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The effect of intra-aortic balloon pump on survival and neurological outcome in patients treated with extracorporeal cardiopulmonary resuscitation: A meta-analysis and systematic review

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ABSTRACT

Introduction: Extracorporeal cardiopulmonary resuscitation (ECPR) is increasingly used to treat refractory cardiac arrest, although with variable results in survival and neurological outcomes. The intra-aortic balloon pump (IABP) showed mixed effects on survival in veno-arterial extracorporeal membrane oxygenation. Furthermore, the impact of IABP on survival and neurological outcomes in ECPR recipients has yet to be fully investigated.
Methods: We searched relevant databases for studies concerning ECPR recipients and intra-aortic balloon pump with information on survival and neurological outcomes. The inverse variance method (95 % confidence intervals) was used to determine the odds ratios of outcomes. We decided on a priori use of the random-effects model with the Hartung-Knapp adjustment.
Results: We included in our analysis nine cohort studies dealing with a total of 4994 patients. The association of IABP with ECPR was associated with a survival benefit compared to ECPR alone: 1029/3124 (32.9 %) patients survived in the ECPR+IABP group versus 379/1870 (20.2 %) in the ECPR group, OR 1.94, 95 % CI [1.36 to 2.77]. Survival with good neurological outcome was analyzed in 4 studies for 4018 patients. The association of ECPR and IABP was associated with a not significant advantage in survival with favorable neurological outcome compared with ECPR alone: 555/2687 (20.7 %) patients with good neurological outcome in the group of ECPR+IABP versus 149/1331 (11.2 %) patients in the group of ECPR, OR 1.33, 95 % CI [0.61 to 2.92].
Conclusions: The association of IABP and ECPR significantly increases survival rates compared to ECPR alone. Nevertheless, the impact on favorable neurological outcomes remains uncertain.

1. Introduction

Cardiac arrest (CA) is the third leading cause of death in Europe, with an annual incidence of out-of-hospital-cardiac arrest (OHCA) between 67 and 170 per 100,000 inhabitants [1]. Similar data come from the U.S. with an incidence of OHCA of 74.3 individuals per 100,000 inhabitants [2]. Extracorporeal cardiopulmonary resuscitation (ECPR) is a type of veno-arterial extracorporeal membrane oxygenation (ECMO) implanted during the conventional cardiopulmonary resuscitation (cCPR) of refractory CA [3,4]. ECPR aims to guarantee oxygenated blood flow adequate for metabolic needs, preventing exceeding the threshold of irreversible organ damage [4]. The interest in ECPR has progressively grown: the Extracorporeal Life Support Organization (ELSO) Registry documented an increase in annual ECPR cases from less than 100 in 2009 to almost 2500 in 2023 [5]. Three recent randomized control trials (RCT) obtained different results in survival and neurological outcomes of ECPR recipients. Nevertheless, the *ARREST* [6], *Prague OHCA* [7], and *INCEPTION* [8] trials presented substantial differences in eligibility,

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randomization, setting, and hospital organization, explaining the difference in the outcomes achieved [9]. A recent meta-analysis [10] demonstrated that ECPR is associated with a reduction in mortality compared to cCPR (OR 0.67, 95 % CI 0.51–0.87, $p = 0.0034$), but this benefit is lost when including only the OHCA population (OR 0.76, 95 % CI 0.54–1.07, $p = 0.12$). The growing pieces of evidence on ECPR induced the American Heart Association (AHA) to make a recommendation on ECPR [11]: "Use of ECPR for patients with cardiac arrest refractory to standard ACLS is reasonable in select patients when provided within an appropriately trained and equipped system of care" (Class of recommendation 2a; Level of evidence B-R).

The intra-aortic balloon pump (IABP) is a polyethylene balloon that inflates and deflates by electrocardiogram or pressure triggers. IABP increases diastolic blood pressure, decreases afterload, increases coronary perfusion pressure, and provides modest ventricular unloading [12]. After the publication of the IABP-Shock II trial in 2012, in which IABP was not able to improve survival [13] and 6-year outcomes [14] in patients with cardiogenic shock due to acute coronary syndrome, the use of counterpulsation has progressively declined. The European Society of Cardiology guidelines [15] downgraded the use of IABP in cardiogenic shock from Class I to Class III ("not recommended"). However, IABP still has a role in veno-arterial ECMO as it could reduce left ventricular afterload, facilitating the unloading, even if it seems to provide only a modest leftward shift in the pressure-volume loop during VA ECMO [12]. A recent meta-analysis demonstrated the survival benefit of ECMO plus IABP compared to no mechanical circulatory support and that ECMO plus IABP was superior to ECMO alone in patients with cardiogenic shock [16].

Nevertheless, the role of IABP in ECPR recipients is not completely clear. During the initial phase of ECPR, patients have no ventricular ejection, so the unloading role of IABP is negligible. Conversely, the pulsatility induced by IABP or the early unloading at the recovery of cardiac native function could have a positive impact on survival.

This study investigates whether IABP plus ECPR is associated with increased survival and favorable neurological outcomes compared to ECPR alone.

2. Materials and methods

We registered the meta-analysis in the PROSPERO International Prospective Register of systematic.

reviews (*CRD42024505985*.). We used the PICOS (Population, Intervention, Comparison, Outcome, Study design) criteria:

- Patients receiving ECPR (P);
- ECPR plus IABP (I);
- ECPR alone (C);
- Survival and neurological outcome at the hospital discharge (O);
- Randomized clinical trials and observational studies (retrospective, prospective) (S).

The systematic search was performed according to PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines [17] by two reviewers (A. M. and G. C.).

2.1. Search strategy and study selection

We searched the MEDLINE (including PubMed) and Embase databases using the search string: ("ECPR" OR "extracorporeal cardiopulmonary resuscitation") AND ("intra-aortic balloon pump" OR "IABP" OR "counterpulsation"). References of relevant studies were hand-searched to identify any additional studies. We did not apply any restriction on publication dates. We followed the succeeding inclusion and exclusion criteria to select relevant studies for the analysis. Inclusion criteria: all studies concerning ECPR recipients and intra-aortic balloon pump, information on survival, and neurological outcomes. Exclusion criteria: non-human experimental studies, case reports. Two investigators (A. M. and G. C.) independently assessed compliance with the selection criteria and selected the studies for the final analysis. The PRISMA flow diagram of the search strategy is shown in Fig. 1.

2.2. Data collection and risk of bias

We checked the eligibility assessment at the title and abstract level.

Subsequently, the final selection of included articles was based on the complete manuscripts, in agreement between the two investigators. Every disagreement was solved by consensus.

We created a data collection sheet based on data of interest extracted by the two investigators. The following variables were collected: journal, first author, year of publication, country, study design, number of patients who received ECPR plus IABP, number of patients who received ECPR alone, number of survivals, and favorable neurological outcomes in each group, as shown in Table 1.

We assessed the risk of bias using the Cochrane risk-of-bias tool for randomized trials version 2 (RoB 2) [18] for each RCT included and the Newcastle–Ottawa Scale (NOS) [19] for non-randomized studies.

The funnel plot revealed publication bias, which was confirmed by Egger's test [20]. When the *p*-value was less than 0.05, publication bias was presumed.

2.3. Data analysis and synthesis

Computations were performed using Meta-Mar software [21]. The inverse variance method (95 % confidence intervals [CI]) was used to determine the odds ratios (OR) of binary outcomes.

Given the diversity of studies and populations, the authors did not assume a common effect size and expected considerable heterogeneity. Therefore, we decided on a priori use of the random-effects model to reduce the probability of type II errors. The Hartung-Knapp adjustment for the random-effects model [22] was used to obtain more adequate error rates than the DerSimonian and Laird approach [23,24].

Effect estimates were displayed for each research as squares, and proportions were shown with their 95 % CI as horizontal lines. Study heterogeneity was assessed using the Q-statistic [25], tau-square, and I^2 tests [26]. We assumed I^2 as the main source of information about the extent of heterogeneity: low (25 %), moderate (50 %), and high (75 %) heterogeneity levels were used to classify it.

3. Results

We updated our search until 26 February 2024. The search yielded a total of 184 articles, 33 after excluding duplicates. Afterward, two reviewers (A. M. and G.C.) independently screened titles and abstracts to exclude studies irrelevant to our purpose. We obtained 25 articles for the full-text review. Sixteen studies did not meet our criteria (Fig. 1). We included in our analysis nine cohort studies dealing with a total of 4994 patients [27–35]. We did not find any randomized controlled trial assessing our scope. The study of *Chen and colleagues* [30] is in the Chinese language: we obtained data necessary for the analysis from the English abstract. Two of the studies analyzed [28,29] included patients for whom VA-ECMO was also implanted immediately after the return of spontaneous circulation (ROSC) due to severe cardiogenic impairment. We presented the studies' characteristics in Table 1. In the *supplementary material,* we presented the assigned risk of bias for each study through the *Newcastle-Ottawa quality assessment scale for the non-randomized trials*.

3.1. Analysis

We analyzed a total of 4994 patients for the survival analysis. The association of IABP with ECPR was associated with a survival benefit compared to ECPR alone: 1029/3124 (32.9 %) patients survived in the

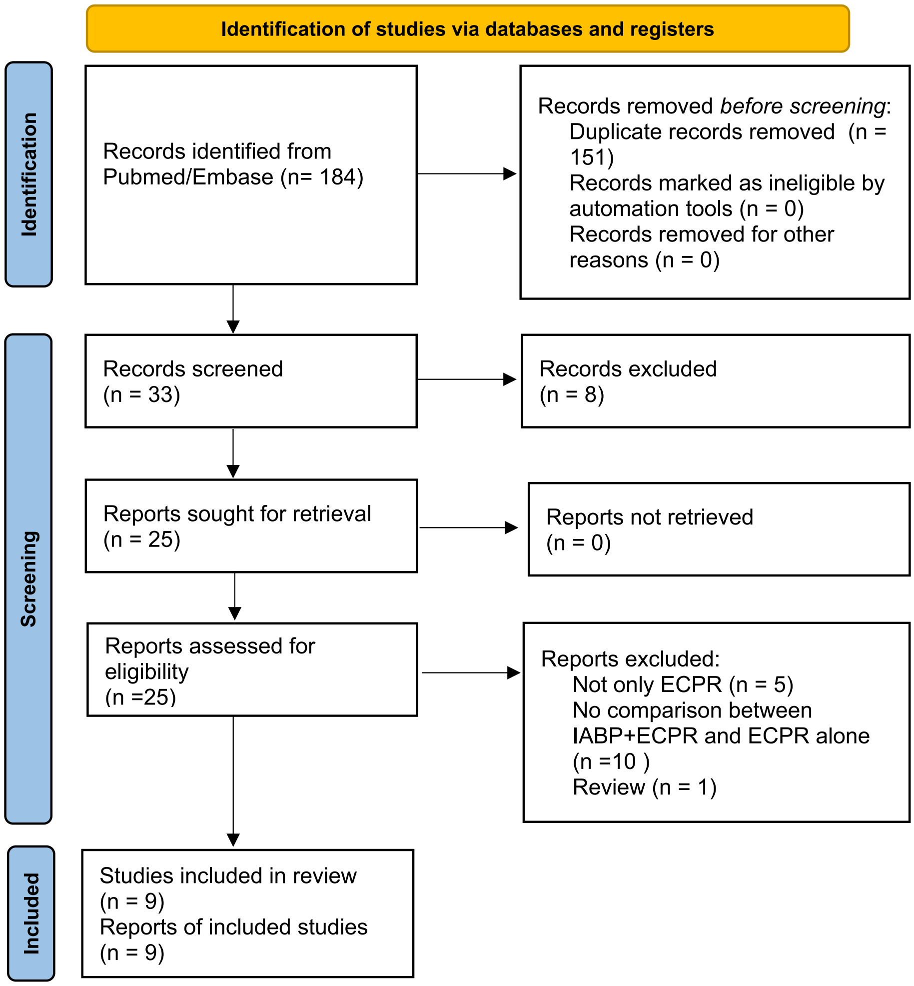

Fig. 1. Preferred reporting items for systematic reviews and meta-analyses flow diagram.

Table 1
Studies' characteristics.

Article	Journal	Country	Study Design	ECPR + IABP (n)	ECPR (n)	Survival in ECPR + IABP (n)	Survival in ECPR (n)	Favorable neurological outcome in ECPR + IABP (n)	Favorable neurological outcome in ECPR (n)
Kagawa et al. 2012	Circulation	Japan	Retrospective cohort study	71	15	25	0	No data	No data
Guru et al. 2021	Journal of Cardiac Surgery	USA	Retrospective cohort study	50	51	26	21	13	16
Kuroki et al. 2021	Resuscitation	Japan	Retrospective cohort study	762	143	282	44	257	43
Chen et al. 2022	Zhonghua Wei Zhong Bing Ji Jiu Yi Xue	China	Retrospective cohort study	31	168	16	46	No data	No data
Sun et al. 2023	Perfusion	China	Retrospective cohort study	23	10	5	1	No data	No data
Scquizzato et al. 2023	Resuscitation Plus	Italy	Retrospective cohort study	200	107	44	7	No data	No data
Kashiura et al. 2023	Resuscitation	Japan	Retrospective cohort study	1173	962	362	139	176	64
Nishimura et al. 2023	Resuscitation	Japan	Retrospective cohort study	702	175	224	42	109	26
Li et al. 2024	American Journal of Emergency Medicine	China	Prospective Multicenter Study	112	239	45	79	No data	No data

ECPR+IABP group versus 379/1870 (20.2 %) in the ECPR group, OR 1.94, 95 % CI [1.36 to 2.77], (Fig. 2). The visual inspection of the funnel plot does not reveal a substantial asymmetry. The Egger's test confirmed the absence of publication bias ($p = 0.9289$). Subsequently, we re-analyzed the data after excluding the two studies involving patients with VA-ECMO implanted immediately after ROSC [28,29] to precisely assess the effect of IABP on ECPR recipients only. In this secondary analysis, the survival benefit of the association of ECPR and IABP was

Study	Experimental Events	Experimental Total	Control Events	Control Total	Weight	Odds Ratio IV, Random, 95% CI
Sun et al. 2023	5	23	1	10	1.6%	2.50 [0.25; 24.72]
Scquizzato et al. 2023	44	200	7	107	8.3%	4.03 [1.75; 9.30]
Kagawa et al. 2012	25	71	0	15	1.0%	17.00 [0.98; 296.04]
Li et al. 2024	45	112	79	239	15.2%	1.36 [0.86; 2.16]
Nishimura et al. 2023	224	702	42	175	17.3%	1.48 [1.01; 2.17]
Kashiura et al. 2023	362	1173	139	962	21.3%	2.64 [2.12; 3.29]
Chen et al. 2022	16	31	46	168	9.1%	2.83 [1.29; 6.18]
Guru et al. 2021	26	50	21	51	9.0%	1.55 [0.70; 3.40]
Kuroki et al. 2021	282	762	44	143	17.2%	1.32 [0.90; 1.94]
Total (95% CI)		**3124**		**1870**	**100.0%**	**1.94 [1.36; 2.77]**

Heterogeneity: $Tau^2 = 0.0957$; $Chi^2 = 21.74$, df = 8 ($P < 0.01$); $I^2 = 63\%$

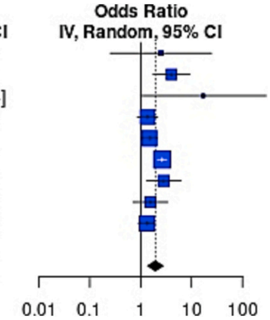

Fig. 2. Forest plot of survival analysis.

confirmed: 721/2312 (31.2 %) patients survived in the ECPR+IABP group versus 314/1676 (18.7 %) in the ECPR group, OR 2.20, 95 % [1.39 to 3.48]. Survival with good neurological outcome was analyzed in 4 studies [28,29,31,34] for 4018 patients. The combination of ECPR and IABP was associated with a not significant advantage in survival with favorable neurological outcome compared with ECPR alone: 555/2687 (20.7 %) patients with good neurological outcome in the group of ECPR+IABP versus 149/1331 (11.2 %) patients in the group of ECPR, OR 1.33, 95 % CI [0.61 to 2.92], (Fig. 3). The visual inspection of the funnel plot reveals a mild degree of asymmetry.

Regarding neurological outcome, we did not meta-analyze data excluding the two studies involving VA-ECMO even implanted after ROSC [28,29] due to the scarcity of the remaining data.

The drapery plots and funnel plots are presented in *supplementary materials*.

4. Discussion

4.1. Key findings

Our analysis demonstrated a significant increase in survival rates for ECPR recipients when an intra-aortic balloon pump is used in conjunction with extracorporeal membrane oxygenation compared to ECMO alone. Specifically, survival rates were 32.9 % in the ECPR+IABP group versus 20.2 % in the ECPR group alone (Fig. 2). This finding is robust, as it persisted even when excluding patients who received VA-ECMO immediately after the return of spontaneous circulation (ROSC), indicating a direct benefit from IABP use. Only four studies evaluated neurological outcome. Applying a random-effect model (Fig. 3 and *supplementary materials*), we did not obtain a statistically significant advantage in survival with a favorable neurological outcome in the group of IABP+ ECPR.

4.2. Relationship to previous studies

Previous studies have shown mixed results regarding the survival benefits of IABP with VA-ECMO in cardiogenic shock. Some meta-analyses reported no benefit of ECMO plus IABP in cardiogenic [36,37] or post-cardiotomy shock [38]. Conversely, one study reported a beneficial effect only on weaning from extracorporeal support [39], others a survival advantage only in the subgroup of patients with cardiogenic shock after acute myocardial infarction [40,41], and yet another study demonstrated a decreased in-hospital death in the whole cardiogenic shock population [42]. The recent network meta-analysis by *Low* et al. [16] showed a lower mortality rate when IABP is used with VA-ECMO compared to all other forms of mechanical circulatory support (HR, 0.55, 95 % CI 0.46–0.66). However, patients undergoing ECPR seem to be a peculiar group of subjects receiving VA-ECMO, and it is challenging to interpret data obtained from studies of patients with cardiogenic shock from the perspective of ECPR. Our study uniquely contributes to this literature by explicitly focusing on the ECPR population, suggesting that adding IABP to ECMO may improve survival in refractory cardiac arrest.

4.3. Significance of study findings and what this study adds to our knowledge

Our research suggests that IABP may enhance survival in ECPR scenarios. As ECPR is used as a last-resort therapy in cardiac arrest and mortality is still high, the potential advantage of IABP combined with ECPR could be relevant in clinical practice. While IABP is traditionally used to manage cardiac after-load and to improve coronary perfusion, its application in ECPR could be particularly beneficial, providing a pulsatile flow and unloading the left ventricle in the recovery phase. However, the hemodynamic effects of IABP in ECPR may differ from those displayed in patients with cardiogenic shock treated with veno-arterial ECMO.

In an animal model of ECPR [43], the combination of IABP and VA-ECMO does not significantly modify carotid blood flow but induces a statistically significant decrease in coronary blood flow compared to VA-ECMO alone ($p = 0.004$). *Farag* et al. obtained similar results in a mock circulation loop study showing no significant variation in cerebral perfusion, but an incremental reduction in coronary blood flow at the progressive reduction of biventricular function [44]. However, the effects on regional blood flow could be affected by cardiac function recovery. *Yang and colleagues* divided their patients into a low pulse pressure group (< 10 mmHg) and a high pulse pressure group (> 10 mmHg). They demonstrated that adding IABP in patients with poor native function (pulse pressure < 10 mmHg) significantly decreases cerebral blood flow [45]. Similarly, *Xu* et al. demonstrated a dramatic decrease in left carotid artery blood flow, but not in right carotid and efflux tract of aorta, in patients on IABP and pulse pressure less than 5

Study	Experimental Events	Experimental Total	Control Events	Control Total	Weight	Odds Ratio IV, Random, 95% CI
Nishimura et al. 2023	109	702	26	175	25.9%	1.05 [0.66; 1.68]
Kashiura et al. 2023	176	1173	64	962	29.8%	2.48 [1.84; 3.34]
Guru et al. 2021	13	50	16	51	16.5%	0.77 [0.32; 1.83]
Kuroki et al. 2021	257	762	43	143	27.8%	1.18 [0.80; 1.74]
Total (95% CI)		**2687**		**1331**	**100.0%**	**1.33 [0.61; 2.92]**

Heterogeneity: $Tau^2 = 0.1908$; $Chi^2 = 16.35$, df = 3 ($P < 0.01$); $I^2 = 82\%$

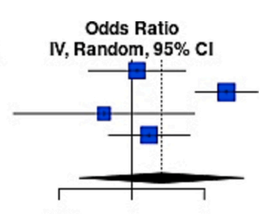

Fig. 3. Forest plot of neurological outcome analysis.

mmHg. In their study, the reduction in carotid blood flow was reversed at the interruption of aortic counterpulsation, but also by increasing ECMO blood flow [46]. Therefore, in the case of extremely reduced native cardiac output, IABP may jeopardize the achievement of adequate cerebral perfusion pressures, arising as an obstacle to the countercurrent ECMO blood flow, although the interplay of cardiac output, ECMO flow, and IABP effects are difficult to predict.

The role of a pulsatile flow in extracorporeal support needs to be clarified. During cardiopulmonary bypass, the pulsatile flow has been advocated instead of continuous flow devices, but short-term or long-term benefits have not yet been established [47–49]. The loss or the persistence of low pulse pressure (< 10 mmHg) in ECPR patients has been strongly associated with a reduction in the chance of weaning and survival [50,51]. Recently, an analysis (not yet peer-reviewed) of more than nine thousand patients on peripheral VA-ECMO in the ELSO registry [52] found that pulsatile pressure $\leq$ 10 mmHg in the first 24 h was independently associated with acute brain injuries (adjusted odds ratio 1.25, 95 % confidence interval = 1.06–1.48, $p = 0.01$). In experimental models of cardiac arrest, assuring pulsatile extracorporeal perfusion maintains endothelial integrity [53,54] and improves cerebral oxygenation [55].

Nevertheless, more relevant determinants of neurological recovery in post-cardiac arrest patients treated with ECPR seem to be the times of 'no-flow' and 'low-flow' [56–58]. Our research found no studies providing information on 'no-flow' time and only two studies reporting data on bystander CPR rate and 'low-flow' time [31,34]. The first one showed similar rates of bystander CPR and no statistically significant difference in 'low-flow' time between the two groups [31]. Conversely, the other study reported substantial differences: the group of IABP exhibited a shorter 'low-flow' time and a higher incidence of bystander CPR compared to the group of ECPR alone [34].

Furthermore, VA-ECMO increases left ventricular after-load leading to ventricular distension that can impair myocardial recovery [59]. Several strategies have been proposed to deal with this issue (intra-aortic balloon pump, trans-septal atrial or pulmonary catheters, direct left ventricular venting, transaortic devices like Impella©) with mixed results on mortality [60]. In this context, IABP demonstrated a lower complication rate than the other unloading techniques [61,62].

Therefore, during VA ECMO support, the addition of IABP could be beneficial, providing a pulsatile flow in the early phases of resuscitation when cardiac activity is still compromised and preventing left ventricular distension. In this respect, the timing of the IABP insertion could be pivotal, modifying regional blood flow.

4.4. Strengths of the study

This is the first meta-analysis specifically addressing the effects of IABP on the restricted population of patients for whom VA-ECMO is implanted for refractory cardiac arrest.

Our meta-analysis showed a survival benefit in patients treated with IABP and ECPR. Therefore, this preliminary finding could suggest considering the early insertion of IABP in cardiac arrest patients submitted to extracorporeal resuscitation.

4.5. Limitations of the study

The absence of randomized controlled trials in our analysis and the reliance on retrospective data limits the ability to infer causality from the observed associations. The heterogeneity in study designs and their retrospective nature increase the risk of 'selection bias,' perhaps contributing to the observed survival advantage in IABP recipients: patients treated with ECPR for whom was expected an unfavorable neurological recovery or a bad prognosis in the early stages could not have received aortic counterpulsation due to futility. Otherwise, the observational nature of studies analyzed, the absence of precise data concerning IABP insertion timing, and the high risk of early mortality could lead to the development of the 'immortal time bias': all patients received ECPR at time zero; some also received IABP at a not-prespecified time. Therefore, all the patients who experienced death before the IABP insertion were necessarily included in the 'ECPR alone' group. Consequently, the IABP recipients appear to be 'immortal' until they receive the treatment (aortic counterpulsation) analyzed, thus potentially favoring survival in IABP+ECPR recipients.

The interpretation of our results on survival with favorable neurological recovery is challenging: we found only four studies, with no data on 'no flow' time and unreliable data on 'low-flow' time.

Finally, the timing of IABP insertion and removal during ECPR was unknown in the studies analyzed, making it more challenging to understand regional blood flow variation induced by IABP during countercurrent ECMO blood flow in the stages of cardiac recovery.

4.6. Future studies and prospects

The accurate timing of the intra-aortic balloon pump insertion could be pivotal in affecting survival and modifying regional blood flow. Moreover, assessing the impact of aortic counterpulsation on the neurological outcome should consider the times of "no-flow" and "low-flow" intervals. Therefore, a randomized control trial is crucial to investigate these issues through the precise selection and randomization of ECPR recipients. Understanding patient-specific factors that influence the effectiveness of IABP could also lead to more targeted and individualized therapeutic strategies. Nevertheless, given the restricted number of subjects receiving ECPR, we acknowledge the complexities of realizing an RCT that targets this issue.

5. Conclusions

This meta-analysis systematically evaluates the efficacy of intra-aortic balloon pump (IABP) in conjunction with extracorporeal cardiopulmonary resuscitation (ECPR). It reveals that IABP is associated with a significant increase in survival rates compared to ECPR alone. Nevertheless, the impact on favorable neurological outcome remains uncertain, indicating that while IABP can improve immediate survival chances, its role in long-term recovery warrants further investigation. As such, our study underscores the need for rigorous randomized controlled trials to explore these findings comprehensively and to optimize IABP application in ECPR settings, ensuring the best possible outcomes for patients experiencing refractory cardiac arrest.

Author statement

We wish to confirm that there are no known conflicts of interest associated with this publication, and there has been no significant financial support for this work that could have influenced its outcome. We confirm that the manuscript has been read and approved by all named authors and that no other persons have satisfied the criteria for authorship but are not listed. We further confirm that we have all approved the authors' order in the manuscript.

We understand that the Corresponding Author is the sole contact for the Editorial process (including the Editorial Manager and direct communications with the office). He is responsible for communicating with the other authors about progress, submissions of revisions, and final approval of proofs. We confirm that we have provided a current, correct email address accessible by the Corresponding Author.

CRediT authorship contribution statement

Alberto Marabotti: Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Giovanni Cianchi:** Writing – review & editing, Writing – original draft, Supervision, Investigation, Data curation, Conceptualization. **Pietro Bertini:** Writing – review &

editing, Writing – original draft, Visualization, Methodology, Formal analysis, Data curation, Conceptualization. **Simona di Valvasone:** Writing – original draft, Visualization, Validation, Formal analysis, Data curation. **Chiara Lazzeri:** Writing – review & editing, Writing – original draft, Methodology. **Pasquale Bernardo:** Writing – review & editing, Writing – original draft, Supervision, Investigation. **Fabio Sangalli:** Writing – review & editing, Writing – original draft, Visualization, Investigation, Conceptualization. **Gianluca Paternoster:** Writing – review & editing, Writing – original draft, Visualization, Investigation, Conceptualization. **Luca Biavati:** Writing – original draft, Visualization, Validation, Conceptualization. **Adriano Peris:** Writing – review & editing, Supervision. **Manuela Bonizzoli:** Writing – review & editing, Writing – original draft, Visualization, Validation.

Declaration of competing interest

None.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijcard.2024.132690.

References

[1] J.-T. Gräsner, J. Herlitz, I.B.M. Tjelmeland, J. Wnent, S. Masterson, G. Lilja, B. Bein, B.W. Böttiger, F. Rosell-Ortiz, J.P. Nolan, L. Bossaert, G.D. Perkins, European Resuscitation Council Guidelines, Epidemiology of cardiac arrest in Europe, Resuscitation 161 (2021) (2021) 61–79, https://doi.org/10.1016/j.resuscitation.2021.02.007.

[2] S.S. Virani, A. Alonso, E.J. Benjamin, M.S. Bittencourt, C.W. Callaway, A.P. Carson, A.M. Chamberlain, A.R. Chang, S. Cheng, F.N. Delling, L. Djousse, M.S.V. Elkind, J. F. Ferguson, M. Fornage, S.S. Khan, B.M. Kissela, K.L. Knutson, T.W. Kwan, D. T. Lackland, T.T. Lewis, J.H. Lichtman, C.T. Longenecker, M.S. Loop, P.L. Lutsey, S. S. Martin, K. Matsushita, A.E. Moran, M.E. Mussolino, A.M. Perak, W.D. Rosamond, G.A. Roth, U.K.A. Sampson, G.M. Satou, E.B. Schroeder, S.H. Shah, C.M. Shay, N. L. Spartano, A. Stokes, D.L. Tirschwell, L.B. VanWagner, C.W. Tsao, American Heart Association Council on epidemiology and prevention statistics committee and stroke statistics subcommittee, heart disease and stroke Statistics-2020 update: a report from the American Heart Association, Circulation 141 (2020) e139–e596, https://doi.org/10.1161/CIR.0000000000000757.

[3] D. Abrams, G. MacLaren, R. Lorusso, S. Price, D. Yannopoulos, L. Vercaemst, J. Bělohlávek, F.S. Taccone, N. Aissaoui, K. Shekar, A.R. Garan, N. Uriel, J. E. Tonna, J.S. Jung, K. Takeda, Y.-S. Chen, A.S. Slutsky, A. Combes, D. Brodie, Extracorporeal cardiopulmonary resuscitation in adults: evidence and implications, Intensive Care Med. 48 (2022) 1–15, https://doi.org/10.1007/s00134-021-06514-y.

[4] Z. Shinar, J. Badulak, ECPR and resuscitative ECMO: a detailed look at emergent extracorporeal life support, extracorporeal life support, Organization (2021) 1–45. Chapter 1 and 2.

[5] ELSO International Summary of Statistics | ECMO | ECLS. https://www.elso.org/registry/internationalsummaryandreports/internationalsummary.aspx, 2024 (accessed June 2, 2024).

[6] D. Yannopoulos, J. Bartos, G. Raveendran, E. Walser, J. Connett, T.A. Murray, G. Collins, L. Zhang, R. Kalra, M. Kosmopoulos, R. John, A. Shaffer, R.J. Frascone, K. Wesley, M. Conterato, M. Biros, J. Tolar, T.P. Aufderheide, Advanced reperfusion strategies for patients with out-of-hospital cardiac arrest and refractory ventricular fibrillation (ARREST): a phase 2, single centre, open-label, randomised controlled trial, Lancet Lond. Engl. 396 (2020) 1807–1816, https://doi.org/10.1016/S0140-6736(20)32338-2.

[7] J. Belohlavek, J. Smalcova, D. Rob, O. Franek, O. Smid, M. Pokorna, J. Horák, V. Mrazek, T. Kovarnik, D. Zemanek, A. Kral, S. Havranek, P. Kavalkova, L. Kompelentova, H. Tomková, A. Mejstrik, J. Valasek, D. Peran, J. Pekara, J. Rulisek, M. Balik, M. Huptych, J. Jarkovsky, J. Malik, A. Valerianova, F. Mlejnsky, P. Kolouch, P. Havrankova, D. Romportl, A. Komarek, A. Linhart, Prague OHCA study group, effect of intra-arrest transport, extracorporeal cardiopulmonary resuscitation, and immediate invasive assessment and treatment on functional neurologic outcome in refractory out-of-hospital cardiac arrest: a randomized clinical trial, JAMA 327 (2022) 737–747, https://doi.org/10.1001/jama.2022.1025.

[8] Martje M. Suverein, S.R. Delnoij Thijs, Lorusso Roberto, J. Brandon Bravo Bruinsma George, Otterspoor Luuk, V. Elzo Kraemer Carlos, P.J. Vlaar Alexander, J. van der Heijden Joris, Scholten Erik, Den Uil Corstiaan, Jansen Tim, Van Den Bogaard Bas, Kuijpers Marijn, Lam Ka Yan, M. Montero Cabezas José, H. G. Driessen Antoine, Z.H. Rittersma Saskia, G. Heijnen Bram, Dos Reis Miranda Dinis, Bleeker Gabe, De Metz Jesse, S. Hermanides Renicus, Lopez Matta Jorge, Eberl Susanne, W. Donker Dirk, J. van Thiel Robert, Akin Sakir, Van Meer Oene, Henriques José, C. Bokhoven Karen, Mandigers Loes, J.H. Bunge Jeroen, E. Bol Martine, Winkens Bjorn, Essers Brigitte, W. Weerwind Patrick, G. Maessen Jos, C.G. van de Poll Marcel, Early extracorporeal CPR for refractory out-of-hospital cardiac arrest, N. Engl. J. Med. 388 (2023) 299–309, https://doi.org/10.1056/NEJMoa2204511.

[9] J.F.H. Ubben, S. Heuts, T.S.R. Delnoij, M.M. Suverein, A.F. van de Koolwijk, I.C. C. van der Horst, J.G. Maessen, J. Bartos, P. Kavalkova, D. Rob, D. Yannopoulos, J. Belohlávek, R. Lorusso, M.C.G. van de Poll, ECPR for refractory OHCA - lessons from 3 randomized controlled trials. The trialists'view, Eur. Heart J. Acute Cardiovasc. Care 12 (2023) 540–547, https://doi.org/10.1093/ehjacc/zuad071.

[10] C.J.W. Low, K. Ramanathan, R.R. Ling, M.J.C. Ho, Y. Chen, R. Lorusso, G. MacLaren, K. Shekar, D. Brodie, Extracorporeal cardiopulmonary resuscitation versus conventional cardiopulmonary resuscitation in adults with cardiac arrest: a comparative meta-analysis and trial sequential analysis, Lancet Respir. Med. 11 (2023) 883–893, https://doi.org/10.1016/S22<13-2600(23)00137-6.

[11] S.M. Perman, J. Elmer, C.B. Maciel, A. Uzendu, T. May, B.E. Mumma, J.A. Bartos, A.J. Rodriguez, M.C. Kurz, A.R. Panchal, J.C. Rittenberger, American Heart Association, American Heart Association focused update on adult advanced cardiovascular life support: an update to the American Heart Association guidelines for cardiopulmonary resuscitation and emergency cardiovascular care, Circulation 149 (2024) (2023) e254–e273, https://doi.org/10.1161/CIR.0000000000001194.

[12] J. Nakata, T. Yamamoto, K. Saku, Y. Ikeda, T. Unoki, K. Asai, Mechanical circulatory support in cardiogenic shock, J. Intensive Care 11 (2023) 64, https://doi.org/10.1186/s40560-023-00710-2.

[13] H. Thiele, U. Zeymer, F.-J. Neumann, M. Ferenc, H.-G. Olbrich, J. Hausleiter, G. Richardt, M. Hennersdorf, K. Empen, G. Fuernau, S. Desch, I. Eitel, R. Hambrecht, J. Fuhrmann, M. Böhm, H. Ebelt, S. Schneider, G. Schuler, K. Werdan, IABP-SHOCK II trial investigators, Intraaortic balloon support for myocardial infarction with cardiogenic shock, N. Engl. J. Med. 367 (2012) 1287–1296, https://doi.org/10.1056/NEJMoa1208410.

[14] H. Thiele, U. Zeymer, N. Thelemann, F.-J. Neumann, J. Hausleiter, M. Abdel-Wahab, R. Meyer-Saraei, G. Fuernau, I. Eitel, R. Hambrecht, M. Böhm, K. Werdan, S.B. Felix, M. Hennersdorf, S. Schneider, T. Ouarrak, S. Desch, S. de Waha-Thiele, IABP-SHOCK II trial (Intraaortic balloon pump in cardiogenic shock II) investigators, IABP-SHOCK II investigators, Intraaortic balloon pump in cardiogenic shock complicating acute myocardial infarction: long-term 6-year outcome of the randomized IABP-SHOCK II trial, Circulation 139 (2019) 395–403, https://doi.org/10.1161/CIRCULATIONAHA.118.038201.

[15] P. Ponikowski, A.A. Voors, S.D. Anker, H. Bueno, J.G.F. Cleland, A.J.S. Coats, V. Falk, J.R. González-Juanatey, V.-P. Harjola, E.A. Jankowska, M. Jessup, C. Linde, P. Nihoyannopoulos, J.T. Parissis, B. Pieske, J.P. Riley, G.M.C. Rosano, L. M. Ruilope, F. Ruschitzka, F.H. Rutten, P. van der Meer, ESC Scientific Document Group, ESC guidelines for the diagnosis and treatment of acute and chronic heart failure: the task force for the diagnosis and treatment of acute and chronic heart failure of the European Society of Cardiology (ESC) developed with the special contribution of the heart failure association (HFA) of the ESC, Eur. Heart J. 37 (2016) (2016) 2129–2200, https://doi.org/10.1093/eurheartj/ehw128.

[16] C.J.W. Low, R.R. Ling, M.P.X.L. Lau, N.S.H. Liu, M. Tan, C.S. Tan, S.L. Lim, B. Rochwerg, A. Combes, D. Brodie, K. Shekar, S. Price, G. MacLaren, K. Ramanathan, Mechanical circulatory support for cardiogenic shock: a network meta-analysis of randomized controlled trials and propensity score-matched studies, Intensive Care Med. 50 (2024) 209–221, https://doi.org/10.1007/s00134-023-07278-3.

[17] M.J. Page, J.E. McKenzie, P.M. Bossuyt, I. Boutron, T.C. Hoffmann, C.D. Mulrow, L. Shamseer, J.M. Tetzlaff, E.A. Akl, S.E. Brennan, R. Chou, J. Glanville, J. M. Grimshaw, A. Hróbjartsson, M.M. Lalu, T. Li, E.W. Loder, E. Mayo-Wilson, S. McDonald, L.A. McGuinness, L.A. Stewart, J. Thomas, A.C. Tricco, V.A. Welch, P. Whiting, D. Moher, The PRISMA 2020 statement: an updated guideline for reporting systematic reviews, BMJ 372 (2021) n71, https://doi.org/10.1136/bmj.n71.

[18] J.A.C. Sterne, J. Savović, M.J. Page, R.G. Elbers, N.S. Blencowe, I. Boutron, C. J. Cates, H.-Y. Cheng, M.S. Corbett, S.M. Eldridge, J.R. Emberson, M.A. Hernán, S. Hopewell, A. Hróbjartsson, D.R. Junqueira, P. Jüni, J.J. Kirkham, T. Lasserson, T. Li, A. McAleenan, B.C. Reeves, S. Shepperd, I. Shrier, L.A. Stewart, K. Tilling, I. R. White, P.F. Whiting, J.P.T. Higgins, RoB 2: a revised tool for assessing risk of bias in randomised trials, BMJ 366 (2019) l4898, https://doi.org/10.1136/bmj.l4898.

[19] J.J. Deeks, J. Dinnes, R. D'Amico, A.J. Sowden, C. Sakarovitch, F. Song, M. Petticrew, D.G. Altman, International Stroke Trial Collaborative Group, European carotid surgery trial collaborative group, evaluating non-randomised intervention studies, Health Technol. Assess. Winch. Engl. 7 (2003), https://doi.org/10.3310/hta7270 iii–x, 1–173.

[20] M. Egger, G. Davey Smith, M. Schneider, C. Minder, Bias in meta-analysis detected by a simple, graphical test, BMJ 315 (1997) 629–634, https://doi.org/10.1136/bmj.315.7109.629.

[21] A. Beheshti, M.-L. Chavanon, H. Christiansen, Emotion dysregulation in adults with attention deficit hyperactivity disorder: a meta-analysis, BMC Psychiatry 20 (2020) 120, https://doi.org/10.1186/s12888-020-2442-7.

[22] J. Hartung, G. Knapp, A refined method for the meta-analysis of controlled clinical trials with binary outcome, Stat. Med. 20 (2001) 3875–3889, https://doi.org/10.1002/sim.1009.

[23] R. DerSimonian, N. Laird, Meta-analysis in clinical trials, Control. Clin. Trials 7 (1986) 177–188, https://doi.org/10.1016/0197-2456(86)90046-2.

[24] J. IntHout, J.P. Ioannidis, G.F. Borm, The Hartung-Knapp-Sidik-Jonkman method for random effects meta-analysis is straightforward and considerably outperforms

the standard DerSimonian-Laird method, BMC Med. Res. Methodol. 14 (2014) 25, https://doi.org/10.1186/1471-2288-14-25.
[25] W.G. Cochran, The combination of estimates from different experiments, Biometrics 10 (1954) 101–129, https://doi.org/10.2307/3001666.
[26] J.P.T. Higgins, S.G. Thompson, Quantifying heterogeneity in a meta-analysis, Stat. Med. 21 (2002) 1539–1558, https://doi.org/10.1002/sim.1186.
[27] E. Kagawa, K. Dote, M. Kato, S. Sasaki, Y. Nakano, M. Kajikawa, A. Higashi, K. Itakura, A. Sera, I. Inoue, T. Kawagoe, M. Ishihara, Y. Shimatani, S. Kurisu, Should we emergently Revascularize occluded coronaries for cardiac arrest? Circulation 126 (2012) 1605–1613, https://doi.org/10.1161/CIRCULATIONAHA.111.067538.
[28] P.K. Guru, T.G. Seelhammer, T.D. Singh, D.K. Sanghavi, S. Chaudhary, J.B. Riley, T. Friedrich, J.M. Stulak, D.T. Haile, R. Kashyap, G.J. Schears, Outcomes of adult patients supported by extracorporeal membrane oxygenation (ECMO) following cardiopulmonary arrest. The Mayo Clinic experience, J. Card. Surg. 36 (2021) 3528–3539, https://doi.org/10.1111/jocs.15804.
[29] N. Kuroki, K. Nagao, T. Otsuka, M. Kuwabara, J. Nakata, T. Takayama, Y. Hosokawa, T. Ashida, K. Suzuki, T. Yamamoto, M. Takayama, Combined use of venoarterial extracorporeal membrane oxygenation and intra-aortic balloon pump after cardiac arrest, Resuscitation 167 (2021) 345–354, https://doi.org/10.1016/j.resuscitation.2021.07.019.
[30] X. Chen, J. Chen, R. Wang, J. Zheng, Q. Yang, J. Chen, D. Wen, X. Xiong, Relationship of in-hospital mortality and using intra-aortic balloon pump with extracorporeal cardiopulmonary resuscitation in patients with cardiac arrest: a secondary analysis based on literature data, Zhonghua Wei Zhong Bing Ji Jiu Yi Xue 34 (2022) 269–273, https://doi.org/10.3760/cma.j.cn121430-20211014-01492.
[31] M. Kashiura, Y. Kishihara, H. Ozawa, S. Amagasa, H. Yasuda, T. Moriya, Intra-aortic balloon pump use in out-of-hospital cardiac arrest patients who underwent extracorporeal cardiopulmonary resuscitation, Resuscitation 182 (2023) 109660, https://doi.org/10.1016/j.resuscitation.2022.11.026.
[32] P. Sun, W. Liu, M. Li, L. Zhang, L.-N. Liu, Z.-X. Liu, X.-D. Wang, Extracorporeal cardiopulmonary resuscitation versus conventional cardiopulmonary resuscitation for patients with refractory out-of-hospital cardiac arrest: a retrospective propensity matching analysis, Perfusion (2023), https://doi.org/10.1177/02676591231222365, 2676591231222365.
[33] T. Scquizzato, M.G. Calabrò, A. Franco, E. Fominskiy, M. Pieri, P. Nardelli, S. Delrio, S. Altizio, A. Ortalda, G. Melisurgo, S. Ajello, G. Landoni, A. Zangrillo, A. M. Scandroglio, ECPR-CARE collaborators, extracorporeal cardiopulmonary resuscitation for refractory out-of-hospital cardiac arrest: 10-year experience in a metropolitan cardiac arrest centre in Milan, Italy, Resusc. Plus 17 (2024) 100521, https://doi.org/10.1016/j.resplu.2023.100521.
[34] T. Nishimura, A. Inoue, T. Taira, M. Suga, S. Ijuin, T. Hifumi, T. Sakamoto, Y. Kuroda, S. Ishihara, SAVE-J II study group, intra-aortic balloon pump in patients with extracorporeal cardiopulmonary resuscitation after cardiac arrest caused by acute coronary syndrome, Resuscitation 195 (2024) 110091, https://doi.org/10.1016/j.resuscitation.2023.110091.
[35] Z. Li, J. Gao, J. Wang, H. Xie, Y. Guan, X. Zhuang, Q. Liu, L. Fu, X. Hou, F. Hei, Mortality risk factors in patients receiving ECPR after cardiac arrest: development and validation of a clinical prognostic prediction model, Am. J. Emerg. Med. 76 (2024) 111–122, https://doi.org/10.1016/j.ajem.2023.11.048.
[36] R. Cheng, R. Hachamovitch, R. Makkar, D. Ramzy, J.D. Moriguchi, F.A. Arabia, F. Esmailian, B. Azarbal, Lack of survival benefit found with use of Intraaortic balloon pump in extracorporeal membrane oxygenation: a pooled experience of 1517 patients, J. Invasive Cardiol. 27 (2015) 453–458.
[37] L.-Y. Lin, C.-W. Liao, C.-H. Wang, N.-H. Chi, H.-Y. Yu, N.-K. Chou, J.-J. Hwang, J.-L. Lin, F.-T. Chiang, Y.-S. Chen, Effects of additional intra-aortic balloon counter-pulsation therapy to cardiogenic shock patients supported by extra-corporeal membranous oxygenation, Sci. Rep. 6 (2016) 23838, https://doi.org/10.1038/srep23838.
[38] D. Huang, A. Xu, Q. Guan, J. Qin, C. Zhang, Venoarterial extracorporeal membrane oxygenation with intra-aortic balloon pump for postcardiotomy cardiogenic shock: a systematic review and meta-analysis, Perfusion 38 (2023) 142–149, https://doi.org/10.1177/02676591211042568.
[39] D. Wang, V. Chao, K.H. Yap, T.E. Tan, Does concurrent use of intra-aortic balloon pumps improve survival in patients with cardiogenic shock requiring venoarterial extracorporeal membrane oxygenation? Interact. Cardiovasc. Thorac. Surg. 30 (2020) 312–315, https://doi.org/10.1093/icvts/ivz256.
[40] S. Vallabhajosyula, J.C. O'Horo, P. Antharam, S. Ananthaneni, S. Vallabhajosyula, J.M. Stulak, M.F. Eleid, S.M. Dunlay, B.J. Gersh, C.S. Rihal, G.W. Barsness, Concomitant intra-aortic balloon pump use in cardiogenic shock requiring Veno-arterial extracorporeal membrane oxygenation, Circ. Cardiovasc. Interv. 11 (2018) e006930, https://doi.org/10.1161/CIRCINTERVENTIONS.118.006930.
[41] Y. Liu, M. Zeng, Y. Zhou, W. Qiu, R. Zeng, Y. Zhou, Effect of intra-aortic balloon pump with veno-arterial extracorporeal membrane oxygenation in acute myocardial infarction with cardiogenic shock: a meta-analysis, Perfusion (2023), https://doi.org/10.1177/02676591231189941, 2676591231189941.
[42] Y. Li, S. Yan, S. Gao, M. Liu, S. Lou, G. Liu, B. Ji, B. Gao, Effect of an intra-aortic balloon pump with venoarterial extracorporeal membrane oxygenation on mortality of patients with cardiogenic shock: a systematic review and meta-analysis†, Eur. J. Cardio-Thorac. Surg. Off. J. Eur. Assoc. Cardio-Thorac. Surg. 55 (2019) 395–404, https://doi.org/10.1093/ejcts/ezy304.
[43] J. Bělohlávek, M. Mlček, M. Huptych, T. Svoboda, Š. Havránek, P. Ošťádal, T. Bouček, T. Kovárník, F. Mlejnský, V. Mrázek, M. Bělohlávek, M. Aschermann, A. Linhart, O. Kittnar, Coronary versus carotid blood flow and coronary perfusion pressure in a pig model of prolonged cardiac arrest treated by different modes of venoarterial ECMO and intraaortic balloon counterpulsation, Crit. Care 16 (2012) R50, https://doi.org/10.1186/cc11254.
[44] J. Farag, A.F. Stephens, W. Juene Chong, S.D. Gregory, S.F. Marasco, Intra-aortic balloon pump use with extra corporeal membrane oxygenation-a mock circulation Loop study, ASAIO J. Am. Soc. Artif. Intern. Organs 1992 (68) (2022) 669–675, https://doi.org/10.1097/MAT.0000000000001547.
[45] F. Yang, Z. Jia, J. Xing, Z. Wang, Y. Liu, X. Hao, C. Jiang, H. Wang, M. Jia, X. Hou, Effects of intra-aortic balloon pump on cerebral blood flow during peripheral venoarterial extracorporeal membrane oxygenation support, J. Transl. Med. 12 (2014) 106, https://doi.org/10.1186/1479-5876-12-106.
[46] B. Xu, C. Li, T. Cai, Y. Cui, Z. Du, Q. Fan, D. Guo, C. Jiang, Z. Xing, M. Xin, P. Wang, L. Wang, F. Yang, M. Jia, H. Wang, X. Hou, Intra-aortic balloon pump impacts the regional haemodynamics of patients with cardiogenic shock treated with femoro-femoral veno-arterial extracorporeal membrane oxygenation, ESC Heart Fail. 9 (2022) 2610–2617, https://doi.org/10.1002/ehf2.13981.
[47] P. Bertini, F. Guarracino, Pro: pulsatile flow during cardiopulmonary bypass, J. Cardiothorac. Vasc. Anesth. 37 (2023) 2370–2373, https://doi.org/10.1053/j.jvca.2023.04.034.
[48] G. Paternoster, S. Scolletta, Con: pulsatile flow during cardiopulmonary bypass, J. Cardiothorac. Vasc. Anesth. 37 (2023) 2374–2377, https://doi.org/10.1053/j.jvca.2023.07.002.
[49] A. Tan, C. Newey, F. Falter, Pulsatile perfusion during cardiopulmonary bypass: a literature review, J Extra Corpor Technol 54 (2022) 50–60, https://doi.org/10.1182/ject-50-60.
[50] S.I. Lee, Y.S. Lim, C.-H. Park, W.S. Choi, C.H. Choi, Importance of pulse pressure after extracorporeal cardiopulmonary resuscitation, J. Card. Surg. 36 (2021) 2743–2750, https://doi.org/10.1111/jocs.15614.
[51] J. Rilinger, A.M. Riefler, X. Bemtgen, M. Jäckel, V. Zotzmann, P.M. Biever, D. Duerschmied, C. Benk, G. Trummer, K. Kaier, C. Bode, D.L. Staudacher, T. Wengenmayer, Impact of pulse pressure on clinical outcome in extracorporeal cardiopulmonary resuscitation (eCPR) patients, Clin. Res. Cardiol. 110 (2021) 1473–1483, https://doi.org/10.1007/s00392-021-01838-7.
[52] A. Kalra, J.K. Kang, C. Wilcox, P. Brown, P. Rycus, M.M. Anders, A.M. Zaaqoq, D. Brodie, G.J.R. Whitman, S.-M. Cho, Impact of pulse pressure on acute brain injury in venoarterial ECMO patients with cardiogenic shock during the first 24 hours of ECMO cannulation: analysis of the extracorporeal life support organization registry, Res. Sq. (2023), https://doi.org/10.21203/rs.3.rs-3646443/v1 rs.3.rs-3646443.
[53] Y. Zhang, J. Zeng, X. He, W. Cao, X. Peng, G. Li, Pulsatility protects the endothelial glycocalyx during extracorporeal membrane oxygenation, Microcirc. N. Y. N 1994 (28) (2021) e12722, https://doi.org/10.1111/micc.12722.
[54] G. Li, S. Zhu, J. Zeng, Z. Yu, F. Meng, Z. Tang, P. Zhu, Arterial Pulsatility augments microcirculatory perfusion and maintains the endothelial integrity during extracorporeal membrane oxygenation via hsa_circ_0007367 upregulation in a canine model with cardiac arrest, Oxidative Med. Cell. Longev. 2022 (2022) 1630918, https://doi.org/10.1155/2022/1630918.
[55] H. Itoh, S. Ichiba, Y. Ujike, T. Douguchi, H. Obata, S. Inamori, T. Iwasaki, S. Kasahara, S. Sano, A. Ündar, Effect of the pulsatile extracorporeal membrane oxygenation on hemodynamic energy and systemic microcirculation in a piglet model of acute cardiac failure, Artif. Organs 40 (2016) 19–26, https://doi.org/10.1111/aor.12588.
[56] A. Guy, T. Kawano, F. Besserer, F. Scheuermeyer, H.D. Kanji, J. Christenson, B. Grunau, The relationship between no-flow interval and survival with favourable neurological outcome in out-of-hospital cardiac arrest: implications for outcomes and ECPR eligibility, Resuscitation 155 (2020) 219–225, https://doi.org/10.1016/j.resuscitation.2020.06.009.
[57] T. Otani, H. Sawano, T. Natsukawa, T. Nakashima, H. Oku, C. Gon, M. Takahagi, Y. Hayashi, Low-flow time is associated with a favorable neurological outcome in out-of-hospital cardiac arrest patients resuscitated with extracorporeal cardiopulmonary resuscitation, J. Crit. Care 48 (2018) 15–20, https://doi.org/10.1016/j.jcrc.2018.08.006.
[58] T. Wengenmayer, S. Rombach, F. Ramshorn, P. Biever, C. Bode, D. Duerschmied, D.L. Staudacher, Influence of low-flow time on survival after extracorporeal cardiopulmonary resuscitation (eCPR), Crit. Care Lond. Engl. 21 (2017) 157, https://doi.org/10.1186/s13054-017-1744-8.
[59] K. Rajagopal, Left ventricular distension in Veno-arterial extracorporeal membrane oxygenation: from mechanics to therapies, ASAIO J. Am. Soc. Artif. Intern. Organs 1992 (65) (2019) 1–10, https://doi.org/10.1097/MAT.0000000000000789.
[60] L. Baldetti, M. Gramegna, A. Beneduce, F. Melillo, F. Moroni, F. Calvo, G. Melisurgo, S. Ajello, E. Fominskiy, F. Pappalardo, A.M. Scandroglio, Strategies of left ventricular unloading during VA-ECMO support: a network meta-analysis, Int. J. Cardiol. 312 (2020) 16–21, https://doi.org/10.1016/j.ijcard.2020.02.004.
[61] K.D. Gandhi, E.C. Moras, S. Niroula, P.D. Lopez, D. Aggarwal, K. Bhatia, Y. Balboul, J. Daibes, A. Correa, A.C. Dominguez, E.Y. Birati, D.A. Baran, G. Serrao, K. Mahmood, S. Vallabhajosyula, A. Fox, Left ventricular unloading with Impella versus IABP in patients with VA-ECMO: a systematic review and meta-analysis, Am. J. Cardiol. 208 (2023) 53–59, https://doi.org/10.1016/j.amjcard.2023.09.023.
[62] E.W. Grandin, J.I. Nunez, B. Willar, K. Kennedy, P. Rycus, J.E. Tonna, N.K. Kapur, S. Shaefi, A.R. Garan, Mechanical left ventricular unloading in patients undergoing Venoarterial extracorporeal membrane oxygenation, J. Am. Coll. Cardiol. 79 (2022) 1239–1250, https://doi.org/10.1016/j.jacc.2022.01.032.