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Simulation and education

The effect of a structured ECPR protocol aided by specific simulation training in a quaternary ECMO centre: A retrospective pre-post study

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Abstract

Background: There is limited literature exploring the relationship between simulation training and extracorporeal cardiopulmonary resuscitation (ECPR) outcomes. We examined whether there was an association between the implementation of an in situ simulation training program and ECPR utilisation, time to extracorporeal membrane oxygenation (ECMO), and neurologically intact survival.

Methods: In this retrospective pre-post study of in-hospital cardiac arrests (IHCA) and out-of-hospital cardiac arrests (OHCA), we analysed data for all patients recorded as receiving ECPR from September 2009 to December 2020 at our institution, relative to the implementation of an in situ ECPR simulation training program and a standardised procedure for high-quality ECPR. The primary outcome was Cerebral Performance Category (CPC) 1 or 2 at hospital discharge.

Results: There were 27 patients in the pre-intervention period and 39 patients in the post-intervention period. The median ECPR rate per year was 2 pre-intervention and 7 post-intervention ($p = 0.073$). There was an association between the implementation of the program and decreased median time from OHCA to ECMO flow, from 87 (IQR 78–95) minutes pre-intervention to 70 (IQR 69–72) minutes post-intervention ($p = 0.002$). Median time from IHCA to ECMO flow was 40 (IQR 20–75) minutes pre-intervention and 28 (IQR 16–41) minutes post-intervention ($p = 0.134$). Survival with CPC 1 or 2 was 7/27 (25.9%) pre-intervention and 15/39 (38.5%) post-intervention ($p = 0.288$).

Conclusion: We observed an association between the implementation of an ECPR-specific simulation program and decreased time from OHCA to ECMO flow. There was no association between the implementation of the program and neurologically intact survival at hospital discharge.

Keywords: Simulation, Education, Extracorporeal membrane oxygenation, Extracorporeal cardiopulmonary resuscitation, Cardiac arrest, Resuscitation

Introduction

Cardiac arrest is the most common cause of sudden death in otherwise healthy adults, with sudden cardiac death accounting for more than 60% of all deaths due to cardiac causes.[1] There is a significant burden of morbidity in those patients that initially survive cardiac arrest, particularly concerning neurological deficit. Survival of out-of-hospital cardiac arrest (OHCA) with favourable neurological function, defined as a cerebral performance category (CPC) score of 1 or 2, is only seen in approximately 8.5% of patients.[1,2] This implies that up to 24% of those that survive OHCA suffer severe neurological deficit or worse. Neurological outcomes following in-hospital cardiac arrest (IHCA) are more favourable; 21.2% of all patients have good functional status at hospital discharge.[1]

Refractory cardiac arrest can generally be defined as that which is incessant after 3 direct current shocks or after the administration of antiarrhythmics, both usually occurring within 15 minutes of commencement of cardiopulmonary resuscitation (CPR).[3] There is a linear and rapid decrease in probability of survival with good functional status as the duration of CPR increases; after 15 minutes of CPR, the probability of a good functional recovery deteriorates below 2%.[4] The rapid deployment of extracorporeal membrane oxygenation (ECMO) provides oxygenation and circulatory support during

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ongoing CPR in patients without sustained return of spontaneous circulation (ROSC) with conventional CPR; this is termed ECPR.[5] In one cohort, more than 80% of patients with refractory VF/VT arrest had underlying clinically significant coronary artery stenosis and over 60% had acute thrombotic lesions[6]; ECPR can be implemented as a means of maintaining perfusion in these patients to allow for reversal of the causative pathology regardless of underlying rhythm.

A systematic review and meta-analysis found that shorter low-flow time was the most consistent predictor of ECPR survival.[7] A small before-after study in the paediatric population reported a significantly reduced ECMO deployment time after the implementation of a high-fidelity simulation program[8] and, in adults, a prospective cohort study examining the utility of high-fidelity simulation training in ECPR delivery in the emergency department (ED) reported sustained improvements in time to ECMO support in a simulation setting following completion of a three-day program.[9] Taken in summation, this presents a unique opportunity to explore the effect of targeted ECPR simulation training on time to ECMO flow and favourable neurological outcome in ECPR patients. To our knowledge, no study has examined the real-world effect of such a program on ECPR utilisation and outcomes in adults.

In this study, we examined 11 years' worth of retrospective ECPR data in relation to the implementation of a multidisciplinary in situ simulation program for ECPR aimed at improving logistics and reducing time to ECMO flow. This included the review and refinement of ECPR delivery and processes at our institution, with ECPR simulation as a vital component. We hypothesised that there would be a decrease in low-flow time, and an increased rate of neurologically intact survival following the intervention.

Methods

Study setting and population

The study took place at St Vincent's Hospital, Sydney (SVHS), a quaternary ECMO referral centre with approximately 60 ECMO runs per year. The ICU outreach team attends all in-hospital arrests and admits about 50 patients post cardiac arrest annually. This study was approved by the St Vincent's Hospital human research ethics committee (ref. LNR/15/SVH/117).

Design

Retrospective observational study of prospectively collected data on all patients who underwent ECPR (both IHCA and OHCA) at SVHS from 2009 to 2020, before and after the revision of the ECPR process at our institution coinciding with the implementation of an ECPR-specific in situ simulation program.

Development of the program began in 2014 and was fully established by the end of 2015. We therefore defined two groups:

- 2009–2015: Pre-intervention group
- 2016–2020: Post-intervention group

Pre-intervention practice

Prior to this described change in process, ECPR was delivered on an ad hoc basis as determined by treating clinicians present at the time of arrest, with cannulation performed by cardiothoracic surgeons or cardiac anaesthetists. No guidelines regarding indications nor standardised processes existed.

Description of the intervention

Development

Following the identification of the need for an improved ECPR protocol at our institution, a multidisciplinary in situ simulation program for ECPR was developed within the department of intensive care (ICU). In situ ECPR simulations with detailed debriefing and video analyses were used to clarify roles and logistics. A procedure for high-quality ECPR was subsequently created using task analysis, video review and structured debriefings, a process which identified barriers to effective ECPR and strategies for improvement, culminating in a new hospital-wide policy. The crux of this intervention was the dissemination of the new procedure to staff in a one-day workshop which included in situ simulation commencing in the pre-hospital setting, through to ED, followed by interventional cardiology and then ICU. Personnel involved in this workshop and simulation session were ICU specialists and registrars, ECMO accredited ICU nursing staff, ED specialists and registrars, perfusionists, and NSW Ambulance personnel. This large-scale simulation was repeated several weeks later, and the implementation of the program was prospectively observed within a clinical multicenter study.[10] Following the implementation of the protocol and simulation training program, cannulations were performed by ICU specialists in addition to cardiothoracic surgeons and cardiac anaesthetists.

Content, frequency and personnel

The ECPR simulation program at our facility was designed as an ongoing and dynamic quality improvement project which includes accreditation processes for medical and nursing staff. Fortnightly short ECPR simulation sessions for ICU nursing staff involve accessing the ECPR trolley, operating the ECMO console, and establishing ECMO flows on the pre-primed ECMO unit designated for ECPR. These one-hour sessions are used to maintain skills and to achieve accreditation for ICU nurses with an average of 5 attendees per session.

Multidisciplinary one day ECMO workshops occur 3–5 times throughout the year involving ICU specialists and registrars, ECPR-accredited nursing staff, and perfusionists. Simulations cover the process of identifying an eligible cardiac arrest, mobilising the ECPR trolley and pre-primed ECMO circuit to the patient, accessing equipment in the ECPR trolley and practicing the process of cannulating the patient onto the ECMO circuit.

In addition, annual simulation training sessions occur which additionally involve ED clinicians to simulate OHCA scenarios; these involve 10–15 clinicians and last for 3 hours including extensive debriefing. Simulations that run through to the cardiac catheterisation lab occur on an ad hoc basis and are usually part of a large scale OHCA scenario involving prehospital and ED personnel. Education material is shared internally as well as externally (https://www.learnecmo.com/ecpr).[11]

Indications and exclusion criteria for ECPR, ECPR team composition and equipment, and a detailed description of the ECPR process is detailed in the appendix.

Primary and secondary endpoints

The primary endpoint was neurologically intact survival to hospital discharge, defined as a CPC score of 1 or 2. Secondary endpoints were time from cardiac arrest to ECMO flow and utilisation of ECPR.

Data extraction and outcome measurement

The investigators retrospectively examined complete records for all patients recorded as having received ECPR at SVHS from 2009 to 2020 before and after the development of a new and structured hospital-wide ECPR protocol and multidisciplinary in situ simulation program for the delivery of high-quality ECPR. These patients were identified from an existing database of all ECMO runs at SVHS.

Circumstances surrounding the implementation of ECMO in each patient were scrutinised to ensure that each encounter met the accepted definition of ECPR.[12] Only records where the cannulation was commenced during ongoing CPR were included. Timeline and survival data were extracted and a CPC score for each survivor at discharge was determined by complete file review.[5]

Data was compiled in REDCap[13] then exported to and organised within Microsoft Excel (Microsoft Excel for Microsoft 365, Version 16.0.13801.20288). Median utilisation per year and median time from cardiac arrest to ECMO flow were calculated for each group, and the Mann-Whitney U test was used to compare differences. Pearson's chi-squared test was implemented to compare survival to hospital discharge with a favourable CPC score in both groups. A p value of <0.05 was considered significant. Statistical analysis was performed using IBM SPSS Statistics 27.[14]

Results

76 patients were identified from a database of all ECMO runs at our institution. 10 patients were excluded (4 underwent ECPR at an external site; 3 did not satisfactorily fulfil the definition of ECPR; medical records for 2 patients were unlocatable; and 1 patient underwent two episodes in a single admission). 66 patients were included in the final cohort. Table 1 displays baseline characteristics and demographics of all 66 included patients.

Demographics

See Table 1.

Primary Endpoint: Neurologically intact survival to hospital discharge

In the pre-intervention period 7/27 (25.9%) patients survived to hospital discharge with a favourable CPC score. Following the implementation of the ECPR simulation program, 15/39 (38.5%) patients survived to hospital discharge with a favourable CPC score (Fig. 1, Table 2). There was no association between the implementation of the ECPR simulation training program and neurologically intact survival ($p = 0.288$). Excepting one patient in the pre-intervention group – who survived with a CPC of 3 – all survivors had good neurological function at discharge (CPC 1 or 2).

Time to ECMO flow (low-flow time)

Median time from cardiac arrest to ECMO flow was 49 (IQR 20–75) minutes in the pre-intervention period and 42.5 (IQR 27–69) minutes in the post-intervention period ($p = 0.277$) when considering OHCA and IHCA as a single cohort (Fig. 2, Table 2).

OHCA

Timeline data was available for 6/7 (85.7%) patients in the pre-intervention period and 13/14 (92.9%) patients in the post-intervention period. We observed an association between the implementation of the ECPR simulation training program and a decrease in time from OHCA to ECMO flow from a median of 87 (IQR 78–95) minutes in the pre-intervention period to a median of 70 (IQR 69–72) minutes in the post-intervention period (Fig. 2, Table 2). This difference was found to be statistically significant ($p = 0.002$).

IHCA

Timeline data was available for all patients in the pre- and post-intervention periods. There was no observed association between the implementation of the simulation training program and time to ECMO flow (Fig. 2, Table 2). Time from IHCA to ECMO flow was 40 (IQR 18–58.5) minutes in the pre-intervention period and 28 (IQR 16–41) minutes in the post-intervention period ($p = 0.134$).

Utilisation

We observed a median ECPR utilisation rate of 2 cases per year in the pre-intervention period and 7 cases per year in the post-intervention period (Fig. 3). There was no association between the implementation of the simulation training program and ECPR utilisation ($p = 0.073$).

Discussion

In this single-centre, observational pre-post study, we observed an association between the implementation of an ECPR simulation training program and decreased time from OHCA to ECMO flow. There was no association between the implementation of the program and the primary outcome of neurologically intact survival to hospital discharge, time from IHCA to ECMO flow, or ECPR utilisation.

The utility of ECPR in improving neurologically intact survival in refractory cardiac arrest is the subject of ongoing research. A meta-analysis of studies comparing survival trends in ECPR and conventional CPR reported twice the rate of survival to discharge in favour of ECPR.[15] Recently, a retrospective multicentre study reported overall survival with favourable neurological outcome in 19% of 423 with refractory IHCA and OHCA treated with ECPR; this increased to 38% when stringent selection criteria for ECPR was applied.[16] This criteria was similar to that used in our institution, and we observed a similar neurologically intact survival rate in the post-intervention period (38.5%).

Conversely, poor survival outcomes in ECPR for refractory OHCA have been recently reported in Germany, with 7.5% survival with a favourable neurological outcome.[17] Importantly, 70% of these patients had a low-flow period of $\geq$90 minutes; in our cohort there were no patients with a low-flow period of this length in the post-intervention period, with a median of 70 minutes low-flow time. Robust evidence from a systematic review and meta-analysis examining predictors of favourable outcomes demonstrates that low-flow time is the most important determinant of survival.[7] Therefore, the pre-hospital management of cardiac arrest (beginning with immediate and effective bystander CPR) is critical. The inclusion of ambulance personnel in simulations and the subsequent improvement in identification and expeditious transfer of candidates in the OHCA cohort likely contributed to the observed decrease in low-flow time temporally related to the intervention, the importance of which has been well quantified; a study analysing 7299 patients with witnessed OHCA but without bystander CPR showed a 13% decrease in survival with favourable neurological outcome for every additional minute of no-flow time before the commencement of high-quality

Table 1 – Patient demographics and cardiac arrest factors.

	Pre-intervention (n = 27)	Post-intervention (n = 39)
Demographics		
Age (years)	51 (3)	55 (3)
Male	17 (63.0%)	28 (71.8%)
BMI[1] (kg/m[2])	27.7 (1.3)	26.9 (0.8)
Cardiac arrest		
Location		
In-hospital	20 (74.1%)	25 (64.1%)
Out-of-hospital	7 (25.9%)	14 (35.9%)
Witnessed	27 (100%)	36 (92.3%)
Bystander CPR[2]		
Initial rhythm	26 (96.3%)	38 (97.4%)
Ventricular fibrillation	6 (22.2%)	15 (38.5%)
Ventricular tachycardia	3 (11.1%)	3 (7.7%)
Pulseless electrical activity	10 (37.0%)	14 (35.9%)
Asystole	6 (22.2%)	4 (10.3%)
Unknown	1 (3.7%)	1 (2.6%)
Any period of ROSC[3] recorded	12 (44.4%)	12 (30.8%)
Comorbidities		
Diabetes mellitus	8 (29.6%)	11 (28.2%)
Chronic renal disease (CKD[4] 1–3)	0 (0.0%)	4 (10.3%)
Heart failure (NYHA[5] 1–2)	1 (3.7%)	3 (7.7%)
Known ischaemic heart disease	7 (25.9%)	6 (15.4%)
Previous cardiac intervention*	10 (37.0%)	13 (33.3%)
Previous heart transplant	3 (11.1%)	7 (17.9%)

Data are n (%) or mean (SD).

[1] Body mass index.

[2] Cardiopulmonary resuscitation.

[3] Return of spontaneous circulation.

[4] Chronic Kidney Disease category.

[5] New York Heart Association functional classification of heart failure.

* Includes previous PCI/coronary stenting, coronary artery bypass grafting, valve replacement or repair, or heart transplant.

CPR.[2] The authors also reported that favourable outcomes were possible with up to 20 minutes of no-flow time, though our cut-off time of 10 minutes is consistent with most ECPR protocols.[18]

The ARREST trial importantly provided the first randomised clinical trial data demonstrating significantly greater survival in patients receiving early VA-ECMO facilitated resuscitation versus standard ACLS in refractory VF cardiac arrest, resulting in an early termination of the study due to the significant survival benefit.[19] The interventional arm of this study also included patients who did not strictly receive ECPR, and for 20% of this group ECMO was not initiated; this pragmatic and broader approach to analysing ECPR patients and patients with ROSC who receive VA-ECMO for worsening haemodynamic instability (e.g. profound cardiogenic shock)[20] accurately reflects cardiac arrest management in a large ECMO centre, and gives credit to the fact that these patients may have regained some temporary spontaneous circulation but are likely to arrest again if no mechanical support is offered. In this study we did not observe an association between the implementation of the simulation training program and neurologically intact survival but believe that this study is underpowered to detect such a difference.

In concordance with our findings, a small study in the paediatric population demonstrated a significant reduction in low-flow time following the implementation of a simulation training protocol.[8] Conflicting results in a similar population were reported more recently, which surprisingly recorded a non-significant increase in low-flow time following the implementation of high-fidelity ECPR simulation training, despite a significant reduction in activation time.[21] All arrests in this study were in-hospital and specifically in the ICU, with the authors speculating that there was simply too little room for improvement to observe any meaningful change in this metric. This is not dissimilar to our own experience with ECPR delivery in the IHCA cohort; we also suggest that there may currently be minimal scope for further reductions in time to ECMO flows in the IHCA setting. Beyond this, the real-world effectiveness of simulation training for ECPR has not yet been clearly established. The implementation of simulation training for ECPR is largely informed by the proven benefit of simulation training in ACLS and resuscitation skill performance and patient outcomes.[22,23]

Though this study did not demonstrate an association between the intervention and ECPR utilisation, we speculate that the raw increase in ECPR numbers was likely due to both an increased awareness and the development of a clear protocol as opposed to a change in rates of refractory cardiac arrest. It has been shown that the development of an ECPR protocol alone may be linked to increased utilisation.[24] Importantly, the 2CHEER study provided significant impetus to expedite both the development of a clear ECPR protocol and the introduction of structured ECPR simulation training at our institution.[10]

This was a single centre, retrospective observational study and inherently has several limitations. Firstly, data extraction and analysis were limited by the accuracy and completeness of recording at the time of arrest and cannulation. Incomplete documentation or

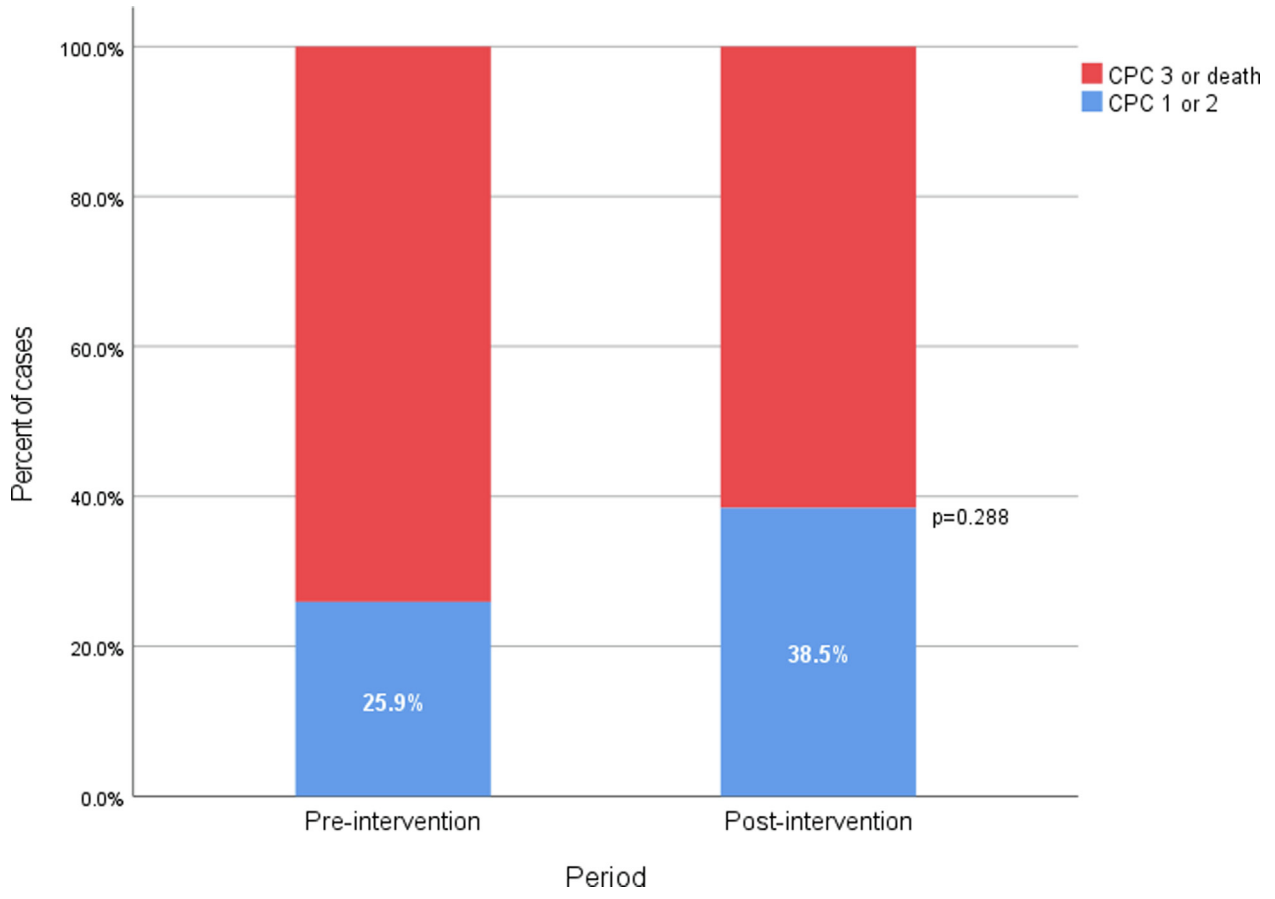

Fig. 1 – Cerebral Performance Category score at discharge. CPC = Cerebral Performance Category.

Table 2 – Outcomes: Neurologically intact survival and time to ECMO flow.

	Pre-intervention	Post-intervention		*p*
CPC score at discharge n (%)	CPC 3 or death	20 (74.1%)	24 (61.5%)	0.288
	CPC 1 or 2	7 (25.9%)	15 (38.5%)	
Time to ECMO flow Median time, mins (IQR)	Overall	49 (20–75)	42.5 (27–69)	0.277
	IHCA	40 (18–58.5)	28 (16–41)	0.134
	OHCA	87 (78–95)	70 (69–72)	0.002

CPC = Cerebral Performance Category score at discharge; IQR = Interquartile range; IHCA = in-hospital cardiac arrest; OHCA = out-of-hospital cardiac arrest.

missing files precluded timeline analysis in 3% of cases; 3.7% in the pre-intervention period and 2.6% in the post-intervention period. Secondly, the small sample size means that this study lacks the statistical power to detect many clinically relevant outcomes, and precluded adjustment for baseline characteristics in reporting the primary outcome of neurologically intact survival.

Thirdly, there are confounding factors that could not be controlled for. The local implementation of mechanical CPR devices in ambulances was an important factor in the OHCA cohort, facilitating the transfer of patients in refractory cardiac arrest whilst maintaining consistent and high-quality CPR as compared to manual CPR.[25] This occurred at a similar time to the development of our ECPR simulation training program and was integral to the protocol of the 2CHEER study.[10] The effect of this on low-flow time could not be controlled for in this study, and our experience is that mechanical CPR devices certainly facilitate expeditious transfer of patients with effective CPR to both allow candidacy for ECPR and achieve earlier ECMO flows.

A further uncontrollable factor is the benefit of time and experience leading to improved team performance, and a subsequent reduction in time to ECMO flows as clinicians gain experience in the implementation of ECPR. Despite analysing 11 years' worth of data, ECPR is a relatively rare event. In situ simulation training allows additional experience to be accrued in the absence of real arrests. The relatively small sample highlights the broader need for large, multicentre studies to further elucidate the degree of effectiveness of ECMO-facilitated CPR, optimal candidates, and broader recommendations for implementation into widespread practice.

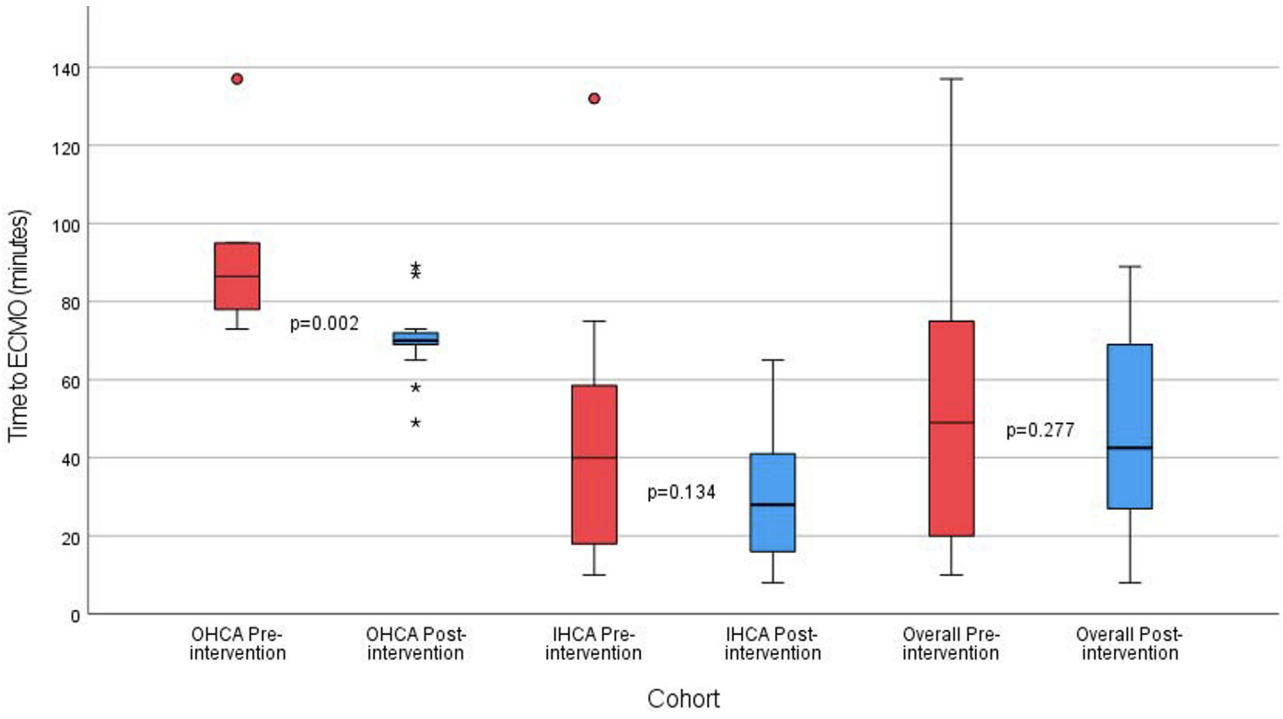

Fig. 2 – Time to ECMO flow, box plot. OHCA = Out-of-Hospital Cardiac Arrest, IHCA = In-Hospital Cardiac Arrest.

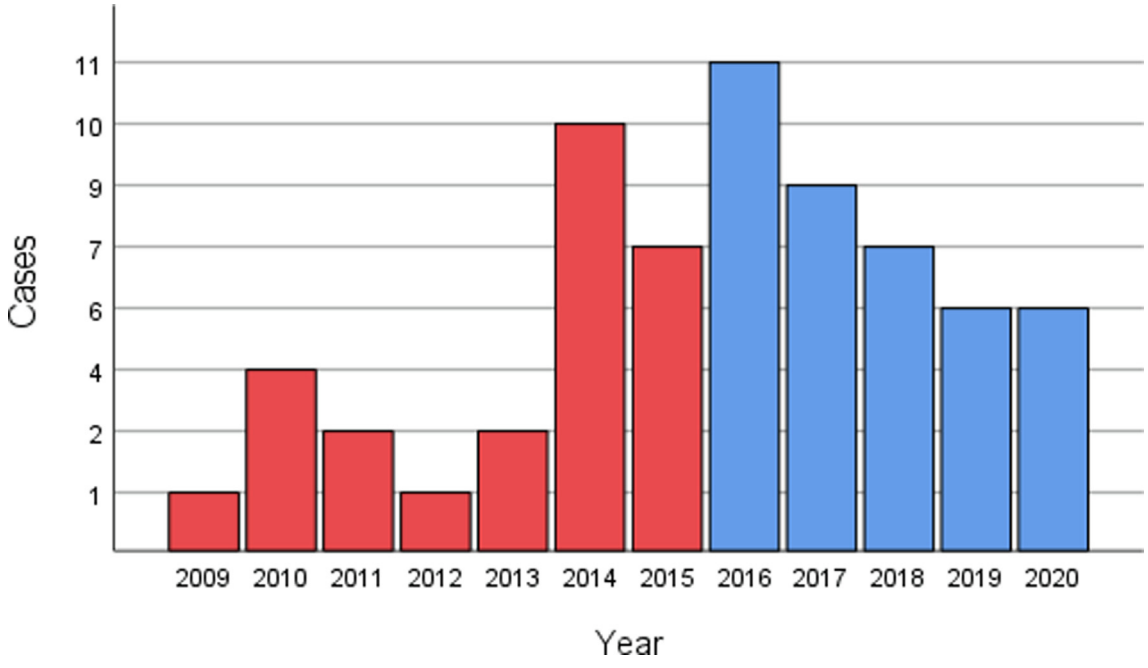

Fig. 3 – ECPR Utilisation 2009–2020.

Conclusions

In this retrospective pre-post study, we observed an association between the implementation of an ECPR simulation training program and a reduction in time from OHCA to ECMO flow in delivering ECPR in real patients at our institution. There was no association between the implementation of the program and the primary outcome of neurologically intact survival. To our knowledge, this is the first study in adult patients to demonstrate the effectiveness of simulation training in reducing low-flow time in ECPR.

Conflicts of interest.

None.

CRediT authorship contribution statement

Andrew C. Read: Investigation, Data curation, Formal analysis, Writing – original draft. **Stephen Morgan:** Writing – review & editing, Validation, Conceptualization. **Claire Reynolds:** Validation, Resources, Supervision. **Jeff Breeding:** Validation, Resources, Data curation, Writing – review & editing. **Sean Scott:** Conceptualization, Validation. **David A. Lowe:** Conceptualization, Methodology. **Sally Newman:** Validation, Resources. **Rosemary Kennedy:** Validation, Resources. **Hergen Buscher:** Conceptualization, Methodology, Supervision, Writing – review & editing.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.resplu.2022.100234.

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