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Comparative Evaluation of the Incidence of Postoperative Pulmonary Complications After Minimally Invasive Valve Surgery vs. Full Sternotomy: A Systematic Review and Meta-Analysis of Randomized Controlled Trials and Propensity Score-Matched Studies

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Background: Postoperative pulmonary complications remain a leading cause of increased morbidity, mortality, longer hospital stays, and increased costs after cardiac surgery; therefore, our study aims to analyze whether minimally invasive valve surgery (MIVS) for both aortic and mitral valves can improve pulmonary function and reduce the incidence of postoperative pulmonary complications when compared with the full median sternotomy (FS) approach.

Methods: A comprehensive systematic literature research was performed for studies comparing MIVS and FS up to February 2021. Randomized controlled trials (RCTs) and propensity score-matching (PSM) studies comparing early respiratory function and pulmonary complications after MIVS and FS were extracted and analyzed. Secondary outcomes included intra- and postoperative outcomes.

Results: A total of 10,194 patients from 30 studies (6 RCTs and 24 PSM studies) were analyzed. Early mortality differed significantly between the groups (MIVS 1.2 vs. FS 1.9%; $p = 0.005$). Compared with FS, MIVS significantly lowered the incidence of postoperative pulmonary complications (odds ratio 0.79, 95% confidence interval [0.67, 0.93]; $p = 0.004$) and improved early postoperative respiratory function status (mean difference −24.83 [−29.90, −19.76]; $p < 0.00001$). Blood transfusion amount was significantly lower after MIVS ($p < 0.02$), whereas cardiopulmonary bypass time and aortic cross-clamp time were significantly longer after MIVS ($p < 0.00001$).

Conclusions: Our study showed that minimally invasive valve surgery decreases the incidence of postoperative pulmonary complications and improves postoperative respiratory function status.

Keywords: cardiac surgery, minimally invasive, valve repair/replacement, meta-analysis (as topic), full sternotomy

INTRODUCTION

Full median sternotomy (FS) has long been the standard incision for cardiac surgery due to it is excellent exposure of the heart and great vessels. However, to reduce the size of the sternotomy, cardiac surgeons have long pursued less extensive incisions to improve outcomes and thus have used minimally invasive approaches that have undergone rapid development in the last

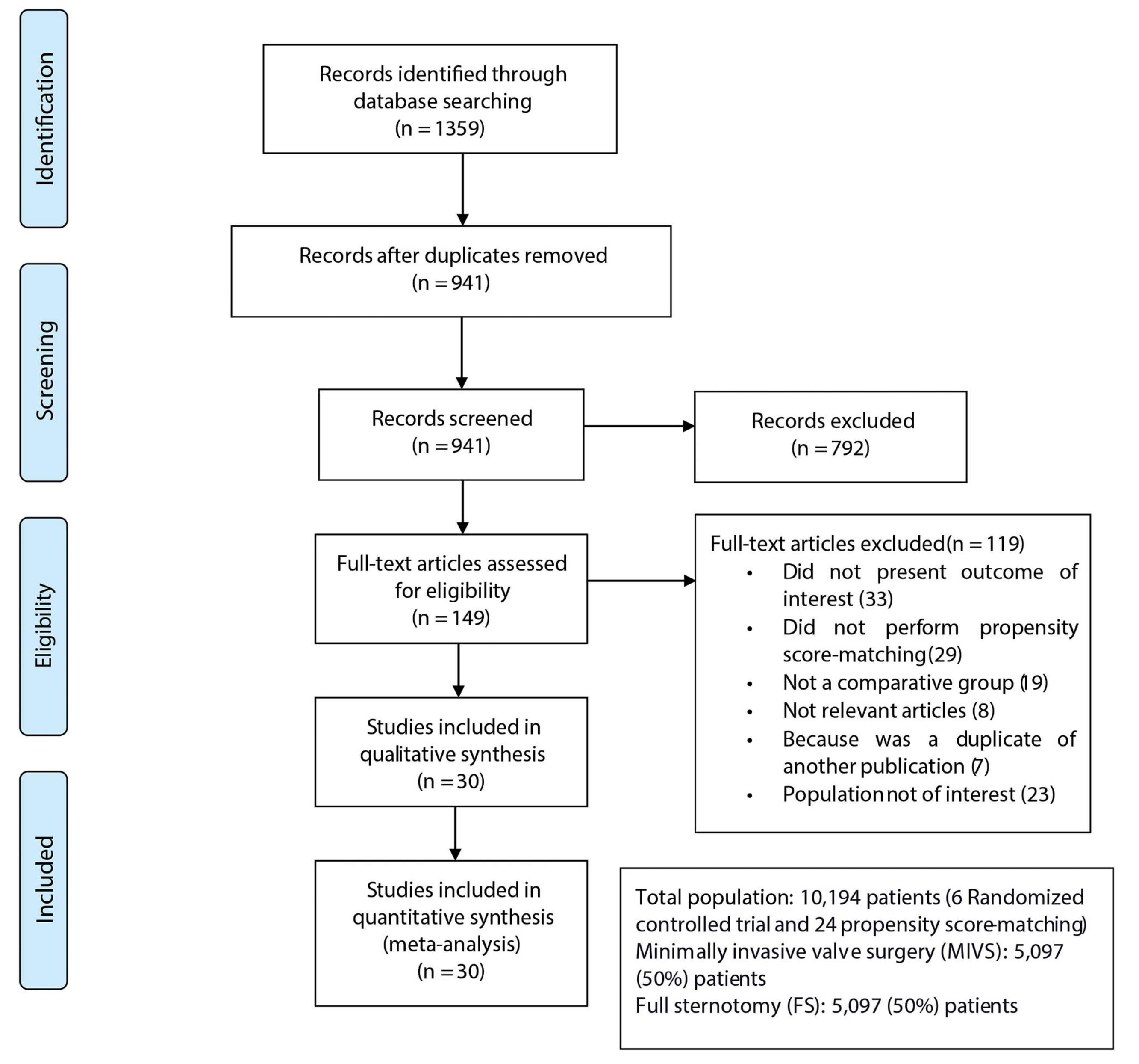

FIGURE 1 | Flowchart for studies included in data search in accordance with PRISMA guidelines.

few decades (1–3). These approaches have multiple benefits over an FS because of a smaller surgical incision, reduced pain, earlier discharge, and quicker postoperative recovery (4, 5). On the other hand, some potential technical disadvantages tend to have prolonged cardiopulmonary bypass (CPB) and aortic cross-clamp time (6, 7).

Given such developments in surgical management and patients' treatment over the years, postoperative pulmonary complications remain a leading cause of mortality and morbidity following cardiac surgery (8, 9). These complications contribute to longer hospital stays and more readmissions into the ICU, significantly affecting health care and increasing healthcare systems' financial burden (8, 10). Atelectasis and pleural effusions, pneumonia, pneumothorax, diaphragm paralysis because of phrenic nerve damage, and pulmonary infection are the most common pulmonary complications (11).

Although considerable benefits were associated with the MIVS over FS, there is still ongoing debate about the advantage of MIVS on postoperative pulmonary complications (PPCs), and the associations remain unclear. To our knowledge, there is still limited evidence on PPCs and respiratory system function analysis of patients after MIVS compared with the FS approach has not been analyzed. Therefore, based on the existing clinical literature, we conducted this systematic review and meta-analysis of high-quality randomized controlled trials (RCTs) and propensity score-matched (PSM) studies to analyze the incidence of PPCs and respiratory function of patients who underwent a minimally invasive approach for mitral or aortic valve vs. FS.

TABLE 1 | Characteristics of included studies.

References	Country	Study interval	Study type	No. of patients MIVS/FS	Surgical approach	Quality assessment	LOE[†]	Median follow-up
Aris et al. (6)	Spain	NS	RCT	20/20	A φ	3/5	2b	6 days
Machler et al. (28)	Austria	1996–1997	RCT	30/30	A φ	3/5	2b	294 days[M]
Bonacchi et al. (14)	Italy	1999–2001	RCT	40/40	A φ	4/5	1b	9.7 ± 5.7 months[M]
Dogan et al. (16)	Germany	2003–2004	RCT	20/20	M §	2/5	3b	NS
Moustafa et al. (5)	Egypt	NS	RCT	30/30	A φ	2/5	3b	NS
Calderon et al. (15)	France	2003–2007	RCT	39/39	A φ	5/5	2b	NS
Albacker et al. (12)	US	1995–2010	PSM	223/223	A §	7	4	2 years
Masiello et al. (29)	Italy	1997–1999	PSM	100/100	A φ	6	3b	1 month
Farhat et al. (17)	France	2000–2001	PSM	50/50	A φ	7	3b	1 month
Tabata et al. (37)	US	1996–2005	PSM	41/41	A φ	7	3b	NS
Iribarne et al. (25)	US	2000–2008	PSM	382/382	M §	8	3b	4.2 ± 2.4 yrs[M]
Holzhey et al. (24)	Germany	1999–2009	PSM	143/143	M §	8	1b	2.4 ± 2.1 yrs[M]
Bang et al. (13)	Korea	1997–2010	PSM	73/73	A ϕ	7	3b	NS
Murzi et al. (31)	Italy	2006–2010	PSM	100/100	A θ	6	2b	3 years
Sansone et al. (32)	Italy	2008–2010	PSM	50/50	A θ	7	3b	NS
Johnston et al. (26)	US	1995–2004	PSM	832/832	A φ	8	3a	6.5 ± 3.0 years[M]
Gilmanov et al. (20)	Italy	2004–2011	PSM	182/182	A θ	7	3b	Until patient discharge
Hiraoka et al. (23)	Japan	2007–2012	PSM	36/36	A ϕ	7	4	NS
Ghanta et al. (19)	US	2011–2013	PSM	289/289	A ϕ	6	4	NS
Gilmanov et al. (21)	Italy	2001–2013	PSM	100/100	A θ	8	3a	33.7 months[M]
Merk et al. (30)	Germany	2003–2012	PSM	477/477	A φ	6	3a	3.1 ± 2.7 years[M]
Shehada et al. (34)	Germany	2002–2012	PSM	585/585	A φ	7	3b	NS
Stoliński et al. (36)	Canada	2010–2013	PSM	211/211	A θ	8	3b	NS
Gasparovic et al. (18)	Slovakia	2010–2013	PSM	34/34	A φ	7	3a	5 years
Levack et al. (27)	US	1995–2014	PSM	483/483	A φ	8	3b	NS
Stolinski et al. (35)	Poland	2011–2014	PSM	212/212	A θ	8	3a	3 months
Seitz et al. (33)	Australia	2013–2016	PSM	53/53	A θ	7	3b	NS
Hawkins et al. (22)	US	2011–2016	PSM	74/74	M §	7	3b	NS
Wang et al. (38)	China	2012–2015	PSM	67/67	M §	6	3a	2.8 years
Zhao et al. (39)	China	2013–2016	PSM	91/91	C δ	8	3a	1 year

A, Aortic valve; C, indicated both mitral and aorta valve; FS, full sternotomy; LOE, level of evidence; MIVS, minimally invasive valve surgery; M, mitral valve; [M], mean; NS, not specified; PSM, propensity score-matching; RCT, randomized control trial; θ, indicates aortic valve surgery right mini-thoracotomy; φ, indicates aortic valve surgery upper mini-sternotomy; ϕ, indicated aortic valve surgery right mini-thoracotomy and upper mini-sternotomy; δ, indicated both mitral and aorta valve surgery right mini-thoracotomy; §, indicated mitral valve surgery right mini-thoracotomy; [†]Based on US Preventive Services Task Force grading system.

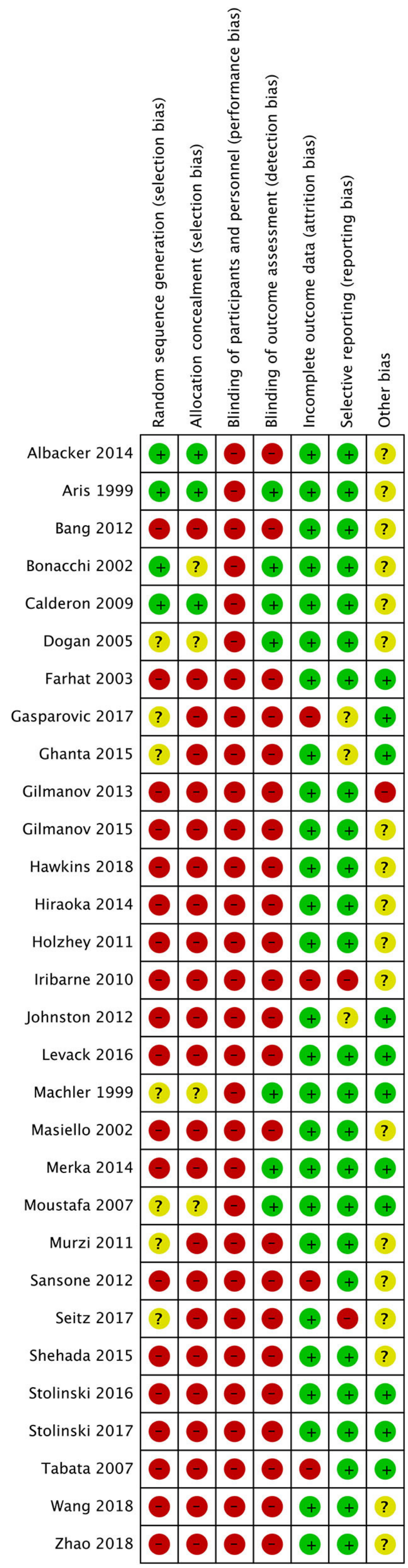

FIGURE 2 | Risk of bias assessment summary.

METHODS

Selection Criteria

We included all articles reporting clinical outcomes for MIVS (repair or replacement of the mitral valve, aortic valve, or both valves) via right/lateral mini-thoracotomy or mini-sternotomy, with either a camera or direct visualization, vs. traditional FS. Studies were considered using a PICOS (Population, Intervention, Comparison, Outcome, and Study) strategy if (1) articles were published in English, (2) articles reported RCTs or PSM studies, (3) articles compared the outcomes of MIVS and FS for either mitral or aortic valve disease, and (4) outcomes included postoperative pulmonary complications and early postoperative respiratory function.

Articles without a full report available, review studies, studies with previous cardiac surgery and concomitant surgical procedures (coronary artery bypass grafting, and procedure involving ascending aortic) other than isolated mitral and aortic or both valve surgery were excluded and studies with no comparison group were also excluded.

Information Sources

The following databases were used: PubMed, MEDLINE, Web of Science, Cochrane Central Register of Controlled Trials, Scopus, and Google Scholar. The reference lists of identified articles were also included in manual searches.

Search Strategy

We searched articles and studies comparing FS vs. MIVS using the following medical subject headings: aortic valve, aortic valve surgery, mitral valve or mitral valve surgery, minimally/partial invasive, full/conventional/partial sternotomy or mini-sternotomy, anterolateral/right mini-thoracotomy, partial upper Hemi-sternotomy or upper mini-sternotomy.

Study Selection

Search strategies, inclusion with exclusion criteria, statistical analysis, and outcomes were predefined. Thirty publications fulfilled our eligibility criteria (5, 6, 12–39). Two independent investigators (MA, SZ) reviewed all abstracts that fulfilled the search criteria. When there were differences of opinion between these investigators, other authors were included to resolve disagreements. **Figure 1** summarizes the search strategy.

Data Extraction

Two reviewers independently extracted data from each included study and performed the quality assessment. Data extracted included the first author's name, year of publication, country, study interval, study type, the number of subjects who underwent MIVS or FS, and outcomes of interest. The following clinical outcomes of interest from each study were extracted to compare MIVS with FS: postoperative pulmonary complications (overall complications, pneumonia, pleural effusion, pneumothorax, pulmonary infection, and respiratory insufficiency), early postoperative pulmonary function variables after 1 week (forced expiratory volume in 1 second [FEV1], forced total lung capacity (TLC), and forced vital capacity [FVC%]). Secondary outcomes of interest included early mortality, blood transfusion and, cardiopulmonary bypass (CPB) time, aortic cross-clamp time, and operative time.

Risk-of-Bias and Study Quality Assessment

Two independent reviewers (SZAS and NID) assessed the risk-of-bias using the Cochrane risk-of-bias (RoB2) tool. The risk-of-bias was categorized as low, high, or unclear risk-of-bias. The RoB2 Excel tool was applied to individual studies, and results were entered into Cochrane's Review Manager 5.3 (40). The Newcastle–Ottawa Scale (NOS) was used to assess the methodological quality of all observational studies. The NOS assesses the following characteristics of a study: selection of the general population, comparability, and adequate assessment of outcomes, to evaluate the methodological quality of studies (41). Based on the NOS, a maximum of 9 points can be given to each study. In this review, the modified NOS scores $\geq$ 7 were considered to indicate high-quality publications. Furthermore, the methodological quality of RCTs was assessed using the Jadad scale, which evaluates RCT quality using a maximum score of 5. A Jadad score $\geq$ 3 was considered to indicate high-quality RCTs (42).

Definitions of Outcomes

MIVS was defined as any procedure not performed with an FS. A full sternotomy was performed from the sternal notch to the xiphoid process. The definitions of the postoperative outcomes mainly depend on the descriptions mentioned in the original articles (8, 18, 39, 43–45). Besides postoperative pulmonary complications were defined as complications occurring in the postoperative period and producing clinical diseases, such as pneumonia, pleural effusion, pneumothorax, pulmonary infection, and respiratory insufficiency (defined as the need for reintubation or tracheostomy after initial extubation), and prolonged ventilation time, which was defined as mechanical ventilatory support requirement for more than 24 h. Pulmonary function tests, represented by FEV1, TLC, and FVC, were assessed based on a spirometry test 1 week after surgery. The incidence of early mortality was defined as death in the hospital or within 30 days post-surgery.

Statistical Analysis

As per Cochrane Collaboration guidelines, all statistical meta-analyses were performed using Review Manager 5.3 software (Cochrane Collaboration, Copenhagen, Denmark). We calculated pooled odds ratios (ORs) with their 95% confidence intervals (CIs) for dichotomous data, which are presented as numbers and percentages. Weighted mean differences (WMDs) were used to assess continuous data, which are presented as means $\pm$ standard deviation or medians with interquartile ranges. We assessed the heterogeneity of studies by means of I^2 and chi-square test. As a sensitivity analysis, FS and MIVS from RCTs and from PSM studies were compared separately. The reported results all are two-sided, and a $p < 0.05$ was considered to indicate statistical significance.

TABLE 2 | Overall and subgroup analysis of postoperative respiratory function and complications comparing MIVS and FS.

Outcome of interest	n/N	No. patients MIVS/FS	Overall effect	*P*	Study heterogeneity			
			WMD/OR (95% CI)†		chi²-test	df	$I^{2\ (\%)}$	*P*-value
Postoperative respiratory function status after 1 week								
Overall spirometry	6 (1,928)	964/964	MD −24.83 [−29.90,-19.76]†	<0.00001	11770.40	13	100	<0.00001
Subgroup analysis								
FEV1%	6 (722)	361/361	−74.06 [−89.14, −58.99]†	<0.00001	1089.82	5	100	<0.00001
FVC%	5 (642)	321/321	4.99 [1.23, 8.75]†	0.009	287.63	4	99	<0.00001
TLC	3 (564)	282/2,282	8.39 [2.00, 14.78]†	0.01	72.03	2	97	<0.00001
Overall PPCs	30 (10,194)	5,097/5,097	0.79 [0.67, 0.93]	0.004	28.51	27	5	0.39
RCT	6 (418)	209/209	OR 0.32 [0.12, 0.90]	0.03	4.29	4	7	0.37
PSM	24 (9,776)	4,888/4,888	OR 0.80 [0.69, 0.94]	0.005	20.98	22	0	0.52
Subgroup analysis								
Pneumonia	5 (916)	458/458	1.42 [0.44, 4.55]	0.56	2.81	4	0	0.59
Pleural Effusion	8 (1,454)	727/727	0.81 [0.45, 1.45]	0.47	10.28	7	32	0.17
Pneumothorax	4 (420)	210/210	1.55 [0.30, 8.12]	0.60	4.50	3	33	0.21
Respiratory insufficient	12 (5,848)	2,924/2,924	0.75 [0.62, 0.91]	0.004	9.30	11	0	0.59
Pulmonary infection	2 (246)	123/123	1.35 [0.16, 11.30]	0.78	1.24	1	19	0.27
Prolonged ventilation time	10 (3,564)	1,782/1,782	0.72 [0.51, 1.01]	0.06	6.92	9	0	0.65

n, number of studies; N, number of participants; MIVS, minimally invasive valve surgery; FS, full sternotomy; PPC, postoperative pulmonary complications; WMD, weighted mean difference; OR, odds ratio; CI, confidence interval; I^2, test of heterogeneity; FEV1, forced expiratory volume in 1 s; FVC, Forced vital capacity; TLC, total lung capacity; †Values of WMD.

RESULTS

Characteristics of Eligible Studies

Our literature search revealed 30 studies that met our selection criteria (5, 6, 12–39). The total number of patients in these studies was 10,194; 5,097 (50%) patients underwent MIVS, and 5,097 (50%) patients underwent FS. Six studies were RCTs (n = 418 patients) (5, 6, 14–16, 28) and 24 were PSM studies (n = 9,776 patients) (12, 13, 17–27, 29–39). The characteristics of these studies are shown in **Table 1**. **Figure 1** shows the PRISMA flowchart of the search and selection strategy (46).

The RCTs scored at least 3 out of 5 on the Jadad scale, and most of the PSM studies scored at least 7 out of 9, based on a modified version of the NOS scale (**Table 1** and **Figure 2**). Therefore, overall, the studies were considered to be of high quality.

Postoperative Pulmonary Complications Outcomes

We analyzed data on postoperative pulmonary complications from 27 studies (6, 12–14, 16–34, 36–39). The overall complications were less in MIVS patients than in FS patients (OR

Study or Subgroup	MIVS Events	MIVS Total	FS Events	FS Total	Weight	Odds Ratio M-H, Random, 95% CI
1.3.1 Randomized controlled trials (RCT)						
Aris 1999	1	20	0	20	0.2%	3.15 [0.12, 82.16]
Bonacchi 2002	3	40	7	40	1.3%	0.38 [0.09, 1.60]
Calderon 2009	0	39	0	39		Not estimable
Dogan 2005	1	20	2	20	0.4%	0.47 [0.04, 5.69]
Machler 1999	1	60	12	60	0.6%	0.07 [0.01, 0.54]
Moustafa 2007	0	30	1	30	0.2%	0.32 [0.01, 8.24]
Subtotal (95% CI)		**209**		**209**	**2.8%**	**0.32 [0.12, 0.90]**
Total events	6		22			
Heterogeneity: Tau² = 0.10; Chi² = 4.29, df = 4 (P = 0.37); I² = 7%						
Test for overall effect: Z = 2.17 (P = 0.03)						
1.3.2 Propensity-matched observational studies (POS)						
Albacker 2014	9	223	18	223	3.7%	0.48 [0.21, 1.09]
Bang 2012	3	73	1	73	0.5%	3.09 [0.31, 30.38]
Farhat 2003	0	50	1	50	0.3%	0.33 [0.01, 8.21]
Gasparovic 2017	3	34	4	34	1.0%	0.73 [0.15, 3.52]
Ghanta 2015	26	289	25	289	7.1%	1.04 [0.59, 1.86]
Gilmanov 2013	24	182	22	182	6.2%	1.10 [0.59, 2.05]
Gilmanov 2015	24	100	22	100	5.6%	1.12 [0.58, 2.16]
Hawkins 2018	5	74	8	74	1.9%	0.60 [0.19, 1.92]
Hiraoka 2014	1	36	0	36	0.3%	3.08 [0.12, 78.27]
Holzhey 2011	22	143	22	143	5.8%	1.00 [0.53, 1.90]
Iribarne 2010	17	382	29	382	6.3%	0.57 [0.31, 1.05]
Johnston 2012	24	832	45	832	9.0%	0.52 [0.31, 0.86]
Levack 2016	10	483	12	483	3.5%	0.83 [0.36, 1.94]
Masiello 2002	7	100	5	100	1.8%	1.43 [0.44, 4.67]
Merka 2014	52	477	67	477	14.0%	0.75 [0.51, 1.10]
Murzi 2011	3	100	4	100	1.1%	0.74 [0.16, 3.41]
Sansone 2012	6	50	0	50	0.3%	14.75 [0.81, 269.34]
Seitz 2017	3	53	3	53	1.0%	1.00 [0.19, 5.19]
Shehada 2015	50	585	69	585	14.2%	0.70 [0.48, 1.03]
Stolinski 2016	28	211	36	211	8.1%	0.74 [0.44, 1.27]
Stolinski 2017	0	212	0	212		Not estimable
Tabata 2007	1	41	3	41	0.5%	0.32 [0.03, 3.18]
Wang 2018	5	67	3	67	1.2%	1.72 [0.39, 7.51]
Zhao 2018	18	91	13	91	4.0%	1.48 [0.68, 3.23]
Subtotal (95% CI)		**4888**		**4888**	**97.2%**	**0.80 [0.69, 0.94]**
Total events	341		412			
Heterogeneity: Tau² = 0.00; Chi² = 20.98, df = 22 (P = 0.52); I² = 0%						
Test for overall effect: Z = 2.82 (P = 0.005)						
Total (95% CI)		**5097**		**5097**	**100.0%**	**0.79 [0.67, 0.93]**
Total events	347		434			
Heterogeneity: Tau² = 0.01; Chi² = 28.51, df = 27 (P = 0.39); I² = 5%						
Test for overall effect: Z = 2.88 (P = 0.004)						
Test for subgroup differences: Chi² = 2.97, df = 1 (P = 0.08), I² = 66.3%						

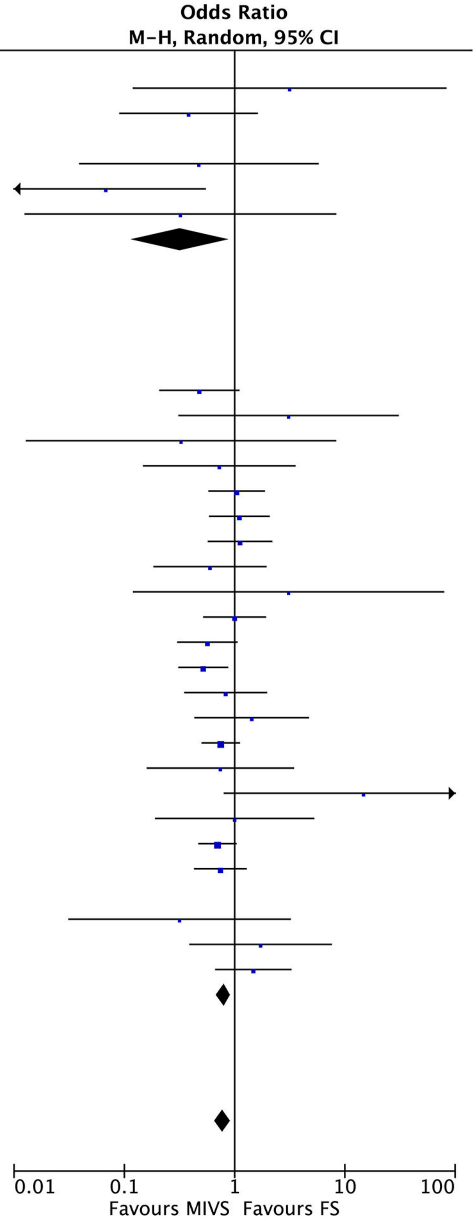

FIGURE 3 | Forest plot demonstrating the overall study incidence of postoperative pulmonary complications between MIVS and FS.

Study or Subgroup	MIVS Events	MIVS Total	FS Events	FS Total	Weight	Odds Ratio M-H, Random, 95% CI
1.2.1 Pneumonia						
Dogan 2005	1	20	0	20	0.2%	3.15 [0.12, 82.16]
Gilmanov 2015	2	100	0	100	0.2%	5.10 [0.24, 107.62]
Hawkins 2018	1	74	2	74	0.4%	0.49 [0.04, 5.56]
Seitz 2017	1	53	2	53	0.4%	0.49 [0.04, 5.58]
Stolinski 2016	3	211	1	211	0.4%	3.03 [0.31, 29.35]
Subtotal (95% CI)		**458**		**458**	**1.7%**	**1.42 [0.44, 4.55]**
Total events	8		5			
Heterogeneity: Tau² = 0.00; Chi² = 2.81, df = 4 (P = 0.59); I² = 0%						
Test for overall effect: Z = 0.59 (P = 0.56)						
1.2.2 Pleural effusion						
Aris 1999	1	20	0	20	0.2%	3.15 [0.12, 82.16]
Dogan 2005	0	20	1	20	0.2%	0.32 [0.01, 8.26]
Gasparovic 2017	3	34	4	34	0.9%	0.73 [0.15, 3.52]
Gilmanov 2013	10	182	5	182	1.9%	2.06 [0.69, 6.14]
Gilmanov 2015	4	100	5	100	1.3%	0.79 [0.21, 3.04]
Machler 1999	1	60	12	60	0.5%	0.07 [0.01, 0.54]
Masiello 2002	6	100	5	100	1.5%	1.21 [0.36, 4.11]
Stolinski 2016	25	211	35	211	7.5%	0.68 [0.39, 1.18]
Subtotal (95% CI)		**727**		**727**	**14.2%**	**0.81 [0.45, 1.45]**
Total events	50		67			
Heterogeneity: Tau² = 0.21; Chi² = 10.28, df = 7 (P = 0.17); I² = 32%						
Test for overall effect: Z = 0.72 (P = 0.47)						
1.2.3 Pneumothorax						
Bonacchi 2002	2	40	3	40	0.7%	0.65 [0.10, 4.11]
Dogan 2005	0	20	1	20	0.2%	0.32 [0.01, 8.26]
Masiello 2002	1	100	0	100	0.2%	3.03 [0.12, 75.28]
Sansone 2012	6	50	0	50	0.3%	14.75 [0.81, 269.34]
Subtotal (95% CI)		**210**		**210**	**1.4%**	**1.55 [0.30, 8.12]**
Total events	9		4			
Heterogeneity: Tau² = 0.96; Chi² = 4.50, df = 3 (P = 0.21); I² = 33%						
Test for overall effect: Z = 0.52 (P = 0.60)						
1.2.4 Respiratory insufficient						
Albacker 2014	9	223	18	223	3.4%	0.48 [0.21, 1.09]
Bonacchi 2002	1	40	2	40	0.4%	0.49 [0.04, 5.60]
Ghanta 2015	26	289	25	289	7.0%	1.04 [0.59, 1.86]
Gilmanov 2015	14	100	10	100	3.1%	1.47 [0.62, 3.47]
Hiraoka 2014	1	24	0	24	0.2%	3.13 [0.12, 80.68]
Holzhey 2011	22	143	22	143	5.6%	1.00 [0.53, 1.90]
Johnston 2012	24	832	45	832	9.0%	0.52 [0.31, 0.86]
Merka 2014	52	477	67	477	15.4%	0.75 [0.51, 1.10]
Seitz 2017	2	53	1	53	0.4%	2.04 [0.18, 23.19]
Shehada 2015	50	585	69	585	15.7%	0.70 [0.48, 1.03]
Wang 2018	3	67	5	67	1.1%	0.58 [0.13, 2.54]
Zhao 2018	2	91	3	91	0.7%	0.66 [0.11, 4.04]
Subtotal (95% CI)		**2924**		**2924**	**61.9%**	**0.75 [0.62, 0.91]**
Total events	206		267			
Heterogeneity: Tau² = 0.00; Chi² = 9.30, df = 11 (P = 0.59); I² = 0%						
Test for overall effect: Z = 2.89 (P = 0.004)						
1.2.5 Pulmonary infection						
Bang 2012	3	73	1	73	0.4%	3.09 [0.31, 30.38]
Farhat 2003	0	50	1	50	0.2%	0.33 [0.01, 8.21]
Subtotal (95% CI)		**123**		**123**	**0.7%**	**1.35 [0.16, 11.30]**
Total events	3		2			
Heterogeneity: Tau² = 0.49; Chi² = 1.24, df = 1 (P = 0.27); I² = 19%						
Test for overall effect: Z = 0.28 (P = 0.78)						
1.2.7 Prolonged ventilation time						
Bonacchi 2002	0	40	2	40	0.2%	0.19 [0.01, 4.09]
Ghanta 2015	5	289	6	289	1.6%	0.83 [0.25, 2.75]
Gilmanov 2013	4	182	9	182	1.6%	0.43 [0.13, 1.43]
Gilmanov 2015	4	100	7	100	1.4%	0.55 [0.16, 1.95]
Hawkins 2018	4	74	6	74	1.3%	0.65 [0.18, 2.40]
Iribarne 2010	17	382	29	382	6.1%	0.57 [0.31, 1.05]
Levack 2016	10	483	12	483	3.2%	0.83 [0.36, 1.94]
Murzi 2011	3	100	4	100	1.0%	0.74 [0.16, 3.41]
Tabata 2007	1	41	3	41	0.4%	0.32 [0.03, 3.18]
Zhao 2018	16	91	10	91	3.2%	1.73 [0.74, 4.04]
Subtotal (95% CI)		**1782**		**1782**	**20.1%**	**0.72 [0.51, 1.01]**
Total events	64		88			
Heterogeneity: Tau² = 0.00; Chi² = 6.92, df = 9 (P = 0.65); I² = 0%						
Test for overall effect: Z = 1.90 (P = 0.06)						
Total (95% CI)		**6224**		**6224**	**100.0%**	**0.77 [0.66, 0.90]**
Total events	340		433			
Heterogeneity: Tau² = 0.00; Chi² = 37.07, df = 40 (P = 0.60); I² = 0%						
Test for overall effect: Z = 3.39 (P = 0.0007)						
Test for subgroup differences: Chi² = 2.24, df = 5 (P = 0.82), I² = 0%						

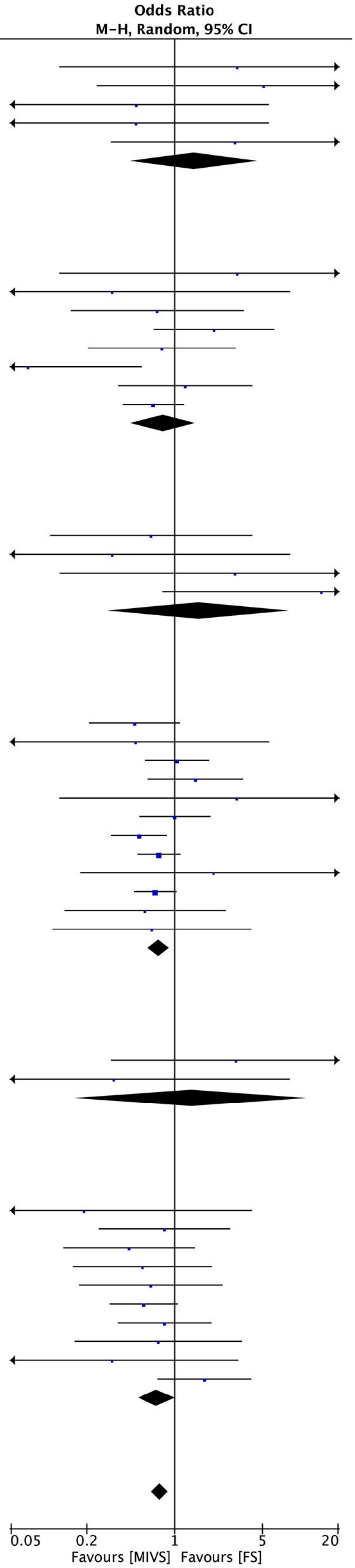

FIGURE 4 | Forest plot demonstrating the subgroup study of the incidence of postoperative pulmonary between MIVS and FS.

Study or Subgroup	MIVS Mean	MIVS SD	MIVS Total	FS Mean	FS SD	FS Total	Weight	Mean Difference IV, Random, 95% CI
1.1.1 FEV1% after 1 week								
Aris 1999	62	16	20	526	12	20	6.2%	−464.00 [−472.77, −455.23]
Bonacchi 2002	80.8	18.6	40	81.7	21.5	40	6.2%	−0.90 [−9.71, 7.91]
Calderon 2009	53.4	15.6	39	55	16	39	6.7%	−1.60 [−8.61, 5.41]
Dogan 2005	1.9	0.8	20	1.7	0.6	20	7.6%	0.20 [−0.24, 0.64]
Moustafa 2007	80.47	0.51	30	78.47	0.51	30	7.6%	2.00 [1.74, 2.26]
Stolinski 2017	79.5	10.1	212	74	11.3	212	7.5%	5.50 [3.46, 7.54]
Subtotal (95% CI)			**361**			**361**	**41.9%**	**−74.06 [−89.14, −58.99]**
Heterogeneity: $Tau^2 = 346.15$; $Chi^2 = 10894.82$, df = 5 (P < 0.00001); $I^2 = 100\%$								
Test for overall effect: Z = 9.63 (P < 0.00001)								
1.1.2 FVC% after 1 week								
Aris 1999	60	17	20	53	12	20	6.1%	7.00 [−2.12, 16.12]
Calderon 2009	55.9	14.1	39	57.9	15.2	39	6.8%	−2.00 [−8.51, 4.51]
Dogan 2005	2.5	0.9	20	2.1	0.8	20	7.6%	0.40 [−0.13, 0.93]
Moustafa 2007	91.5	0.51	30	86.6	0.95	30	7.6%	4.90 [4.51, 5.29]
Stolinski 2017	64.8	8.8	212	51.5	11.1	212	7.5%	13.30 [11.39, 15.21]
Subtotal (95% CI)			**321**			**321**	**35.7%**	**4.99 [1.23, 8.75]**
Heterogeneity: $Tau^2 = 14.34$; $Chi^2 = 287.63$, df = 4 (P < 0.00001); $I^2 = 99\%$								
Test for overall effect: Z = 2.60 (P = 0.009)								
1.1.3 TLC after 1 week								
Bonacchi 2002	65.9	10	40	59.6	8.3	40	7.3%	6.30 [2.27, 10.33]
Moustafa 2007	65.5	0.51	30	60.5	0.51	30	7.6%	5.00 [4.74, 5.26]
Stolinski 2017	67.1	7.5	212	53.3	13	212	7.5%	13.80 [11.78, 15.82]
Subtotal (95% CI)			**282**			**282**	**22.4%**	**8.39 [2.00, 14.78]**
Heterogeneity: $Tau^2 = 30.23$; $Chi^2 = 72.03$, df = 2 (P < 0.00001); $I^2 = 97\%$								
Test for overall effect: Z = 2.57 (P = 0.01)								
Total (95% CI)			**964**			**964**	**100.0%**	**−24.83 [−29.90, −19.76]**
Heterogeneity: $Tau^2 = 87.70$; $Chi^2 = 11770.40$, df = 13 (P < 0.00001); $I^2 = 100\%$								
Test for overall effect: Z = 9.60 (P < 0.00001)								
Test for subgroup differences: $Chi^2 = 104.02$, df = 2 (P < 0.00001), $I^2 = 98.1\%$								

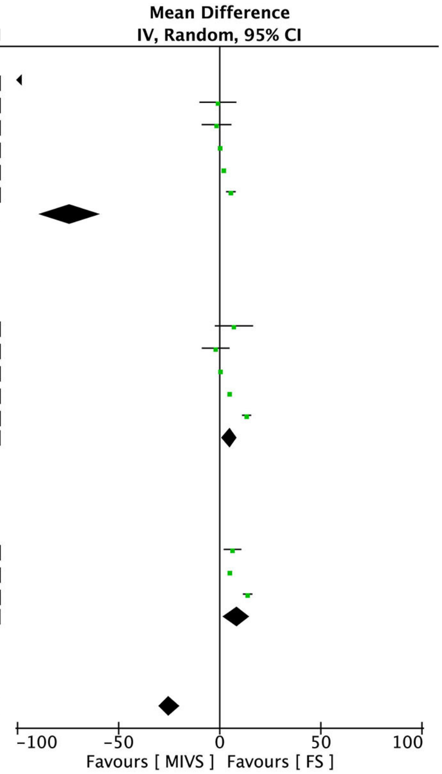

FIGURE 5 | Forest plot demonstrating the incidence of postoperative respiratory function between the MIVS and FS.

0.79; 95% CI [0.67, 0.93]; $p = 0.004$). The results of our meta-analysis are summarized in **Table 2**, and forest plots are shown in **Figure 3**.

In subgroup analysis, postoperative pulmonary complications differed significantly between the two groups ($p = 0.0007$) in terms of the incidence of postoperative respiratory insufficiency, reported by 12 studies (12, 14, 19, 21, 23, 24, 26, 30, 33, 34, 38, 39) (OR 0.75; 95% CI [0.62, 0.91]; $p = 0.004$). Two studies reported on pulmonary infection: MIVS was associated with a lower chance of infection, but this difference was not significant (OR 1.35; 95% CI [0.16, 11.30]; $p = 0.78$) (13, 17). The incidence of postoperative pleural effusion was reported in 8 studies; this was not significantly different between the groups (OR 0.81; 95% CI [0.45, 1.45]; $p = 0.47$) (6, 16, 18, 20, 21, 28, 29, 36). We also compared the incidence of prolonged ventilation time based on data pooled from 10 studies; there was no significant difference between the groups (OR 0.72; 95% CI [0.51, 1.01]; $p = 0.06$) (14, 19–22, 25, 27, 31, 37, 39). Although the observed proportions of patients with pneumonia (OR 1.42; 95% CI [0.44, 4.55]; $p = 0.56$) and pneumothorax (OR 1.55 95% CI; [0.30, 8.12]; $p = 0.60$) were less among MIVS patients, these were not significantly different between the groups. Subgroup analysis are summarized in **Table 2** and forest plots are shown in **Figure 4**.

Six studies (5, 6, 14–16, 35) reported on postoperative respiratory function tests based on spirometry, revealing that the overall complications were significantly reduced with MIVS compared to FS (964 vs. 964, WMD −24.83 95% CI [−29.90, −19.76]; $p = < 0.00001$). Most pulmonary function tests showed that the MIVS group had better respiratory function than the FS group 1 week after surgery. There was significant heterogeneity among the studies ($p < 0.00001$).

A subgroup analysis of postoperative respiratory function identified that FEV1% (WMD: −78.06; 95% CI [−89.14, −58.99]; $p < 0.00001$), FVC% (WMD: 4.99; 95% CI [1.23, 8.75]; $p = 0.009$), and TLC (WMD: 8.39; 95% CI [2.00, 14.78]; $p = 0.01$) were all significantly better in the MIVS group. There was significant heterogeneity among the studies overall, as well as in the RCT and PSM subgroup ($p < 0.00001$) (**Table 2** and **Figure 5**).

Early Mortality Outcomes

Early mortality was reported as an outcome in 30 studies (5, 6, 12–39), including 5 RCTs (6, 14–16, 28) and 25 PSM studies (12, 13, 17–27, 29–39). The incidence of early death was 1.2 and 1.9% with MIVS, and FS approaches, respectively. Thus, the early mortality rate after MIVS was significantly lower than that after FS (OR 1.58 95% CI: 1.15, 2.16; $p = 0.005$). There was no significant heterogeneity between the groups ($p = 0.97$) (**Figures 6A,B**).

Intraoperative Variable Outcomes

MIVS was associated with a significantly prolonged CPB time (WMD: 11.06; 95% CI: 4.29, 17.84 min; $p = 0.001$) (**Figure 7**)

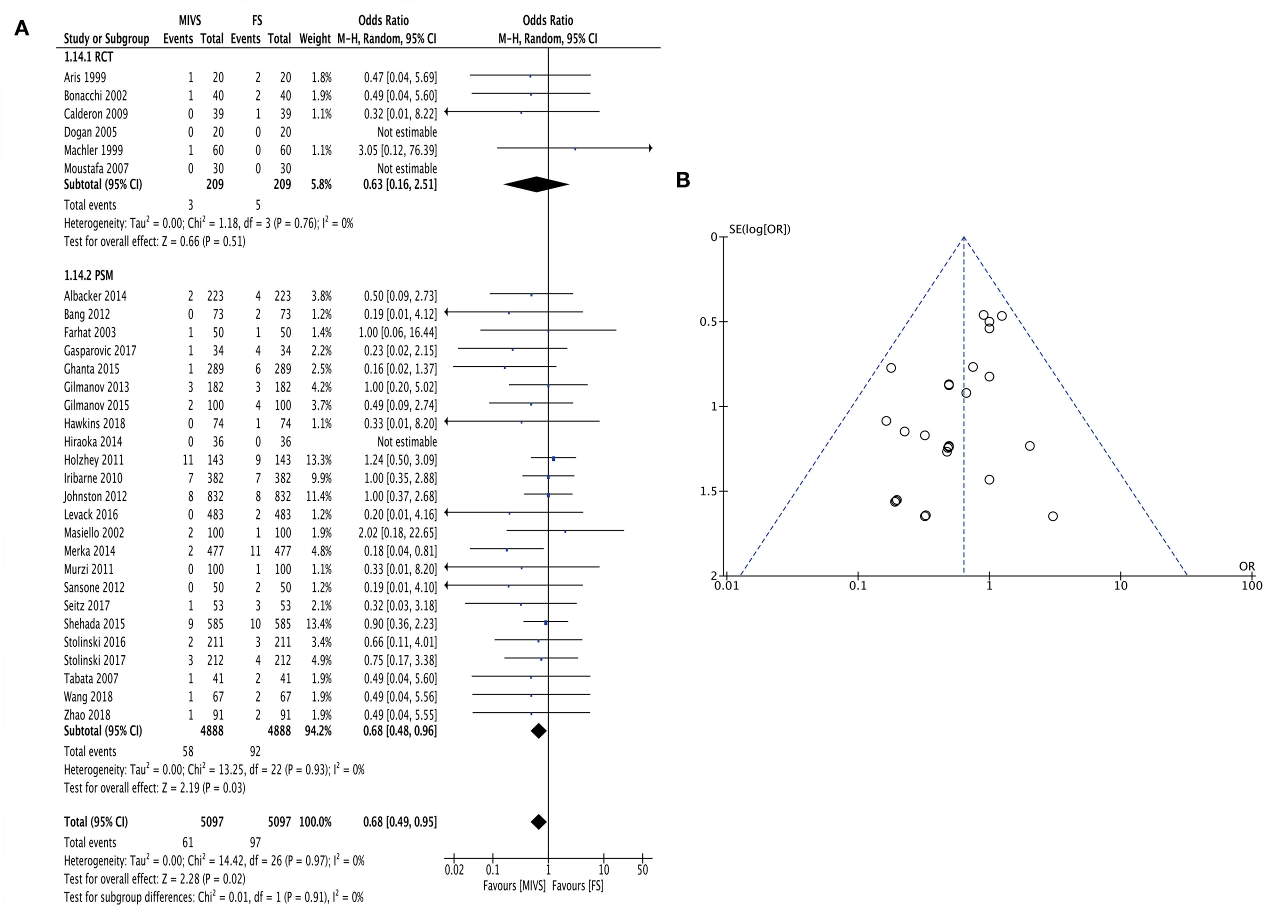

FIGURE 6 | (A) Forest plot MIVS vs. FS (Overall early mortality) and **(B)** Funnel plot MIVS vs. FS (overall early mortality).

and aortic cross-clamping time (WMD: 23.28; 95% CI: 5.65, 40.87 min; $p = 0.009$) (**Figure 8**). Thus, the MIVS approach took longer than the FS surgery, although there was no significant difference in the operative time (WMD: 0.39; 95% CI: −0.39, 1.77 h; $p = 0.32$) between the groups (**Figure 9**). However, the overall heterogeneity between the two approaches was significantly different ($p < 0.00001$). **Table 3** provides a summary of these studies.

Need for Blood Transfusion Outcomes

Fourteen studies [2 RCTs (15, 16) and 12 PSM studies (19, 20, 22, 23, 26, 27, 30, 32, 33, 36, 37, 39)] reported on the need for blood transfusion in patients. Twenty-two percent of patients required red blood cell (RBC) transfusion after MIVS, compared to 28% after FS (OR 0.69, 95% CI 0.51, 0.93; $p = 0.02$) (**Figure 10**).

Ten studies [3 RCTs (5, 13, 14) and 7 PSM studies (16–18, 24, 31, 36, 38)] reported the units of RBC transfused after MIVS and FS. Those who underwent MIVS used significantly fewer units of RBCs for transfusion than those who underwent FS (WMD −0.59, 95%CI [−2.08, 0.90 U]; $p = 0.44$). There was significant heterogeneity among the studies overall as well for the RCTs and PSM studies ($p < 0.00001$) (**Figure 11**).

DISCUSSION

Over the past decades, a steady evolution has taken place in the practice of MIVS, with excellent postoperative outcomes, according to the literature. The minimally invasive approach used for the aorta or mitral valve has advantages over the FS method in terms of decreased surgical trauma, postoperative blood loss, and length of ICU and hospital stay (4, 47). Nevertheless, postoperative pulmonary complications remain a common cause of postcardiac surgical morbidity, poor outcomes, increased cost, and hospital stays (48). Therefore, in the context of postoperative pulmonary complications and recovery of early respiratory system function, we considered it necessary to compare MIVS with FS.

In this meta-analysis, we analyzed data of 10,194 patients (5,097 [50%] vs. 5,097 [50%] patients in MIVS vs. FS groups, respectively), from 30 studies (6 RCTs and 24 PSM studies) to evaluate postoperative pulmonary functions status and pulmonary complications after MIVS vs. FS. We also assessed early mortality, CPB time, aortic cross-clamp time, procedure time, and need for blood transfusion between the MIVS and FS. Using the best available level of evidence based

Study or Subgroup	MIVS Mean	MIVS SD	MIVS Total	FS Mean	FS SD	FS Total	Weight	Mean Difference IV, Random, 95% CI
1.5.1 RCT								
Aris 1999	95	20	20	83	19	20	3.6%	12.00 [−0.09, 24.09]
Calderon 2009	77.1	32.4	39	71.3	30.4	39	3.5%	5.80 [−8.14, 19.74]
Dogan 2005	141.7	32.1	20	132.6	35.6	20	3.0%	9.10 [−11.91, 30.11]
Machler 1999	84	32.1	60	82	61.25	60	3.2%	2.00 [−15.50, 19.50]
Moustafa 2007	85.67	6.79	30	90	8.3	30	4.1%	−4.33 [−8.17, −0.49]
Subtotal (95% CI)			**169**			**169**	**17.4%**	**3.26 [−4.83, 11.34]**
Heterogeneity: Tau² = 43.08; Chi² = 9.03, df = 4 (P = 0.06); I² = 56%								
Test for overall effect: Z = 0.79 (P = 0.43)								
1.5.2 PSM								
Bang 2012	106.3	45.3	73	101.9	39.6	73	3.5%	4.40 [−9.40, 18.20]
Farhat 2003	89	18	50	70	11	50	4.0%	19.00 [13.15, 24.85]
Gasparovic 2017	79.9	14.9	34	61.9	13.7	34	4.0%	18.00 [11.20, 24.80]
Gilmanov 2013	117.5	41.9	100	104.1	34.6	100	3.7%	13.40 [2.75, 24.05]
Gilmanov 2015	92	7.17	74	94	6.17	74	4.1%	−2.00 [−4.16, 0.16]
Hawkins 2018	155	35	36	108	65	36	2.7%	47.00 [22.88, 71.12]
Hiraoka 2014	129	28	36	125	47	36	3.2%	4.00 [−13.87, 21.87]
Holzhey 2011	142	54	143	102	45	143	3.7%	40.00 [28.48, 51.52]
Iribarne 2010	139.7	2.6	382	117.1	2	382	4.1%	22.60 [22.27, 22.93]
Johnston 2012	73	32	832	95	37	832	4.1%	−22.00 [−25.32, −18.68]
Levack 2016	70	26	483	87	36	483	4.1%	−17.00 [−20.96, −13.04]
Masiello 2002	82.4	22	100	66.8	16	100	4.0%	15.60 [10.27, 20.93]
Merka 2014	82.2	217	477	81	19.9	477	3.1%	1.20 [−18.36, 20.76]
Murzi 2011	119	30	100	106	32	100	3.9%	13.00 [4.40, 21.60]
Sansone 2012	101.4	35.2	50	62.8	18.3	50	3.7%	38.60 [27.60, 49.60]
Seitz 2017	112	44	53	98	25	53	3.5%	14.00 [0.38, 27.62]
Shehada 2015	93.5	25	585	88	28	585	4.1%	5.50 [2.46, 8.54]
Stolinski 2016	111	25	211	97.6	19.4	211	4.1%	13.40 [9.13, 17.67]
Stolinski 2017	109.3	26.5	212	97.6	19.6	212	4.1%	11.70 [7.26, 16.14]
Tabata 2007	122.2	48.5	41	112.1	39.8	41	3.1%	10.10 [−9.10, 29.30]
Wang 2018	138.4	34.6	67	112.4	28.8	67	3.7%	26.00 [15.22, 36.78]
Zhao 2018	112.5	12.9	91	103.5	12.2	91	4.1%	9.00 [5.35, 12.65]
Subtotal (95% CI)			**4230**			**4230**	**82.6%**	**12.43 [4.97, 19.89]**
Heterogeneity: Tau² = 289.78; Chi² = 1746.47, df = 21 (P < 0.00001); I² = 99%								
Test for overall effect: Z = 3.27 (P = 0.001)								
Total (95% CI)			**4399**			**4399**	**100.0%**	**11.06 [4.29, 17.84]**
Heterogeneity: Tau² = 289.56; Chi² = 1924.40, df = 26 (P < 0.00001); I² = 99%								
Test for overall effect: Z = 3.20 (P = 0.001)								
Test for subgroup differences: Chi² = 2.67, df = 1 (P = 0.10), I² = 62.6%								

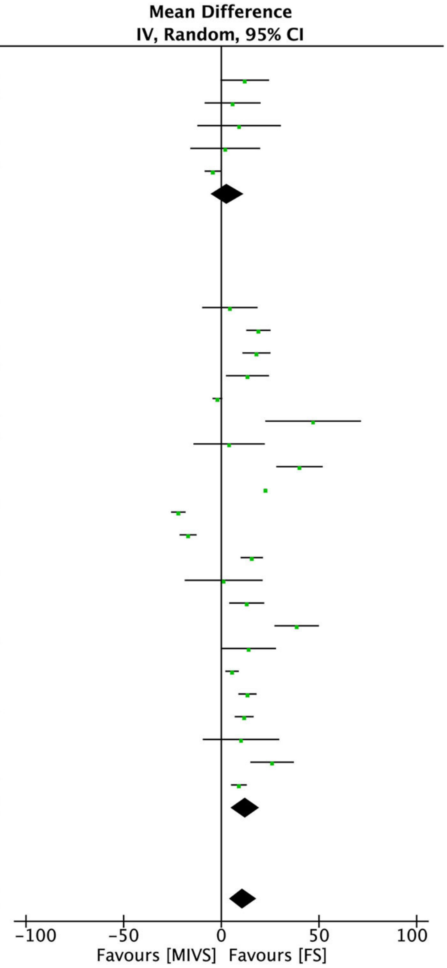

FIGURE 7 | Forest plot of cardiopulmonary bypass time (minutes) between MIVS vs. FS.

on RCTs and PSM studies, our meta-analysis added to the literature that the MIVS is safe and had a significantly reduced overall incidence of postoperative pulmonary complications and respiratory insufficiency and decreased mechanical ventilation time compared with FS.

Moreover, the overall findings for the secondary outcomes suggested that MIVS, both aortic and mitral, significantly reduced early mortality and blood transfusion requirements. To the best of our knowledge, no previous meta-analyses have indicated whether the incidence of pulmonary complications is lower after MIVS compared with FS. Most studies that describe the effect of cardiac surgery on pulmonary complications were related to patients who underwent a coronary bypass operation through full median sternotomy (49).

It has been reported that the MIVS showed better preserved early postoperative respiratory function status and reduced the time needed to make a full recovery of pulmonary status compared with FS (50). However, there has not been explained this improved respiratory function in the MIVS group so far. This study found that patients undergoing MIVS had a reduced incidence of postoperative pulmonary complications and better postoperative respiratory function outcomes than patients undergoing valve surgery via full median sternotomy. Therefore, we believe that our finding of a reduced incidence of pulmonary complications after the MIVS group may explain the improved lung function than patients with a full median sternotomy. As a result, we believe these phenomena are more likely caused by preserving the chest wall's integrity and reduced surgical trauma. Because of their improved respiratory condition, patients could begin mobilization quicker and perform pulmonary bronchial tree ventilation and cleaning more adequately.

Several risk factors may influence the impairment of spirometry and change in pulmonary gas exchange after cardiac surgery performed via a sternotomy; these include surgical trauma, prolonged operative and CPB time (6, 12, 14, 51). CPB causes an inflammatory cascade of compounds associated with the systemic inflammatory syndrome due to blood interaction with the CPB circuit and decreased pulmonary regeneration,

Study or Subgroup	MIVS Mean	MIVS SD	MIVS Total	FS Mean	FS SD	FS Total	Weight	Mean Difference IV, Random, 95% CI
1.7.1 RCT								
Aris 1999	70	19	20	51	13	20	3.6%	19.00 [8.91, 29.09]
Bonacchi 2002	517	12.2	40	52.4	9.8	40	3.6%	464.60 [459.75, 469.45]
Calderon 2009	55	9.3	39	50.6	11.9	39	3.6%	4.40 [-0.34, 9.14]
Dogan 2005	84.8	24.4	20	88	19	20	3.5%	-3.20 [-16.75, 10.35]
Machler 1999	60	20.25	60	60	19	60	3.6%	0.00 [-7.03, 7.03]
Moustafa 2007	85.67	6.79	30	90	8.3	30	3.6%	-4.33 [-8.17, -0.49]
Subtotal (95% CI)			**209**			**209**	**21.4%**	**80.10 [-98.13, 258.32]**
Heterogeneity: Tau² = 49595.70; Chi² = 27352.47, df = 5 (P < 0.00001); I² = 100%								
Test for overall effect: Z = 0.88 (P = 0.38)								
1.7.2 PSM								
Bang 2012	106.3	45.3	73	101.9	39.6	73	3.5%	4.40 [-9.40, 18.20]
Farhat 2003	66	15	50	49	10	50	3.6%	17.00 [12.00, 22.00]
Gasparovic 2017	63.4	12.7	34	50.3	11.6	34	3.6%	13.10 [7.32, 18.88]
Gilmanov 2013	83.8	28.5	182	71.3	27.5	182	3.6%	12.50 [6.75, 18.25]
Gilmanov 2015	59	4.667	100	63	4.333	100	3.6%	-4.00 [-5.25, -2.75]
Hawkins 2018	101	24	74	77	44	74	3.5%	24.00 [12.58, 35.42]
Hiraoka 2014	91	22	36	90	30	36	3.5%	1.00 [-11.15, 13.15]
Holzhey 2011	74	44	143	64	28	143	3.6%	10.00 [1.45, 18.55]
Iribarne 2010	83.7	1.9	382	79.6	1.5	382	3.6%	4.10 [3.86, 4.34]
Johnston 2012	58	25	832	71	28	832	3.6%	-13.00 [-15.55, -10.45]
Levack 2016	55	21	483	70	30	483	3.6%	-15.00 [-18.27, -11.73]
Masiello 2002	63.8	17.2	100	50.2	13	100	3.6%	13.60 [9.37, 17.83]
Merka 2014	59.4	16	477	56.9	14.6	477	3.6%	2.50 [0.56, 4.44]
Murzi 2011	83	20	100	74	28	100	3.6%	9.00 [2.26, 15.74]
Sansone 2012	74.6	26.7	50	44.8	13.4	50	3.6%	29.80 [21.52, 38.08]
Seitz 2017	76	35	53	76	17	53	3.5%	0.00 [-10.48, 10.48]
Shehada 2015	65.6	18.4	585	64.3	19.8	585	3.6%	1.30 [-0.89, 3.49]
Stolinski 2016	78.2	13.6	211	63.4	12.9	211	3.6%	14.80 [12.27, 17.33]
Stolinski 2017	77.7	14.9	212	62.6	13.1	212	3.6%	15.10 [12.43, 17.77]
Tabata 2007	81.9	31.8	41	71.6	30	41	3.5%	10.30 [-3.08, 23.68]
Wang 2018	80.4	19.6	67	67.5	18.2	67	3.6%	12.90 [6.50, 19.30]
Zhao 2018	79.5	12.5	91	72.9	11.8	91	3.6%	6.60 [3.07, 10.13]
Subtotal (95% CI)			**4376**			**4376**	**78.6%**	**7.21 [3.98, 10.43]**
Heterogeneity: Tau² = 49.03; Chi² = 729.99, df = 21 (P < 0.00001); I² = 97%								
Test for overall effect: Z = 4.38 (P < 0.0001)								
Total (95% CI)			**4585**			**4585**	**100.0%**	**23.28 [5.69, 40.87]**
Heterogeneity: Tau² = 2240.41; Chi² = 35361.85, df = 27 (P < 0.00001); I² = 100%								
Test for overall effect: Z = 2.59 (P = 0.009)								
Test for subgroup differences: Chi² = 0.64, df = 1 (P = 0.42), I² = 0%								

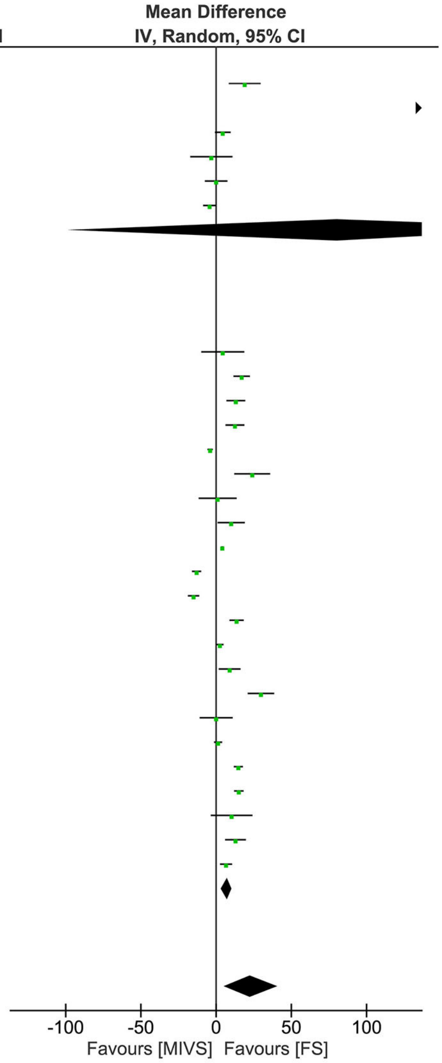

FIGURE 8 | The forests plot demonstrates aortic cross-clamp time (minutes) between MIVS and FS.

mostly because of insufficient surfactant release triggered by poor perfusion of the alveolar epithelium during CPB (49). Because of the more technical problem, patients in the MIVS group had a longer mean CPB duration than those in the FS group. However, we believe that this variation has no influence impact on postoperative pulmonary complications.

However, if CPB duration were the underlying cause, we would predict the MIVS group to have more significant postoperative pulmonary complications. This study found that patients who underwent MIVS had significantly longer cardiopulmonary bypass time, which may have contributed to the lower number of pulmonary complications observed in this group. A randomized clinical trial would be the only approach to analyze the influence of these independent factors on the incidence of postoperative pulmonary problems. MIVS did not result in an adverse postoperative pulmonary complication. It is likely that patients in whom the MIVS approach was used tended to have better early recovery and more favorable improvement of postoperative pulmonary function because of the shorter mechanical ventilation time, preservation of the chest wall integrity, and reduced postoperative pain, as compared with FS (50, 52, 53). Previous studies drew a similar conclusion to ours: there is less impaired respiratory function among patients who underwent surgery using the MIVS approach (11).

However, other investigators found no significant differences between the MIVS and FS regarding postoperative respiratory function system improvement (14, 15, 36, 54).

Moreover, we found that patients who underwent MIVS had a significant reduction in the incidence of early mortality (1.2%) compared with FS (1.9%). This finding was in line with that of previously published studies. A study by Mark et al. (30), who analyzed 477 PSM patients who underwent MIVS or FS, showed

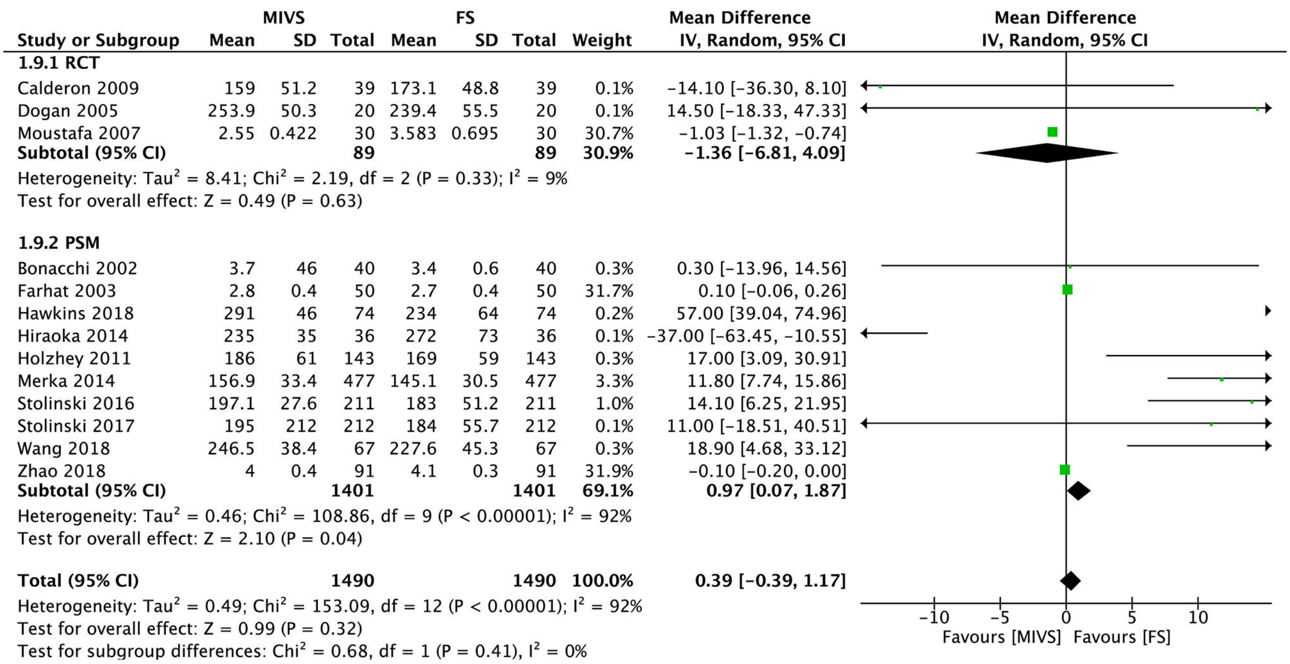

FIGURE 9 | The forests plot demonstrates operative time (hours) between MIVS and FS.

TABLE 3 | Overall analysis of demographic, intraoperative, and postoperative outcomes comparing MIVS and FS.

Variables	n(N)	No. patients MIVS/FS	Overall effect WMD/OR (95% CI)†	*P*	Study heterogeneity			
					chi²-test	df	$I^{2(\%)}$	*p*
Age, y ± SD	30 (10,194)	5,097/5,097	−0.43 [−1.05, −0.18]†	0.17	91.87	29	68	<0.00001
Male, %	27 (9,628)	4,814/4,814	1.01 [0.95, 1.12]	0.48	9.61	26	0	1.00
LVEF %, ± SD	23 (2,910)	3,455/3,455	0.65 [−0.09, 1.39]†	0.09	1288.37	22	98	<0.00001
COPD, %	17 (8,132)	4,066/4,066	0.87 [0.74, 1.03]	0.11	4.51	15	0	1.00
Early mortality, %	30 (10,194)	5,097/5,097	0.68 [0.49, 0.95]	0.02	14.42	26	0	0.97
Blood transfusion (unit) ± SD	10 (1,536)	768/768	−0.59 [−2.08, 0.90]†	0.44	166.69	9	95	<0.00001
Blood transfusion (patient), %	14 (5,756)	2,878/2,878	0.69 [0.51, 0.93]	0.02	48.53	13	73	<0.00001
CBP time ± SD	27 (8,798)	4,399/4,399	11.06 [4.29, 17.84]†	0.001	1924.40	26	99	<0.00001
Cross clamping time, minutes ± SD	28 (9,170)	4,585/4,585	23.28 [5.69, 40.87]†	0.009	35361.85	27	100	<0.00001
Operative time, minutes ± SD	13 (2980)	1,490/1,490	0.39 [−0.39, 1.17]†	0.32	153.09	12	92	<0.00001

COPD, chronic obstructive pulmonary disease; CBP, cardiopulmonary bypass; CI, confidence interval; FS, Full sternotomy; I^2, test of heterogeneity; LVEF, left ventricular ejection fraction; MIVS, minimally invasive valve surgery; n, number of studies; N, number of participants; OR, odds ratio; SD, standard deviation; WMD, weighted mean difference; †Values of WMD.

that MIVS was associated with lower hospital mortality (0.4 vs. 2.3%, respectively). This result was also in line with the results of Paparella et al. (55), who reported on 5,801 patients from different centers who underwent mini-aortic valve replacement vs. conventional aortic valve replacement.

Shehada et al. and Johnston et al. (26, 34) reported on 2,103 and 2,689 patients, respectively, in PSM analyses that compared minimally invasive to conventional aortic valve surgery. They reported a significantly lower incidence of the need for blood transfusion, as well as respiratory insufficiency in MIVS patients. Similarly, we found that the number of patients who required blood transfusion and the number of units of RBC required for transfusion were significantly reduced in MIVS than in FS.

Our observations provide evidence for the value of MIVS as an acceptable alternative option to traditional FS for patients at higher risk of developing pulmonary complications and for patients with chronic lung

Study or Subgroup	Experimental Events	Experimental Total	Control Events	Control Total	Weight	Odds Ratio M-H, Random, 95% CI
1.19.1 RCT						
Calderon 2009	18	39	20	39	6.0%	0.81 [0.33, 1.98]
Dogan 2005	8	20	8	20	3.9%	1.00 [0.28, 3.54]
Subtotal (95% CI)		**59**		**59**	**9.8%**	**0.87 [0.42, 1.80]**
Total events	26		28			
Heterogeneity: Tau² = 0.00; Chi² = 0.07, df = 1 (P = 0.79); I² = 0%						
Test for overall effect: Z = 0.37 (P = 0.71)						
1.19.2 PSM						
Ghanta 2015	71	289	92	289	10.5%	0.70 [0.48, 1.00]
Gilmanov 2013	1	182	2	182	1.4%	0.50 [0.04, 5.53]
Hawkins 2018	6	74	12	74	5.0%	0.46 [0.16, 1.29]
Hiraoka 2014	15	36	24	36	5.5%	0.36 [0.14, 0.93]
Johnston 2012	202	832	286	832	11.7%	0.61 [0.49, 0.76]
Levack 2016	26	483	34	483	9.0%	0.75 [0.44, 1.27]
Merka 2014	134	477	94	477	11.0%	1.59 [1.18, 2.15]
Sansone 2012	13	50	25	50	6.3%	0.35 [0.15, 0.81]
Seitz 2017	14	53	14	53	6.1%	1.00 [0.42, 2.37]
Stolinski 2016	103	211	142	211	10.2%	0.46 [0.31, 0.69]
Tabata 2007	19	41	13	41	5.9%	1.86 [0.76, 4.57]
Zhao 2018	16	91	34	91	7.5%	0.36 [0.18, 0.71]
Subtotal (95% CI)		**2819**		**2819**	**90.2%**	**0.67 [0.48, 0.93]**
Total events	620		772			
Heterogeneity: Tau² = 0.21; Chi² = 48.21, df = 11 (P < 0.00001); I² = 77%						
Test for overall effect: Z = 2.41 (P = 0.02)						
Total (95% CI)		**2878**		**2878**	**100.0%**	**0.69 [0.51, 0.93]**
Total events	646		800			
Heterogeneity: Tau² = 0.19; Chi² = 48.53, df = 13 (P < 0.00001); I² = 73%						
Test for overall effect: Z = 2.43 (P = 0.02)						
Test for subgroup differences: Chi² = 0.42, df = 1 (P = 0.52), I² = 0%						

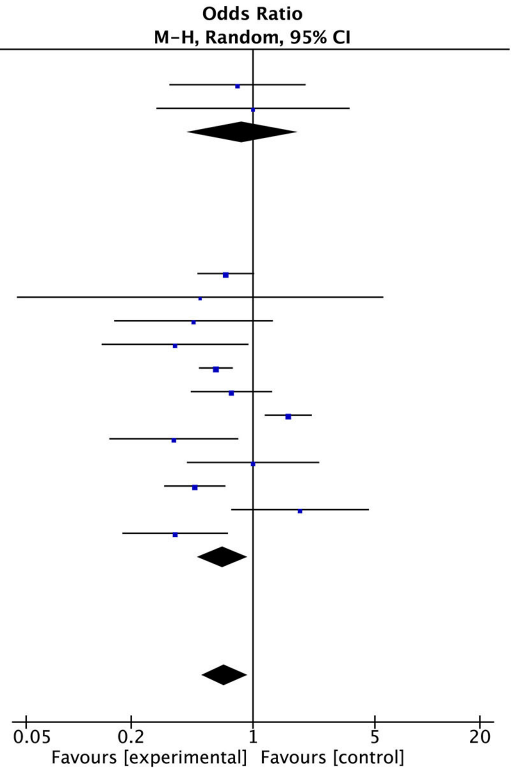

FIGURE 10 | Forest plot of patients transfused red blood cells between MIVS and FS.

Study or Subgroup	MIVS Mean	MIVS SD	MIVS Total	FS Mean	FS SD	FS Total	Weight	Mean Difference IV, Random, 95% CI
1.21.1 RCT								
Bonacchi 2002	157	98	40	293	172	40	0.1%	−136.00 [−197.35, −74.65]
Dogan 2005	200	309.9	20	421.1	514.1	20	0.0%	−221.10 [−484.18, 41.98]
Moustafa 2007	1.77	0.68	30	3.13	0.78	30	20.7%	−1.36 [−1.73, −0.99]
Subtotal (95% CI)			**90**			**90**	**20.7%**	**−88.29 [−212.15, 35.56]**
Heterogeneity: Tau² = 8912.40; Chi² = 21.18, df = 2 (P < 0.0001); I² = 91%								
Test for overall effect: Z = 1.40 (P = 0.16)								
1.21.2 PSM								
Bang 2012	680	826	73	633	738	73	0.0%	47.00 [−207.09, 301.09]
Farhat 2003	394	219	50	465	318	50	0.0%	−71.00 [−178.02, 36.02]
Gasparovic 2017	1.2	1.2	34	1.3	1.5	34	20.1%	−0.10 [−0.75, 0.55]
Holzhey 2011	3.6	6.2	143	3.9	4.6	143	18.2%	−0.30 [−1.57, 0.97]
Murzi 2011	0.7	1.1	100	2	3	100	20.2%	−1.30 [−1.93, −0.67]
Stolinski 2016	298.1	317.1	211	527.7	427	211	0.0%	−229.60 [−301.36, −157.84]
Wang 2018	2.2	1.2	67	1.1	0.8	67	20.7%	1.10 [0.75, 1.45]
Subtotal (95% CI)			**678**			**678**	**79.3%**	**−0.27 [−1.93, 1.38]**
Heterogeneity: Tau² = 2.69; Chi² = 88.86, df = 6 (P < 0.00001); I² = 93%								
Test for overall effect: Z = 0.33 (P = 0.75)								
Total (95% CI)			**768**			**768**	**100.0%**	**−0.59 [−2.08, 0.90]**
Heterogeneity: Tau² = 2.77; Chi² = 166.69, df = 9 (P < 0.00001); I² = 95%								
Test for overall effect: Z = 0.77 (P = 0.44)								
Test for subgroup differences: Chi² = 1.94, df = 1 (P = 0.16), I² = 48.4%								

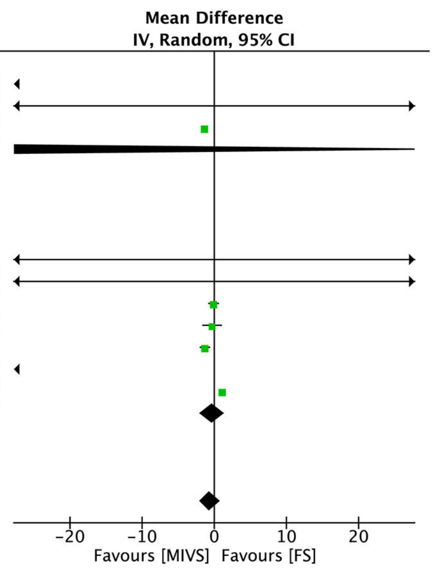

FIGURE 11 | Forest plot of units of red blood transfused between MIVS and FS.

disease and chronic obstructive pulmonary disease undergoing mitral or/and aortic valve operations (12, 56).

Nevertheless, our study has certain limitations. Most studies did not report similar outcomes, and there was limited information about the pulmonary effects of MIVS. Follow-up for most studies was limited; hence, we were unable to compare long-term results.

CONCLUSIONS

Based on the above findings in our meta-analysis, MIVS, both mitral and aortic, seem to provide better clinical and surgical outcomes than FS, particularly the benefits of early recovery of postoperative respiratory system functions and reduced incidence of postoperative pulmonary complications. Moreover, MIVS was not associated with an increased incidence of early mortality or a greater need for blood transfusion than FS. We believe that our findings might help surgeons in patient selection, particularly when dealing with patients with a high risk of pulmonary disease undergoing cardiac valve surgical repair or replacement. Finally, further studies comparing MIVS and FS are recommended to validate our findings.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

MM and SA: data analysis/writing. MM and SD: data collection/writing. RL, ND, CC, and XW: reviewers/editing. All authors contributed to the article and approved the submitted version.

REFERENCES

1. Doll N, Borger MA, Hain J, Bucerius J, Walther T, Gummert JF, et al. Minimal access aortic valve replacement: effects on morbidity and resource utilization. *Ann Thorac Surg.* (2002) 74:S1318–22. doi: 10.1016/s0003-4975(02)03911-5
2. Chitwood WR, Wixon CL, Elbeery JR, Moran JF, Chapman WHH, Lust RM. Video-assisted minimally invasive mitral valve surgery. *J Thorac Cardiov Sur.* (1997) 114:773–80. doi: 10.1016/S0022-5223(97)70081-3
3. Boix-Garibo R, Uzzaman MM, Bapat VN. Review of minimally invasive aortic valve surgery. *Interv Cardiol.* (2015) 10:144–48. doi: 10.15420/icr.2015.10.03.144
4. Bouhout I, Morgant MC, Bouchard D. Minimally invasive heart valve surgery. *Can J Cardiol.* (2017) 33:1129–37. doi: 10.1016/j.cjca.2017.05.014
5. Moustafa MA, Abdelsamad AA, Zakaria G, Omarah MM. Minimal vs median sternotomy for aortic valve replacement. *Asian Cardiovasc Thorac Ann.* (2007) 15:472–5. doi: 10.1177/021849230701500605
6. Aris A, Camara ML, Montiel J, Delgado LJ, Galan J, Litvan H. Ministernotomy versus median sternotomy for aortic valve replacement: a prospective, randomized study. *Ann Thorac Surg.* (1999) 67:1583–7. doi: 10.1016/s0003-4975(99)00362-8
7. Cheng DC, Martin J, Lal A, Diegeler A, Folliguet TA, Nifong LW, et al. Minimally invasive versus conventional open mitral valve surgery: a meta-analysis and systematic review. *Innovations.* (2011) 6:84–103. doi: 10.1097/IMI.0b013e3182167feb
8. Miskovic A, Lumb AB. Postoperative pulmonary complications. *Br J Anaesth.* (2017) 118:317–34. doi: 10.1093/bja/aex002
9. Weissman C. Pulmonary complications after cardiac surgery. *Semin Cardiothorac Vasc Anesth.* (2004) 8:185–211. doi: 10.1177/108925320400800303
10. Canet J, Gallart L, Gomar C, Paluzie G, Valles J, Castillo J, et al. Prediction of postoperative pulmonary complications in a population-based surgical cohort. *Anesthesiology.* (2010) 113:1338–50. doi: 10.1097/ALN.0b013e3181fc6e0a
11. Weissman C. Pulmonary function after cardiac and thoracic surgery. *Curr Opin Anaesthesiol.* (2000) 13:47–51. doi: 10.1097/00000539-199906000-00014
12. Albacker TB, Blackstone EH, Williams SJ, Gillinov AM, Navia JL, Roselli EE, et al. Should less-invasive aortic valve replacement be avoided in patients with pulmonary dysfunction? *J Thorac Cardiovasc Surg.* (2014) 147:355–61. doi: 10.1016/j.jtcvs.2012.12.014
13. Bang JH, Kim JW, Lee JW, Kim JB, Jung SH, Choo SJ, et al. Minimally invasive approaches versus conventional sternotomy for aortic valve replacement: a propensity score matching study. *Korean J Thorac Cardiovasc Surg.* (2012) 45:80–4. doi: 10.5090/kjtcs.2012.45.2.80
14. Bonacchi M, Prifti E, Giunti G, Frati G, Sani G. Does ministernotomy improve postoperative outcome in aortic valve operation? A prospective randomized study. *Ann Thorac Surg.* (2002) 73:460–5. doi: 10.1016/s0003-4975(01)03402-6
15. Calderon J, Richebe P, Guibaud JP, Coiffic A, Branchard O, Asselineau J, et al. Prospective randomized study of early pulmonary evaluation of patients scheduled for aortic valve surgery performed by ministernotomy or total median sternotomy. *J Cardiothorac Vasc Anesth.* (2009) 23:795–801. doi: 10.1053/j.jvca.2009.03.011
16. Dogan S, Aybek T, Risteski PS, Detho F, Rapp A, Wimmer-Greinecker G, et al. Minimally invasive port access versus conventional mitral valve surgery: prospective randomized study. *Ann Thorac Surg.* (2005) 79:492–8. doi: 10.1016/j.athoracsur.2004.08.066
17. Farhat F, Lu Z, Lefevre M, Montagna P, Mikaeloff P, Jegaden O. Prospective comparison between total sternotomy and ministernotomy for aortic valve replacement. *J Card Surg.* (2003) 18:396–401. doi: 10.1046/j.1540-8191.2003.02047.x
18. Gasparovic I, Artemiou P, Hudec V, Hulman M. Long-term outcomes following minimal invasive versus conventional aortic valve replacement: a propensity match analysis. *Bratisl Lek Listy.* (2017) 118:479–84. doi: 10.4149/BLL_2017_092
19. Ghanta RK, Lapar DJ, Kern JA, Kron IL, Speir AM, Fonner E, et al. Minimally invasive aortic valve replacement provides equivalent outcomes at reduced cost compared with conventional aortic valve replacement: A real-world multi-institutional analysis. *J Thorac Cardiovasc Surg.* (2015) 149:1060–5. doi: 10.1016/j.jtcvs.2015.01.014
20. Gilmanov D, Bevilacqua S, Murzi M, Cerillo AG, Gasbarri T, Kallushi E, et al. Minimally invasive and conventional aortic valve replacement: a propensity score analysis. *Ann Thorac Surg.* (2013) 96:837–43. doi: 10.1016/j.athoracsur.2013.04.102
21. Gilmanov D, Farneti PA, Ferrarini M, Santarelli F, Murzi M, Miceli A, et al. Full sternotomy versus right anterior minithoracotomy for isolated aortic valve replacement in octogenarians: a propensity-matched study dagger. *Interact Cardiovasc Thorac Surg.* (2015) 20:732–41. doi: 10.1093/icvts/ivv030
22. Hawkins RB, Mehaffey JH, Kessel SM, Dahl JJ, Kron IL, Kern JA, et al. Minimally invasive mitral valve surgery is associated with excellent resource utilization, cost, and outcomes. *J Thorac Cardiovasc Surg.* (2018) 156:611–16. doi: 10.1016/j.jtcvs.2018.03.108
23. Hiraoka A, Totsugawa T, Kuinose M, Nakajima K, Chikazawa G, Tamura K, et al. Propensity score-matched analysis of minimally invasive aortic valve replacement. *Circ J.* (2014) 78:2876–81. doi: 10.1253/circj.CJ-14-0861
24. Holzhey DM, Shi W, Borger MA, Seeburger J, Garbade J, Pfannmuller B, et al. Minimally invasive versus sternotomy approach for mitral valve surgery in patients greater than 70 years old: a propensity-matched comparison. *Ann Thorac Surg.* (2011) 91:401–5. doi: 10.1016/j.athoracsur.2010.08.006
25. Iribarne A, Russo MJ, Easterwood R, Hong KN, Yang J, Cheema FH, et al. Minimally invasive versus sternotomy approach for mitral valve surgery: a propensity analysis. *Ann Thorac Surg.* (2010) 90:1471–7. doi: 10.1016/j.athoracsur.2010.06.034
26. Johnston DR, Atik FA, Rajeswaran J, Blackstone EH, Nowicki ER, Sabik JF, et al. Outcomes of less invasive J-incision approach to aortic valve surgery.

J Thorac Cardiovasc Surg. (2012) 144:852–58. doi: 10.1016/j.jtcvs.2011.12.008

27. Levack MM, Aftab M, Roselli EE, Johnston DR, Soltesz EG, Gillinov AM, et al. Outcomes of a less-invasive approach for proximal aortic operations. *Ann Thorac Surg.* (2017) 103:533–40. doi: 10.1016/j.athoracsur.2016.06.008
28. Machler HE, Bergmann P, Anelli-Monti M, Dacar D, Rehak P, Knez I, et al. Minimally invasive versus conventional aortic valve operations: a prospective study in 120 patients. *Ann Thorac Surg.* (1999) 67:1001–5. doi: 10.1016/s0003-4975(99)00072-7
29. Masiello P, Coscioni E, Panza A, Triumbari F, Preziosi G, Di Benedetto G. Surgical results of aortic valve replacement via partial upper sternotomy: comparison with median sternotomy. *Cardiovasc Surg.* (2002) 10:333–8. doi: 10.1016/s0967-2109(02)00026-1
30. Merk DR, Lehmann S, Holzhey DM, Dohmen P, Candolfi P, Misfeld M, et al. Minimal invasive aortic valve replacement surgery is associated with improved survival: a propensity-matched comparison. *Eur J Cardiothorac Surg.* (2015) 47:11–7. doi: 10.1093/ejcts/ezu068
31. Murzi M, Cerillo AG, Bevilacqua S, Gilmanov D, Farneti P, Glauber M. Traversing the learning curve in minimally invasive heart valve surgery: a cumulative analysis of an individual surgeon's experience with a right minithoracotomy approach for aortic valve replacement. *Eur J Cardiothorac Surg.* (2012) 41:1242–6. doi: 10.1093/ejcts/ezr230
32. Sansone F, Punta G, Parisi F, Dato GM, Zingarelli E, Flocco R, et al. Right minithoracotomy versus full sternotomy for the aortic valve replacement: preliminary results. *Heart Lung Circ.* (2012) 21:169–73. doi: 10.1016/j.hlc.2011.10.004
33. Seitz M, Goldblatt J, Paul E, Marcus T, Larobina M, Yap CH. Minimally invasive aortic valve replacement via right anterior mini-thoracotomy: propensity matched initial experience. *Heart Lung Circ.* (2019) 28:320–26. doi: 10.1016/j.hlc.2017.11.012
34. Shehada SE, Ozturk O, Wottke M, Lange R. Propensity score analysis of outcomes following minimal access versus conventional aortic valve replacement. *Eur J Cardiothorac Surg.* (2016) 49:464–9. doi: 10.1093/ejcts/ezv061
35. Stolinski J, Musial R, Plicner D, Fijorek K, Medrzycki M, Andres J, et al. Respiratory functional status after conventional and minimally invasive aortic valve replacement surgery - a propensity score analysis. *Kardiochir Torakochirurgia Pol.* (2017) 14:5–9. doi: 10.5114/kitp.2017.66922
36. Stolinski J, Plicner D, Grudzien G, Wasowicz M, Musial R, Andres J, et al. A comparison of minimally invasive and standard aortic valve replacement. *J Thorac Cardiovasc Surg.* (2016) 152:1030–9. doi: 10.1016/j.jtcvs.2016.06.012
37. Tabata M, Umakanthan R, Cohn LH, Bolman RM, 3rd, Shekar PS, Chen FY, et al. Early and late outcomes of 1000 minimally invasive aortic valve operations. *Eur J Cardiothorac Surg.* (2008) 33:537–41. doi: 10.1016/j.ejcts.2007.12.037
38. Wang Q, Xi W, Gao Y, Shen H, Min J, Yang J, et al. Short-term outcomes of minimally invasive mitral valve repair: a propensity-matched comparison. *Interact Cardiovasc Thorac Surg.* (2018) 26:805–12. doi: 10.1093/icvts/ivx402
39. Zhao D, Wei L, Zhu SJ, Zhang Z, Liu H, Yang Y, et al. Combined mitral and aortic valve procedure via right mini-thoracotomy versus full median sternotomy insights from a single-center study of propensity-matched data. *Int Heart J.* (2019) 60:336–44. doi: 10.1536/ihj.18-186
40. Higgins JPT, Altman DG. Assessing risk of bias in included studies. In: Higgins JPT, Green S, editors. *Cochrane Handbook for Systematic Reviews of Interventions*. Chichester: Wiley (2008). p. 187–241.
41. Ottawa Hospital Research Institu. *The Newcastle-Ottawa Scale (nos) for Assessing the Quality of Nonrandomised Studies in Meta-Analyses.* (2019). Available online at: http://www.ohri.ca/programs/clinical_epidemiology/oxford.asp (accessed August 14, 2019).
42. Jadad AR, Carroll D, Glynn CJ, Moore RA, McQuay HJ. Morphine responsiveness of chronic pain: double-blind randomised crossover study with patient-controlled analgesia. *Lancet.* (1992) 339:1367–71. doi: 10.1016/0140-6736(92)91194-d
43. Gallart L, Canet J. Post-operative pulmonary complications: understanding definitions and risk assessment. *Best Pract Res Clin Anaesthesiol.* (2015) 29:315–30. doi: 10.1016/j.bpa.2015.10.004
44. Szelkowski LA, Puri NK, Singh R, Massimiano PS. Current trends in preoperative, intraoperative, and postoperative care of the adult cardiac surgery patient. *Curr Problems Surg.* (2014) 52:531–69. doi: 10.1067/j.cpsurg.2014.10.001
45. Tanner TG, Colvin MO. Pulmonary complications of cardiac surgery. *Lung.* (2020) 198:889–96. doi: 10.1007/s00408-020-00405-7
46. Moher D, Liberati A, Tetzlaff J, Altman DG, Group P. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *PLoS Med.* (2009) 6:e1000097. doi: 10.1371/journal.pmed.1000097
47. Cosgrove DM, 3rd, Sabik JF. Minimally invasive approach for aortic valve operations. *Ann Thorac Surg.* (1996) 62:596–7.
48. Badenes R, Lozano A, Belda FJ. Postoperative pulmonary dysfunction and mechanical ventilation in cardiac surgery. *Crit Care Res Pract.* (2015) 2015:420513. doi: 10.1155/2015/420513
49. Chetta A, Bobbio A, Aiello M, Del Donno M, Castagnaro A, Comel A, et al. Changes in lung function and respiratory muscle strength after sternotomy vs. laparotomy in patients without ventilatory limitation. *Eur Surg Res.* (2006) 38:489–93. doi: 10.1159/000096008
50. e Silva AM, Saad R, Stirbulov R, Rivetti LA. Off-pump versus on-pump coronary artery revascularization: effects on pulmonary function. *Interact Cardiovasc Thorac Surg.* (2010) 11:42–5. doi: 10.1510/icvts.2009.229617
51. Ragnarsdottir M, KristjAnsdottir A, Ingvarsdottir I, Hannesson P, Torfason B, Cahalin L. Short-term changes in pulmonary function and respiratory movements after cardiac surgery via median sternotomy. *Scand Cardiovasc J.* (2004) 38:46–52. doi: 10.1080/14017430310016658
52. Shenkman Z, Shir Y, Weiss YG, Bleiberg B, Gross D. The effects of cardiac surgery on early and late pulmonary functions. *Acta Anaesthesiol Scand.* (1997) 41:1193–9.
53. Khoshbin E, Prayaga S, Kinsella J, Sutherland FW. Mini-sternotomy for aortic valve replacement reduces the length of stay in the cardiac intensive care unit: meta-analysis of randomised controlled trials. *BMJ Open.* (2011) 1:e000266. doi: 10.1136/bmjopen-2011-000266
54. Lim JY, Deo SV, Altarabsheh SE, Jung SH, Erwin PJ, Markowitz AH, et al. Conventional versus minimally invasive aortic valve replacement: pooled analysis of propensity-matched data. *J Card Surg.* (2015) 30:125–34. doi: 10.1111/jocs.12493
55. Paparella D, Malvindi PG, Santarpino G, Moscarelli M, Guida P, Fattouch K, et al. Full sternotomy and minimal access approaches for surgical aortic valve replacement: a multicentre propensity-matched study. *Eur J Cardiothorac Surg.* (2020) 57:709–16. doi: 10.1093/ejcts/ezz286
56. Santana O, Reyna J, Benjo AM, Lamas GA, Lamelas J. Outcomes of minimally invasive valve surgery in patients with chronic obstructive pulmonary disease. *Eur J Cardiothorac Surg.* (2012) 42:648–52. doi: 10.1093/ejcts/ezs098

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.