extubation

Fig. 6 League table for the change in the incidence of extubation protocol failure (primary outcome). The left lower field presents the results of the network meta-analysis; the right upper field presents the results of pairwise meta-analyses. The data in each cell is RR (95% CI) comparing row definition processing and column definition processing. RR < 1 or RR > 1 indicates better results. The results in bold are significant

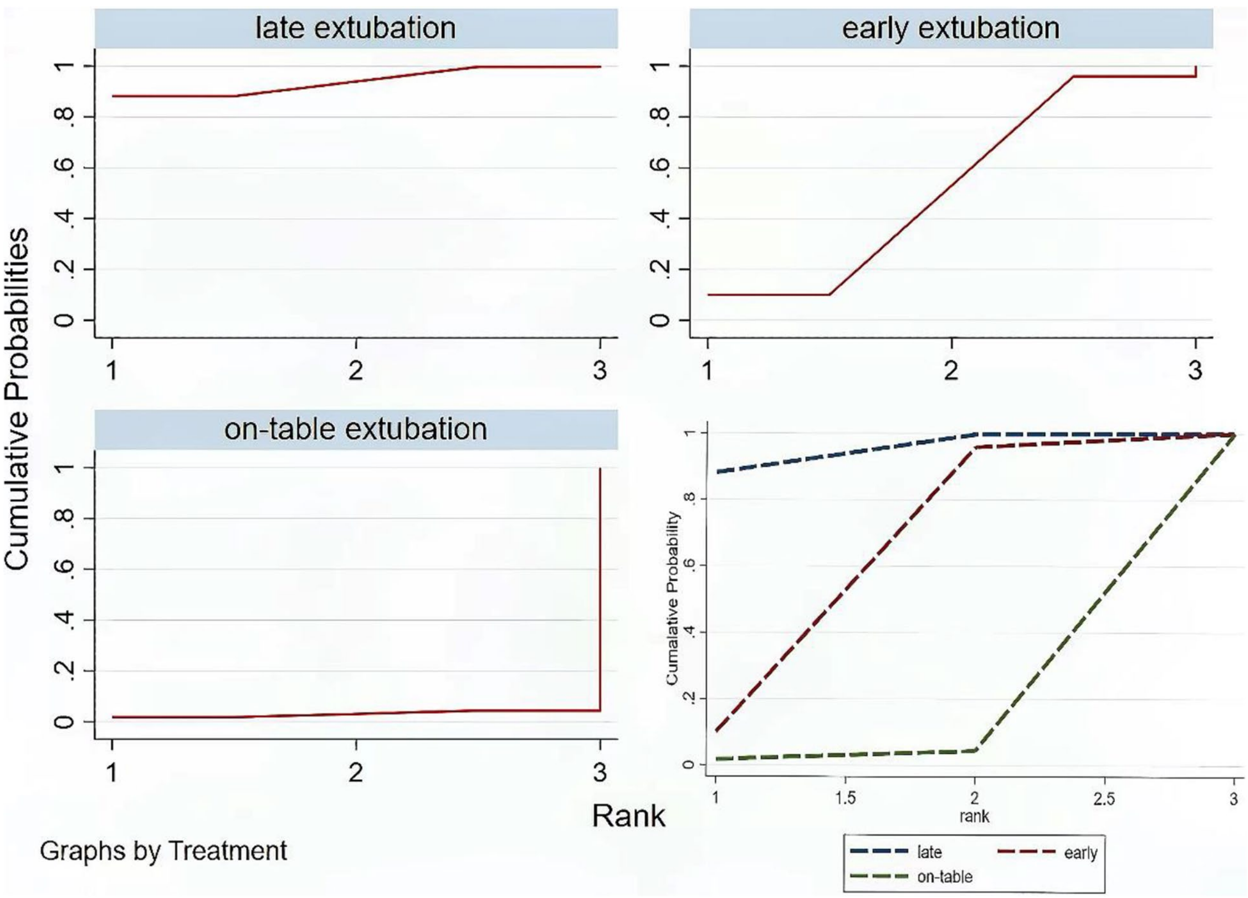

Fig. 7 Ranking diagram of the incidence of extubation protocol failure (primary outcome)

the Egger regression test ($P = 0.08 > 0.05$) from Supplementary Fig. S6 did not reveal evidence of publication bias.

Length of ICU stay

A total of six studies, involving 1,070 patients, reported on the ICU length of stay. Our forest plot outcome (Supplementary Fig. S7) demonstrates that early extubation is superior to late extubation in reducing the ICU length of stay, with a significant difference noted between the groups (MD = −16.17, 95% CI: −21.71 ~ −10.63, $P < 0.001$). Substantial heterogeneity was observed among the included studies ($I^2 = 99\%$). Network meta-analysis provided additional insights, indicating that the three extubation strategies did not form a closed network for direct comparison, rendering six pairwise comparisons possible. According to our SCURA ranking (Supplementary Fig. S10), early extubation is the most advantageous strategy in terms of reducing the ICU length of stay (SCURA = 77.7%). The Egger regression analysis, depicted in Supplementary Fig. S11, indicated potential publication bias ($P = 0.025, < 0.05$). However, fewer than ten studies were incorporated into this review.

Complications

A total of seven studies detailed complications, involving 1097 patients. Our forest plot (Supplementary Fig. S12) illustrates that early extubation is more effective than late extubation in mitigating complications, with a statistically significant variance between the two groups (RR = 0.77, 95% CI: 0.67 ~ 0.88, $P = < 0.01$). No substantial heterogeneity was observed across the included studies (I^2 = 37%).The network meta-analysis further demonstrated that the three extubation strategies — late, early, and immediate — form a loop that enables nine comparisons. The prevalence of complications in the late, early, and immediate extubation groups were 46.3% (268/579), 33.5% (192/573), and 27% (27/100) respectively. Our league table (Supplementary Fig. S15) presents that the early extubation strategy outperforms both immediate and late extubation in terms of minimizing complications (RR = 0.59, 95% CI: 0.38 ~ 0.94; RR = 0.75, 95% CI: 0.65 ~ 0.86). Similarly, our SCURA plot (Supplementary Fig. S16) indicates that early extubation is the most successful strategy in reducing the incidence of complications (99.4%).The findings across the segments were generally aligned, with all P values > 0.05. Furthermore, the Egger regression test ($P = 0.08 > 0.05$) found no evidence of publication bias (Supplementary Fig. S17).

Mortality rate

Four investigations, encompassing a cohort of 781 patients, provided data on mortality rates. The late extubation group exhibited a mortality rate of 2.05% (8 out of 390), while in the early extubation group, the mortality rate was observed to be 0.51% (2 out of 391). As depicted in our forest plot (Supplementary Fig. S18), no statistically significant divergence was seen between the two groups (RR = 0.33, 95% CI: 0.09 ~ 1.23, $P = 0.39$), and the studies included demonstrated no significant heterogeneity (I2 = 0%). Due to the limited number of studies reporting on mortality rates (only those offering a comparison between early and late extubation), a network meta-analysis was not conducted for this particular outcome.

Subgroup analyses

In 12 studies, the age of the patient was reported, with a particular focus on patients aged ≤ 60 in four of these studies. The forest plot (Supplementary Fig. S85) reveals a significant correlation between applying an immediate extubation strategy for patients aged ≤ 60 and a marked reduction in the duration of ICU stays (MD = −26.61; 95% CI: −40.63 to −12.59; MD = −22.18; 95% CI: −41.18 to −3.18). This trend is also observed in the SCURA results (Supplementary Fig. S86), indicating a high degree of confidence (SCURA = 99.5%).

CBP time for patients were documented in ten studies, with four of these investigations presenting CBP time of less than or equal to 80 min. As indicated by both the Forest plot (Supplementary Fig. S91) and SCURA data analysis (Supplementary Fig. S92), an immediate extubation approach may significantly reduce the duration to extubation in patients with an CBP time less than or equal to 80 min (MD = −10.63, 95% Confidence Interval (CI): −14.95 to −6.32; MD = −4.55, 95% CI: −8.82 to −0.82; SCURA = 89.1%).

After excluding studies that demonstrated significant elongation in extubation times and Intensive Care Unit (ICU) stays, a sensitivity analysis was performed. Results from our Forest plot (Supplementary Fig. S135) and SCURA data analysis (Supplementary Fig. S136) suggest that an immediate extubation strategy correlates with a decreased length of ICU stay (Mean Difference (MD) = −26.53, 95% Confidence Interval (CI): −39.96 to −13.10; MD = −18.70, 95% CI: −35.41 to −1.99; SCURA = 98.8%). Outcomes were not significantly impacted by other subgroup analyses or sensitivity analyses. Refer to the appendix for a comprehensive overview of the subgroup analysis results.

Discussion

Despite the progress made in early extubation strategies, the failure and re-intubation rates associated with these protocols remain notably high. Our principal findings illustrate that strategies involving late extubation yield a higher success rate compared to those involving immediate or early extubation, a conclusion supported by robust evidence. According to the multicenter retrospective study by Etchill and colleagues, compared to early ICU extubation, patients who were extubated in the operating room demonstrated a higher incidence of reintubation (5.2% vs 2.9%, $P = 0.003$), reoperation due to bleeding (1.5% vs 0.7%, $P < 0.01$), and pneumonia (1.9%) [1]. Late extubation permits a thorough evaluation of a patient's readiness for extubation, encompassing aspects such as respiratory function, hemodynamic stability, and overall recovery status, thereby mitigating the risks linked to premature extubation [32]. Research [24, 33] has suggested that immediate or early extubation post-cardiac surgery can escalate cardiac and respiratory load, precipitating hemodynamic instability and an augmented release of catecholamines. Such physiological changes may amplify sympathetic nervous system activity, exacerbate myocardial ischemia, or trigger the onset of respiratory failure. The novel short-acting anesthetic, remimazolam, demonstrates superior hemodynamic stability and a lower risk of respiratory depression, suggesting its potential compatibility with immediate extubation protocols [34, 35].

Early and immediate extubation strategies are correlated with higher incidences of protocol non-compliance. Nevertheless, in terms of safety and cost-effectiveness, these strategies offer significant advantages over late extubation. Early extubation, in comparison to immediate and late extubation, notably reduces the timeframe until extubation and shortens the duration of ICU stay. Implementing early extubation enables a more regulated, step-by-step process of transitioning from mechanical ventilation. Performing extubation in an ICU setting facilitates close patient monitoring for potential signs of respiratory distress or hemodynamic instability, subsequently minimizing the duration of both mechanical ventilation and ICU stay. Research [3, 10, 36], has demonstrated a correlation between early extubation and decreased ICU stay duration, without an associated increase in postoperative complications. In contrast, immediate extubation may increase the likelihood of extubation failure or necessitate re-intubation, as the patient may not have had sufficient time to recuperate from the impacts of anesthesia and surgery—resulting in an elevated risk of respiratory complications and the imperative for re-intubation [10, 37, 38]. Our research outcomes are consistent with a 2016 review [39] which asserted that early removal of the tracheal tube after cardiac surgery diminishes ICU stay duration, minimizes dependency on nursing and critical care resources, curtails operating room expenses, and ultimately reduces total hospitalization costs [33]. Our results also suggest that immediate extubation, could potentially shorten the duration of ventilator usage and reduce the length of ICU stay. However, we postulate that this approach's effectiveness may vary among different patient demographics. According to our subgroup analysis, immediate extubation appears to be more beneficial for younger patients and those with shorter CBP times. As younger patients typically possess superior physiological resilience, they tend to recover more swiftly from anesthesia and surgical stress [40, 41]. Similarly, patients with shorter CBP times have been associated with a reduced inflammatory response and a lower risk of organ dysfunction [42], hence, they are less likely to experience complications such as respiratory failure or hemodynamic instability. Recent studies have shown that minimally invasive extracorporeal circulation strategies (MiECC) can mitigate systemic inflammatory response syndrome (SIRS) induced by cardiopulmonary bypass [43, 44]. Concurrently, research [45] has found that corticosteroids, with their potent anti-inflammatory properties and multi-effect inhibitory action on the components of extracorporeal circulation-induced inflammation, can alleviate CBP-induced SIRS. As such, anesthesiologists and clinical decision-makers might consider immediate extubation strategies for younger patients, those undergoing MiECC, or those with relatively lower risk, in conjunction with the use of corticosteroids to reduce the incidence of SIRS. This approach could potentially lower the risk of complications, enhance hemodynamic stability, and align with accelerated recovery protocols.

In the context of safety, early extubation appears to confer potential benefits by reducing the incidence of complications, with no discernible difference in mortality rates. Early extubation protocols are typically implemented in the ICU within hours post-surgery. The execution of extubation within the ICU environment, coupled with continuous intra-arterial blood pressure monitoring via arterial catheterization, allows for setting appropriate mean arterial pressure (MAP) targets based on individual patient needs. This vigilant monitoring can help identify potential signs of respiratory distress or hemodynamic instability, consequently minimizing the duration of mechanical ventilation and ICU stay [46]. Conversely, immediate extubation post-cardiac surgery may escalate cardiac and respiratory burdens, potentially intensifying myocardial ischemia or precipitating respiratory failure, thereby amplifying the potential for complications [36]. On the other hand, undue delay in extubation may also increase the incidence of specific complications, which can include accidental tracheal tube dislodgement, aspiration-induced pulmonary hypertension crisis, the requirement for additional sedatives and analgesics, and the onset of ventilator-associated pneumonia [33].

Our review is subject to several limitations. Firstly, the quality of the incorporated studies is of concern, with only 17% of the trials involving more than 100 patients per group. Due to the interventional nature of these studies, it is difficult to implement blinding techniques or conceal treatment allocation, which may introduce bias into the results. Secondly, our study is characterized by heterogeneity, which could potentially impact our findings. However, we utilized a random effects model and conducted subgroup and sensitivity analyses to identify and reduce the influence of this heterogeneity. Despite these measures, we cannot pinpoint all sources of heterogeneity. Thirdly, some of our secondary outcomes may be subject to publication bias, potentially affecting these results. However, these outcomes incorporated fewer than ten studies, a factor which may limit the comprehensiveness of our findings. Lastly, our network meta-analysis, even though it forms a closed loop, is constrained by the limited number of studies directly comparing immediate extubation and early extubation (with only two studies), potentially affecting the validity of the results.

Conclusion

Among three distinct extubation strategies, late extubation displays a notably higher success rate compared to early and immediate extubation. However, when considering cost-effectiveness and safety, the results from early and immediate extubation seem to surpass those of late extubation. Further, it is crucial for anesthesiologists and clinical decision-makers to adapt extubation strategies based on the specific conditions of patients. The plan for immediate extubation is recommended for patients who are younger, have shorter CBP times, or present relatively lower risks. At present, there is a scarcity of extensive research related to immediate extubation plans. Future research should undertake larger-scale, more standardized randomized clinical trials to investigate these three extubation strategies and produce high-quality evidence.

Abbreviations

ICU	Intensive care unit
LOS	Length of stay
RR	Relative risk
CI	Confidence interval
NMA	Network meta-analysis
WMD	Weighted mean difference
SCURA	Surface under the cumulative ranking

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12871-025-02952-z.

Supplementary Material 1.

Acknowledgements

No

Authors' contributions

We the undersigned declare that this manuscript entitled "Different extubation protocols for adult cardiac surgery: A systematic review and pairwise/network meta-analysis" is original, has not been published before and is not currently being considered for publication elsewhere. We would like to draw the attention of the Editor to the following publications of one or more of us that refer to aspects of the manuscript presently being submitted. Where relevant copies of such publications are attached. We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us. We understand that the Corresponding Author is the sole contact for the Editorial process. He is responsible for communicating with the other authors about progress, submissions of revisions and final approval of proofs. Signed by all authors.

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Data availability

All data generated or analysed during this study are included in this published article [and its supplementary information files].

Declarations

Ethics approval and consent to participate

Dear Editors.

The Ethics Committee of the Zhejiang Provincial People's Hospital conducts work in strict accordance with ICH-GCP. GCP and relevant regulations. and performs the duties of ethical review or life sciences and medical researches involving humans.

The paper Different extubation protocols for adult cardiac surgery: A systematic review and pairwise/network meta-analysis- submitted by Luoruo Yu from our hospital to your journal is meta-analysis. it does not need to review according to current ethical standards. it does not necessitate obtaining informed consent from the participating individuals.

Ethics committee

Zhejiang Provincial People's Hospital.

Aug 23,2024.

Consent for publication

We the undersigned declare that this manuscript entitled "Different extubation protocols for adult cardiac surgery: A systematic review and pairwise/network meta-analysis" is original, has not been published before and is not currently being considered for publication elsewhere. We would like to draw the attention of the Editor to the following publications of one or more of us that refer to aspects of the manuscript presently being submitted. Where relevant copies of such publications are attached. We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us. We understand that the Corresponding Author is the sole contact for the Editorial process. He is responsible for communicating with the other authors about progress, submissions of revisions and final approval of proofs. Signed by all authors as follows: Luo Ruo Yu (MD)1,2, Fan Ying Ying (MD)1,2, Wang Meng Tian (MD)1, Yuan Chao Yun (MD)1, Sun Yuan Yuan (MD)1, Huang Tian Cha (MD)3, Jing Ji Yong (MD)1* (Corresponding Author).

Our research constitutes a systematic meta-analysis, which does not involve the inclusion of patient images or any personal or clinical specifics pertaining to the participants. As such, obtaining patient consent for publication is not required in this case. Not Applicable.

Competing interests

The authors declare no competing interests.

Author details

[1]Zhejiang Provincial People'S Hospital, People'S Hospital of Hangzhou Medical College, No. 158 Shangtang Rd, Hangzhou, Zhejiang 310014, China. [2]School of Nursing, Zhejiang Chinese Medical University, Zhejiang 310053, China. [3]Intensive Care Unit, the Second Affiliated Hospital, School of Medicine, Zhejiang University, Zhejiang Province, Hangzhou, China.

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