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The Effect of Different Types of Mechanical Circulatory Support on Mortality of Patients after Adult Cardiac Surgery: A Systematic Review and Meta-Analysis

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ABSTRACT

Objectives: Sample size may limit the ability of individual studies to detect differences in clinical outcomes between extracorporeal membrane oxygenation (ECMO) alone and ECMO plus intra-aortic balloon pump (IABP) after adult cardiac surgery. Therefore, we undertook a meta-analysis of the best evidence available on the comparison of clinical outcomes of ECMO alone and ECMO plus IABP after adult cardiac surgery.

Methods: PubMed, EMBASE, Web of Science, and Cochrane Center Registry of Controlled Trials were searched for studies comparing the use of ECMO alone and ECMO plus IABP after adult cardiac surgery. A meta-analysis and a sensitivity analysis were conducted.

Results: Among the 472 screened articles, 24 studies (1302 cases of ECMO plus IABP and 1603 cases of ECMO) were included. A significant relationship between patient risk profile and benefits from IABP plus ECMO was found in terms of the 30-day mortality (odds ratio [OR] 0.75; 95% confidence interval [CI] 0.62 to 0.91; $P = .004$) with postcardiotomy shock (PCS). However, ECMO alone was associated with lower in-hospital mortality (OR 1.75; 95% CI 1.06 to 3.01; Z = 2.19; $P = .03$) compared with ECMO plus IABP without PCS.

Conclusions: Pooled data show that patients receiving IABP plus ECMO with PCS have lower 30-day mortality than those receiving ECMO also, which in turn show higher 30-day mortality in patients with IABP plus ECMO without PCS. Further randomized studies are warranted to corroborate these observational data.

INTRODUCTION

Severe postcardiotomy myocardial dysfunction after cardiac surgery is a leading cause of mortality, and the utilization rates of extracorporeal membrane oxygenation (ECMO) and intra-aortic balloon pump (IABP) can be 3% to 5% in the patients with postcardiotomy shock (PCS) after cardiac surgery [Guttendorf 2014; Ko 2002]. Traditionally, the main life-threatening complications of cardiac surgery fall into 2 categories, PCS and postcardiotomy failure (PCF) [Jaski 2010; Magovern 1994], both of which show higher mortality (>60%) [Committee for Scientific Affairs 2011]. PCS also remains the leading cause of death in patients with acute myocardial infarction (AMI), myocarditis, and graft failure after heart transplantation. In addition to pharmacologic measures, treatment with mechanical circulatory support can

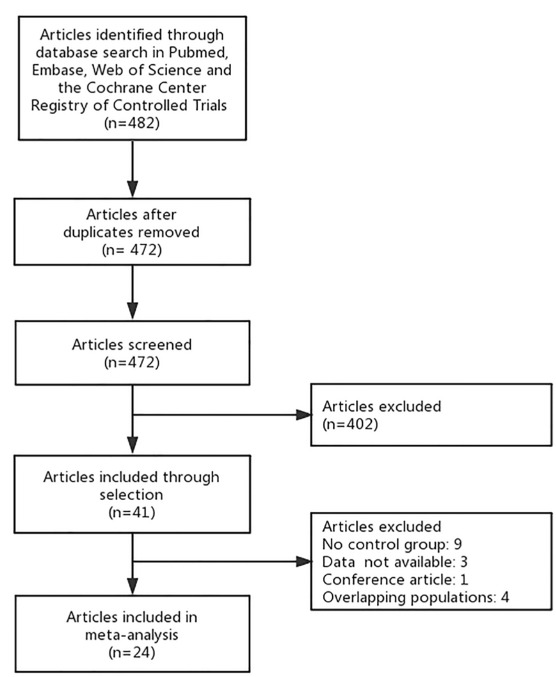

Figure 1. Search strategy.

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Table 1. Quality Analysis of 24 Studies*

Reference	Date Range	Selection			Comparability		Outcome		
		Group A	Group B	Group C	Group D	Group E	Group F	Group G	Total
Acheampong 2016	1/2001 to 12/2013	1	1	1	5	4	1	0	13
Biancari 2017	9/2005 to 6.2016	1	0	1	5	3	1	1	12
Doll 2004	11/1997 to 7/2002	1	1	1	5	4	1	0	13
Elsharkawy 2017	2/1995 to 10/2005	1	0	1	3	3	1	0	9
Guihaire 2017	2/2005 to 11/2014	1	1	1	5	4	1	1	14
Guru 2015	5/2001 to 12/2014	1	0	1	3	5	1	0	11
Hei 2011	11/2004 to 11/2009	1	1	1	3	4	1	1	12
Magovern 1999	11/1991 to 8/1997	1	0	1	4	4	1	0	11
Mikus 2013	2/2007 to 8/2011	1	1	0	4	3	1	1	11
Muehrcke 1996	9/1992 to 6/1994	1	0	1	3	4	1	0	10
Murashita 2004	4/1991 to 8/2002	1	0	1	3	3	1	1	10
Papadopoulos 2015	11/2001 to 6/2013	1	1	1	4	5	1	0	13
Pokersnik 2012	2/2005 to 11/2010	1	1	1	4	4	1	1	13
Rastan 2010	5/1996 to 5/2008	1	1	1	3	4	1	0	11
Ruoyu 2006	1/2005 to 8/2012	1	1	1	4	5	1	0	13
Santarpino 2015	2005 to 2015	1	0	1	3	4	0	1	10
Saxena 2015	2/2003 to 2/2013	1	0	1	4	3	1	1	11
Slottosch 2012	1/2006 to 12/2010	1	0	1	3	3	1	1	10
Smedira 2001	1/1992 to 6/1999	1	1	1	4	2	0	0	9
Unosawa 2012	4/1992 to 6/2007	1	0	0	4	4	1	0	10
Wang 2013	1/2004 to 12/2011	1	0	1	4	4	1	1	12
Xie 2017	1/2011 to 12/2015	1	0	1	3	3	1	0	9
Yan 2009	2004 to 2008	1	0	1	3	3	0	1	9
Zhang 2016	2/1996 to 10/2004	0	1	1	4	3	1	0	10

*Group A: Assignment for treatment-any criteria reported (if yes, score 1)? Group B: How representative was the reference group (VA-ECMO) in comparison to the general population after cardiac surgery? (If yes, score 1; no score if the patients were selected or selection of group was not described). Group C: How representative was the treatment group (IABP plus ECMO) in comparison to the general population after cardiac surgery? (If drawn from the same community as the reference group, score 1; no score if drawn from a different source or selection of group was not described.) Comparability variables: (1) age; (2) sex; (3) hypertension; (4) diabetes; (5) ejection fraction; (6) 3-vessel disease; (7) left main stem disease; (8) urgent/emergency operation; (9) viability studies; (10) surgeon or hospital volume. Group D: Groups comparable for 1, 2, 3, 4, 5. (If yes, score 1 for each; no score was assigned if the 2 groups differed.) Group E: Groups comparable for 6, 7, 8, 9, 10. (If yes, score 1 for each; no score was assigned if the 2 groups differed.) Group F: Clearly defined outcome of interest (if yes, score 1). Group G: Follow-up (score 1 if described.)

be considered, especially in more severe forms of circulatory failure [Hoy 2000]. The aim of mechanical circulatory support, for example ECMO and IABP, is to unload the failing heart ventricle and provide temporary circulatory support for vital organs.

ECMO, also called extracorporeal life support (ELS), is regarded as a modified way to treat critically ill patients with respiratory and cardiovascular failure, especially after cardiac surgery [Gray 2015; Cashen 2015]. However, an increase of left ventricle afterload, elevated left ventricular end-diastolic pressure, acute pulmonary edema, and increased myocardial oxygen consumption are detrimental side effects of ECMO [Chung 2017; Burkhoff 2015]. Nevertheless, it is still unclear whether ECMO effectively increases the survival rate [Meani 2017].

IABP is no longer recommended as a routine therapy for patients after cardiac surgery [Thiele 2013], and the role of IABP in providing additional circulatory support and left ventricular decompression in patients with concomitant ECMO is controversial [Cheng 2015]. IABP could theoretically reduce aortic volume through a vacuum-like effect, improve coronary blood flow and cardiac output, and reduce heart rate and pulmonary capillary wedge pressure [Altayyar 2014]. In

Study or Subgroup	ECMO+IABP Events	ECMO+IABP Total	ECMO Events	ECMO Total	Weight	Odds Ratio M–H, Fixed, 95% CI
acheampong2016	6	14	5	10	1.4%	0.75 [0.15, 3.83]
chen2006	19	31	5	5	1.5%	0.14 [0.01, 2.79]
Doll 2004	106	144	61	75	8.7%	0.64 [0.32, 1.28]
Elsharkawy 2010	15	22	134	211	3.3%	1.23 [0.48, 3.15]
Guihaire 2017	14	25	44	67	4.3%	0.67 [0.26, 1.70]
Guru 2015	24	50	28	51	5.9%	0.76 [0.35, 1.66]
Hei 2011	5	11	20	57	1.4%	1.54 [0.42, 5.69]
Magovern 1999	8	11	27	44	1.2%	1.68 [0.39, 7.22]
Mikus 2012	6	13	1	1	0.6%	0.29 [0.01, 8.39]
Muehrcke1996	7	17	3	6	1.1%	0.70 [0.11, 4.54]
Papadopoulos2015	57	79	201	281	10.1%	1.03 [0.59, 1.80]
Pokersnik2012	20	29	13	20	2.0%	1.20 [0.36, 4.01]
Rastan 2009	284	383	105	134	16.5%	0.79 [0.49, 1.27]
Ro 2013	41	60	139	193	8.6%	0.84 [0.45, 1.57]
Slottosch 2012	50	72	4	5	0.9%	0.57 [0.06, 5.38]
smedira2001	41	110	44	92	12.3%	0.65 [0.37, 1.14]
Unosawa 2013	2	8	16	39	1.7%	0.48 [0.09, 2.68]
Wang 2013	13	41	31	46	8.2%	0.22 [0.09, 0.55]
Xie 2017	35	110	23	67	8.0%	0.89 [0.47, 1.70]
Zhang 2006	3	9	15	23	2.3%	0.27 [0.05, 1.36]
Total (95% CI)		**1239**		**1427**	**100.0%**	**0.75 [0.62, 0.91]**
Total events	756		919			

Heterogeneity: $Chi^2 = 16.46$, df = 19 (P = 0.63); $I^2 = 0\%$

Test for overall effect: Z = 2.91 (P = 0.004)

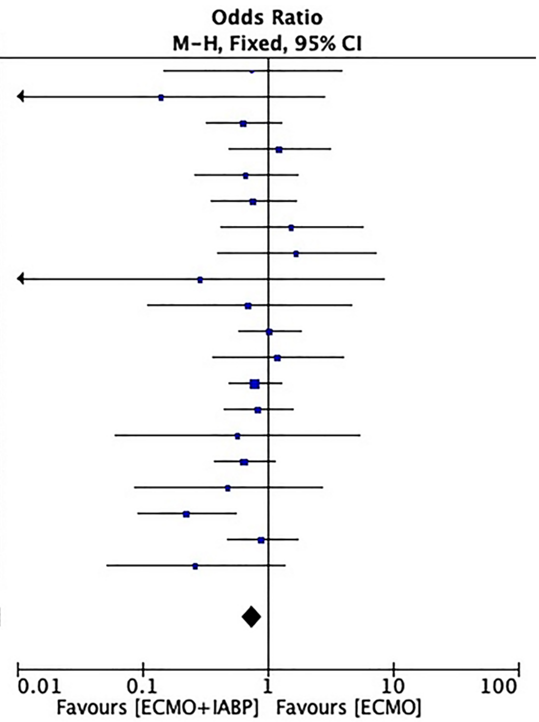

Figure 2. In-hospital mortality between ECMO plus IABP and ECMO alone in cardiac surgery with PCS.

light of the multiple recent studies with contrasting results [Thiele 2012; Aso 2016; Mascio 2014], we sought to systematically review the available evidence of the role of concomitant IABP for patients with cardiogenic shock. Studies of IABP as a second conduit have focused on all-cause death and have shown better survival rates for ECMO alone [Vallabhajosyula 2018; Mascio 2014]. Therefore, our primary hypothesis that use of concomitant IABP is associated with higher short-term mortality in patients after cardiac surgery with ECMO.

METHODS

This systematic review and meta-analysis was conducted according to the guidelines of Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) and Meta-analysis of Observational Studies in Epidemiology (MOOSE) [Liberati 2009; Stroup 2000].

Search Strategy and Definition

A medical librarian developed searches to identify studies that compared clinical outcomes between IABP and ECMO. PubMed, EMBASE, Web of Science, and Cochrane Center Registry of Controlled Trials were searched for studies published from January 1990 to January 2018. Searches used subject headings and keywords for the following terms: "intra-aortic balloon pump," "extracorporeal membrane oxygenation," "cardiac surgery," "postcardiotomy shock," "cardiopulmonary bypass," "postcardiotomy failure," and "circulatory assist devices."

To be eligible for inclusion in the meta-analysis, trials had to conform to the following criteria: observational studies comparing ECMO and IABP as main technique for cardiac surgery including a majority of operations (coronary artery bypass graft, mitral, aortic valve repair, combination surgery, dissection, etc). Animal studies, reviews, and urgent/emergent cases were excluded. Studies that did not have any of the desired outcome measures or included patients treated by other modalities were excluded; those with incomplete data were excluded. Studies that included interventions other than IABP versus ECMO were excluded (Figure 1).

Patients were considered to be candidates for ECMO if satisfactory systemic perfusion could not be maintained despite high-dose inotropic agents, IABP, or both. The fundamental criteria for ECMO support were as follows: systolic blood pressure <80 mmHg, left atrial pressure >20 mmHg, cardiac index of 1.8 L/min/m^2, and drug-resistant fetal arrhythmia. PCS was defined as heart failure that either resulted in an inability to wean from cardiopulmonary bypass or that occurred in the immediate postoperative period, accounting for the most common indication for mechanical circulatory support (MCS).

Ethics Approval

As a meta-analysis, no patients were involved the study, making ethics approval unnecessary.

Data Extractions and Quality Assessment

Three reviewers (Z. Guan; K. Gu; J. Lin) independently extracted the following data from each study: first author, year of publication, trial characteristics, study design, inclusion

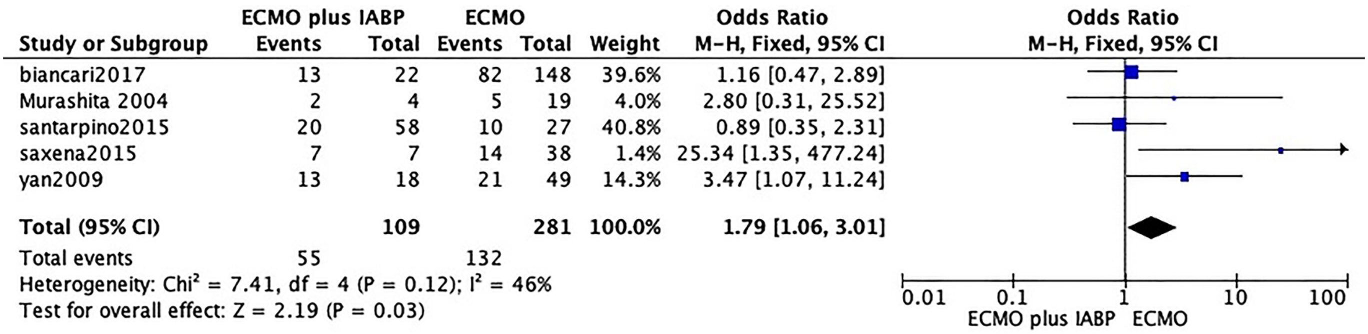

Figure 3. In-hospital mortality between ECMO plus IABP and ECMO alone in cardiac surgery without PCS.

and exclusion criteria, graft type, and clinical outcome (Table 1). The following variables were included: study demographics (sample size, design, and country), patient demographics and comorbidities (age, sex, diabetes status, ejection fraction, chronic obstructive pulmonary disease status). The modified Newcastle-Ottawa scale, summarized in Table 1, is used in our meta-analysis with a quality assessment score. We define a study score of >6 as high quality. The quality of all studies was evaluated by 2 independent researchers (W. Zhou; J. Lin).

Description of Outcomes

The operative mortality was defined as in-hospital mortality within 30 days after cardiac surgery of ECMO alone or ECMO plus IABP [Acheampong 2016].

Statistical Analysis

The efficacy of ECMO alone and ECMO plus IABP was compared directly by pooling data from the included studies using meta and metaphor packages in R (version 3.5.3, R Project; R Foundation for Statistical Computing, Vienna, Austria) [Viechtbauer 2010]. We pooled the clinical outcomes using odds ratios (ORs) with 95% confidence intervals (CIs). ORs were used as the common measure for dichotomous data. The random-effects model was used because of the variation among studies due to patients undergoing operations in different centers with varying risk profiles, as well as different selection criteria for each surgical technique. We evaluated heterogeneity by focusing on ECMO alone and ECMO plus IABP after cardiac surgery and a quality score >6; heterogeneity was reported as low (I^2 = 0% to 25%), moderate (I^2 = 26% to 50%), or high (I^2 > 50%), consistent with guidelines. Publication bias was assessed visually by funnel plot and quantitatively by the Egger test [Higgins 2003]. We calculated pooled ORs using the Mantel-Haenszel method, with weight assigned to each included study adjusted to include a measure of variation in the effects reported between studies. Statistical significance was assumed for $P < .05$.

RESULTS

General Characteristics of the Included Studies

Table 2 is presents the baseline characteristics of the meta-analysis. All studies were retrospective observational studies, and 8 studies conducted by the Extracorporeal Life Supporting Organization Registry Center, with nonoverlapping patients [Acheampong 2016; Guihaire 2017; Biancari 2017; Toshifumi 2015; Saxena 2015; Santarpino 2015; Papadopoulos 2015; Guru 2015; Kyun 2014; Wang 2013; Satoshi 2013; Ingo 2013; Pokersnik 2012; Feilong 2011; Elsharkawy 2010; Ardawan 2010; Doll 2004; Smedira 2001; Magovern 1999; Muehrcke 1996; Mikus 2013; Xie 2017; Xiaolei 2010; Ruoyu 2006].

Among the 472 screened articles, a total of 24 studies (2905 patients; 1302 ECMO plus IABP and 1603 ECMO alone) met the inclusion criteria (Table 2). Eight studies were in the United States, 5 in Germany, 3 in China, 3 in Japan, 2 in France, 1 in "Europe," and 1 each from Korea and Italy. All observational studies included were matched or adjusted and were of high quality and low risk of bias. The number of patients in the individual studies ranged from 4 to 340 in the ECMO plus IABP group and 1 to 211 in the ECMO alone group. The mean age of the population was 58.70 years; 71.3% were men; and the average time on ECMO was 5.01 days. The overall in-hospital mortality was about 66.67%. Based on patients with cardiac surgery with or without PCS, the mortality was 62.35% with PCS and 37.39% without PCS.

In-Hospital Mortality

In-hospital mortality was 61.02% (756 of 1239) with IABP plus ECMO versus 64.40% (919 of 1427) with ECMO alone (incidence rate ratio 0.75; 95% CI 0.62 to 0.91, $P < .05$) (Figure 2) in the group with cardiac surgery with PCS. In patients having cardiac surgery without PCS, the in-hospital mortality was significantly different for ECMO with and without IABP: 50.46% (55 of 109) versus 46.98% (132 of 281); (OR 1.79; 95% CI 1.06 to 3.01; Z = 2.19; $P = .03$). Heterogeneity between studies was moderate in these studies ($\chi^2 = 7.59$; $P = .16$; $I^2 = 34\%$), and the fixed model was suggested in subgroup analysis (Figure 3). A funnel plot shows low publication bias (χ^2 22.21; $P = .27$; $I^2 = 14\%$) (Figure 4), and the Egger test intercept was –1.23 to 0.13, $P = .21$.

DISCUSSION

We conducted a meta-analysis with 2905 patients treated with IABP plus ECMO or ECMO alone for PCS and other

Table 2. Baseline between ECMO plus IABP and ECMO Alone

Reference	Study Type	Data Range	Age (y)	Male Sex	No. of Patients		Patient Type	ELSO Center	Country
					ECMO+ IABP	ECMO		Yes	
Acheampong 2016	RCS	1/2001 to 12/2013	41 ± 00.00	14 (58.3)	14	10	PCS	Yes	USA
Biancari 2017	RCS	9/2005 to 6.2016	65.4 ± 9.4	116 (57)	38	62	Other	Yes	France
Doll 2004	RCS	11/1997 to 7/2002	61.3 ± 12.1	160 (73)	144	75	PCS	Yes	Germany
Elsharkawy 2017	RCS	2/1995 to 10/2005	56.98± 0.0	157 (67)	22	211	PCS	Yes	USA
Guihaire 2017	RCS	2/2005 to 11/2014	63 ± 00.00	54 (59)	25	67	PCS	Yes	France
Guru 2015	RCS	5/2001 to 12/2014	56.0 ± 22.2	53 (52.5)	50	51	PCS	Yes	USA
Hei 2011	RCS	11/2004 to 11/2009	47.7 ± 14.1	52 (76)	11	57	PCS	Yes	China
Magovern 1999	RCS	11/1991 to 8/1997	62 6 ± 1.4	31 (56)	11	44	PCS	Yes	USA
Mikus 2013	RCS	2/2007 to 8/2011	53.1 ± 14.3	9 (64)	13	1	PCS	Yes	Italy
Muehrcke 1996	RCS	9/1992 to 6/1994	47.3 + 16.4	17 (74)	17	6	PCS	Yes	USA
Murashita 2004	RCS	4/1991 to 8/2002	58 ± 15	16 (63)	4	19	Other	Yes	Japan
Papadopoulos 2015	RCS	11/2001 to 6/2013	62 ± 17	274 (76)	79	281	PCS	Yes	Germany
Pokersnik 2012	RCS	2/2005 to 11/2010	65 ±13	33 (67.3)	29	20	PCS	Yes	USA
Rastan 2010	RCS	5/1996 to 5/2008	63.5 ± 11.2	369 (71.5)	340	177	PCS	Yes	Germany
Ruoyu 2006	RCS	1/2005 to 8/2012	58.8 ± 15.3	154 (60.9)	60	193	PCS	No	Korea
Santarpino 2015	RCS	2005 to 2015	64.6 10.3	62 (73)	58	0	Other	Yes	European
Saxena 2015	RCS	2/2003 to 2/2013	76.8 ± 4.6	31 (68.9)	6	39	Other	Yes	USA
Slottosch 2012	RCS	1/2006 to 12/2010	60 ± 13	18 (23.4)	70	7	PCS	Yes	Germany
Smedira 2001	RCS	1/1992 to 6/1999	55.0 ± 14.0	145 (71.7)	110	92	PCS	Yes	USA
Unosawa 2012	RCS	4/1992 to 6/2007	64.4 ± 12.5	35 (74.4)	23	6	PCS	Yes	Japan
Wang 2013	RCS	1/2004 to 12/2011	65 ± 67	41.3 (36)	41	46	PCS	Yes	China
Xie 2017	RCS	1/2011 to 12/2015	56.15 ± 0.0	121 (68)	110	67	PCS	Yes	Japan
Yan 2009	RCS	2004 to 2008	50.5 ± 13.6	48 (72)	18	49	Other	Yes	China
Zhang 2016	RCS	2/1996 to 10/2004	55.4 ± 11.9	18 (56)	9	23	PCS	Yes	Germany

Data are mean ± SD or n (%) unless noted otherwise.

cardiac surgery. In the comparison between IABP plus ECMO versus ECMO alone with PCS, the analysis confirmed that IABP plus ECMO was associated with significantly decreased in-hospital mortality.

Short-Term MCS after Cardiac Surgery

The incidence of heart dysfunction with cardiac surgery is as high as 3% to 5% among patients receiving routine cardiac surgery procedures, and the majority of those patients can be weaned from CPB using inotropic drugs or IABP after cardiac surgery [Meani 2018; Doshi 2018]. Hemodynamic deterioration, occurrence of multiorgan dysfunction, and development of the systemic inflammatory response syndrome are reasons for patients with PCS needing ECMO with or without IABP, referred as extracorporeal life support (ELS) [Roland 2010].

Despite the theoretical advantage of MCS devices after cardiac surgery, there is limited high-quality evidence supporting their use. In 2015, a long-term study showed high cost and serious complication rates for postcardiotomy cardiogenic shock in nontransplant cardiothoracic surgery [Khorsandi 2015]. MCS for refractory PCS carries a survival benefit and achieves acceptable functional recovery; however, it still has a higher complication rate [Khorsandi 2016]. Recent large-scale data have demonstrated an increasing trend of MCS use in the management of medical and surgical cardiogenic shock [Agarwal 2015]. Consistent with this literature, our study confirms the most frequent use of ECMO use in cardiogenic shock, in 20 of 24 the studies. ECMO have multiple theoretical advantages with cardiac surgery that include increased cardiac output and coronary and cerebral perfusion, decreased ventricular workload, diastolic augmentation [Pfluecke 2014; Scheidt 1973], rapid bedside access with or without fluoroscopy, high cardiac output support, and robust support of both cardiac and pulmonary function [Brugts 2014]. However, increased left ventricular afterload in ECMO can result in worsening LV performance, increasing pulmonary congestion [Bréchot 2017].

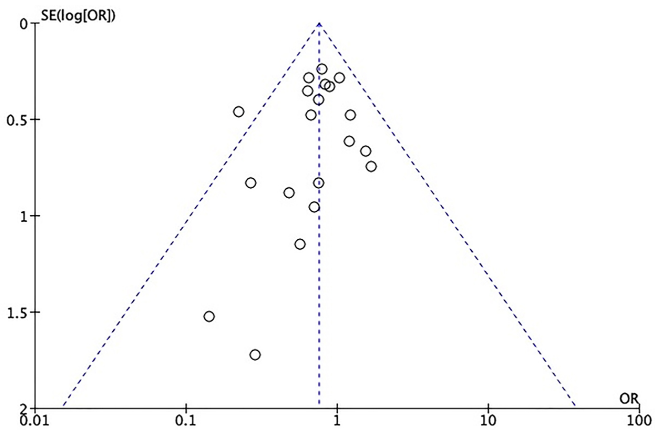

Figure 4. Funnel plot of in-hospital mortality between ECMO plus IABP and ECMO in PCS.

Combined IABP and ECMO after Cardiac Surgery

The rationale for IABP as a concomitant MCS device after cardiac surgery requiring ECMO is multifold. First, IABP offers the theoretical advantage in decreasing ventricular workload to protect myocardial function and increasing cardiac output to improve distal organ function, especially coronary and cerebral perfusion [Aso 2016]. Importantly, a decrease in left ventricular wall tension, wall stress, and myocardial oxygen demand/consumption [Williams 1982] and improvement in sublingual microcirculatory flow are evident with ECMO [Jung 2008]. Second, ECMO is preferable to IABP because it can provide more robust biventricular support by increasing right ventricular drainage, which can improve gas exchange with the use of bedside equipment [Mosier 2015]. Third, MCS is regarded as a bridge to recovery after cardiac transplantation, and percutaneous MCS, such left ventricular assist, has a lower cost and fewer complications. Thus ECMO plus IABP has been regarded as the second MCS device of choice [Aso 2016]. The purpose of ECMO plus IABP in the PCS is to compensate for heart afterload with improved support of biventricular functions and avoid pulmonary failure, especially after surgery. There are also many risks accompanying ECMO plus IABP: for example, preoperative LV systolic dysfunction and advanced age are associated with poor survival rates in patients with PCS [Muller 2016; Erwan 2014]. In cardiac surgery without PCS, clinical outcome were not improved with IABP plus ECMO versus ECMO alone [Pokersnik 2012; Peigh 2015]. ECMO after adult cardiac surgery is associated with a higher risk of in-hospital mortality, and the negative prognostic effect may be explained by the combined impact of cardiac disease and the extent of the surgical procedures, along with any possible concomitant technical complications occurring during surgery [Truby 2015; Carroll 2015].

To our knowledge, this is the first study to report the comparison of IABP plus ECMO with ECMO alone in cardiac surgery patients. Only 3 meta-analyses have mentioned the risk of MCS after cardiac surgery. Li et al [2019] included 12 studies with 925 cases of ECMO plus IABP and 1190 cases of ECMO and found that ECMO combined with IABP was better than ECMO alone in patients with PCS. This result was similar to our study, but intake was insufficient. Khorsandi et al [2017] conducted a meta-analysis of 24 studies of ECMO for PCS. The in-hospital mortality was 69.2%, which was similar to our study; however, they did not compare ECMO plus IABP after cardiac surgery. Wang et al [2018] also found that short-term and midterm survival rates of PCS treated with ECMO were disappointingly low (34.0%), and complication rates were relatively high. Therefore, the survival rates of patients after surgery were not changed through the use of ECMO associate with IABP.

Recently, ECMO plus IABP has revealed a potential survival benefit in many critical conditions such as PCS [Karl 2014; Yih-Sharng 2008], PCF [Ma 2014], acute cardiomyopathy or acute myocarditis [Mariana 2011], and postcardiac surgery complications [Alan 2014]. A large, prospective, randomized trial showed that ECMO support was associated with higher in-hospital mortality among adult PCS patients with major vascular complications. Observational studies showed that IABP plus ECMO was an independent risk factor for major vascular complications [Yang 2018] and decreased the rate of heart failure [Doshi 2018; Musiał 2015]. Thus, ECMO plus IABP is a viable option for adult heart transplant with severe rejection and refractory cardiogenic shock [Raffa 2019]. What is more, peripheral and central ECMO configurations showed comparable in-hospital survival and risk of bleeding, and continuous veno-venous hemofiltration and blood product transfusion were significantly lower with the peripheral cannulation strategy [Ouyang 2018].

Limitations

This study's limitations should be acknowledged. First, it was retrospective, and the lack of randomized studies may cause selection bias. The patients with ECMO plus IABP may also have been associated with an increased risk for adverse outcomes. Several studies did not give clear criteria for patient allocation, which may cause bias in patient selection. Second, no studies on the ELS complications of ECMO plus IABP after surgery in our meta-analysis were included. What is more, the included studies were variable in indications, strategy, cannulation methods, and hemodynamic models of ECMO and IABP. In the future, more detail regarding patient characteristics and treatment algorithms across the studies' pooled data is essential. Finally, this study was largely skewed to patients with surgery, so the results may not necessarily be generalizable to patients with bridges to ventricular assistive devices, and the lack of long term follow-up prevents actuary assessment of treatment effects in both groups.

Conclusions

Our study showed that the use of IABP plus ECMO with PCS was associated with a lower in-hospital mortality rate; however, for patients without PCS, ECMO plus IABP had no significant advantage in survival rate. In the future, multicenter prospective studies or large prospective multicenter registries are needed to provide further insight into the effects of the combined application.

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