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Clinical paper

The impact of injuries at the time of cardiac arrest on the prognosis of extracorporeal cardiopulmonary resuscitation (ECPR) in out-of-hospital cardiac arrest patients

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Abstract

Aim: Extracorporeal cardiopulmonary resuscitation (ECPR) is an effective treatment for out-of-hospital cardiac arrest and refractory ventricular fibrillation. Despite the success of this intervention, trauma is a potential complication that may adversely impact patient outcomes. This study assessed the incidence and impact of trauma in patients who underwent ECPR. We hypothesized that all trauma incurred until the conclusion of ECPR would have a significant negative effect on survival and neurological outcomes.

Methods: This retrospective observational study examined all ECPR patients admitted to a tertiary emergency medical center between January 2015 and December 2021. All patients underwent pan-scan computed tomography (CT) before admission to the intensive care unit. The head and body trauma were assessed from CT images taken after ECPR. Trauma was defined as all trauma affecting post-ECPR management. In other words, all trauma caused by collapse, trauma caused by resuscitative actions such as chest compressions, and vascular injuries associated with ECPR were included. Univariate analysis of neurological prognosis and 30-day survival due to complicated trauma was performed.

Results: A total of 189 patients (mean age 55.2 ± 13.4 years; 85.2% male) were included in this study. Four patients (2.1%) had head trauma, and 31 patients (16.4%) had torso trauma. All patients with head trauma died during extracorporeal membrane oxygenation management. In patients with torso trauma, 30-day survival was not significantly different compared with that in those without trauma (31.5% vs. 41.9%, $P = 0.60$); good neurological outcomes were almost the same (26.0% vs. 25.8%, $P = 1.00$). Approximately half of the patients with torso trauma (48%) underwent transarterial embolization.

Conclusion: Patients treated with ECPR can suffer a variety of traumatic injuries from the time of collapse to the establishment of ECMO. Head trauma may be lethal and warrants caution. With appropriate treatment, patients with torso trauma may have an equivalent prognosis to those without traumatic complications.

Keywords: Extracorporeal membrane oxygenation, Extracorporeal cardiac life support, Trauma

Introduction

The prognosis after out-of-hospital cardiac arrest (OHCA) is poor, with a 30-day survival of 4.6–16.4%.[1] Extracorporeal cardiac life support (ECPR), a resuscitation strategy encompassing extracorporeal membrane oxygenation (ECMO), has demonstrated improved survival rates, ranging from 24% to 33%.[2]

Continuous anticoagulation is required to maintain the ECMO function.[3] In patients with concomitant trauma, there are concerns regarding hemorrhagic complications; therefore, clinicians often avoid using anticoagulants. Previous observational studies have

Abbreviations: OHCA, Out-of-hospital cardiac arrest, ECPR, Extracorporeal cardiac life support, ECMO, Extracorporeal membrane oxygenation, CT, Computed tomography, CPC, Cerebral performance category, TAE, Transcatheter arterial embolization

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reported that 16–65% of patients who undergo ECPR have concomitant trauma.[4] No guidelines exist on how to administer anticoagulation to trauma patients on ECMO. Empirically, when the ECMO flow rate is 3 L/min or higher, the risk of thrombosis can be reduced without the need for aggressive anticoagulation.

However, these studies included only 42–68% of patients who received ECPR simultaneously whilst undergoing computed tomography (CT) imaging, leading to potential selection bias.[4,5] Furthermore, no study has thoroughly investigated trauma before the initiation of ECMO, including trauma caused by a fall at the moment of collapse and resuscitative procedures such as chest compression. Therefore, information regarding the prognosis of concomitant trauma is still lacking, and further research is required.

Trauma can include pre-arrival trauma from collapse or chest compressions and trauma complicated during ECPR. We hypothesized that all trauma incurred until the conclusion of ECPR adversely affects the survival and neurological outcomes of patients who undergo ECPR.

Methods

Study design and setting

This retrospective observational study used the medical records from a single tertiary emergency hospital. The hybrid emergency room of the hospital was equipped with a multislice IVR-CT system (Aquilion CX, TSX-101A; Toshiba Medical System Corp., Tochigi, Japan) and a movable C-arm. The equipment enabled us to perform VA-ECMO cannulation using a C-arm as soon as the patient arrived at the hospital and subsequent routine pan-scan CT without moving to the examination room.[6]

The indications for ECPR of OHCA at our institution are as follows: (i) patients aged ≦65 years who had experienced cardiac arrest with the first recorded cardiac rhythm of ventricular fibrillation or ventricular tachycardia or (ii) patients aged ≦70 years who collapsed after the arrival of emergency medical service personnel and were presumed to have a reversible etiology. All ECMO cannulations were performed percutaneously. The femoral artery and vein were punctured under ultrasonographic guidance. A 16Fr cannula was used for the femoral artery and a 22Fr cannula for the femoral vein. The ECMO circuit consisted of a centrifugal pump (HCF-MP23H) and hollow-fiber HPO-23WH-C oxygenator (MERA CPB Circuit; Senko Medical Instrument Mfg. Corp., Tokyo, Japan).

Patients

Patients transported to the hybrid emergency room and who underwent ECPR for OHCA between January 1, 2015, and December 31, 2021, were included in the study. CT images were retrospectively evaluated for head and torso trauma by radiologist. The Institutional Review Board of Tokyo Metropolitan Bokutoh Hospital approved the study (institutional approval reference number 05–060), which complied with the tenets of the Declaration of Helsinki. The requirement for informed consent was waived due to the retrospective design of the study.

Study outcomes

The primary outcome was survival 30 days after the arrest. The secondary outcome was an excellent neurological prognosis, which was defined as a cerebral performance category (CPC) of 1 or 2 at discharge. The CPC scale ranged from 1 to 5, with 1 representing intact function and 5 representing brain death.[7] All CT images were reviewed by a radiologist, and reports were written from which data relating to trauma were extracted. Skull fractures and intracranial hemorrhages were included as head trauma, whereas fractures and internal organ injuries in the chest and abdomen were included as torso trauma. Among the traumatic injuries identified on CT, puncture complications of ECMO were defined as injuries to the puncture vessel, the vessel through which the wire travelled, or branches that could stray. In this study, puncture complications associated with ECPR were included in torso trauma to investigate how trauma caused by all resuscitative actions affects prognosis. The two groups were divided into head and torso trauma, and AIS was used to compare the different degrees of trauma. Max AIS score was defined to compare the AIS of the different regions: head, chest, abdomen and extremities. This was defined as the maximum value of the AIS in the different regions.

Statistical analysis

Continuous variables were reported as medians with interquartile ranges, and categorical variables as numbers with percentages. We compared characteristics across all patients and between survivors and non-survivors. Univariate analysis was performed using Fisher's exact test for categorical variables. We compared the primary and secondary outcomes between patients with head trauma and those without trauma, and between patients with torso trauma and those without trauma. All statistical tests were two-tailed, and P values < 0.05 were considered significant. All statistical analyses

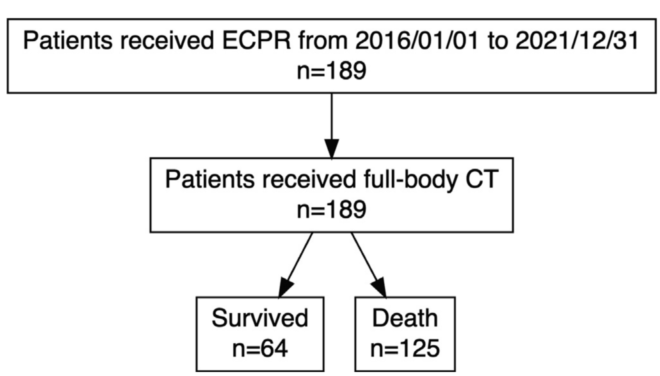

Fig. 1 – Study flow chart. ECPR, extracorporeal cardiopulmonary resuscitation; CT. computed tomography.

Table 1 – Patients characteristics in 189 patients performed ECLS for OHCA.

	Overall	Survivor	Non-survivor
Variables	n = 189	n = 64	n = 125
age (mean (SD))	55.2 (13.4)	54.5 (14.8)	55.6 (12.7)
Male	161 (85.2)	54 (84.4)	107 (85.6)
Antiplatelet drug			
None	166 (87.8)	56 (87.5)	110 (88.0)
Single antiplatelet therapy	14 (7.4)	5 (7.8)	9 (7.2)
Dual antiplatelet therapy	9 (4.8)	3 (4.7)	6 (4.8)
Anticoagulant	10 (5.3)	2 (3.1)	8 (6.4)
Background			
Hypertension	62 (32.8)	14 (21.9)	48 (38.4)
Diabetes mellitus	39 (20.6)	10 (15.6)	29 (23.2)
Dyslipidemia	51 (27.0)	12 (18.8)	39 (31.2)
Atrial fibrillation	3 (1.6)	0 (0.0)	3 (2.4)
Old myocardial infarction	16 (8.5)	4 (6.2)	12 (9.6)
Old cerebral infarction	6 (3.2)	2 (3.1)	4 (3.2)
Chronic kidney disease	15 (7.9)	2 (3.1)	13 (10.4)
Hemodialysis	5 (2.6)	2 (3.1)	3 (2.4)
Liver cirrhosis	4 (2.1)	0 (0.0)	4 (3.2)
Initial rhythm			
Asystole	10 (5.3)	2 (3.1)	8 (6.4)
PEA	50 (26.5)	15 (23.4)	35 (28.0)
Pulseless VT	2 (1.1)	1 (1.6)	1 (0.8)
VF	127 (67.2)	46 (71.9)	81 (64.8)
Time from collapse to ECMO [min](median[IQR])	43.0 [36.0, 52.0]	40.0 [32.8, 52.2]	44.5 [37.0, 52.0]
Time from ECMO to CT scan [min](median[IQR])	33.0 [19.0, 89.2]	51.5 [19.5, 116.5]	28.0 [18.0, 66.5]
Laboratory data			
Hb [g/dL] (median [IQR])	12.0 [10.4, 13.3]	12.1 [11.0, 14.0]	11.9 [10.4, 13.1]
Plt [x10^4/μL] (median [IQR])	13.9 [8.1, 17.3]	14.7 [12.3, 20.4]	12.2 [6.5, 16.4]
PT [%] (median [IQR])	59.3 [45.6, 71.1]	61.2 [43.1, 82.1]	58.9 [46.1, 70.3]
APTT [sec] (median [IQR])	130.0 [60.9, 130.0]	108.0 [40.5, 130.0]	130.0 [69.9, 130.0]
Fib [mg/dL] (median [IQR])	210.0 [170.0, 264.0]	205.0 [165.5, 266.2]	215.0 [171.0, 263.0]
D-dimer [μg/mL] (median [IQR])	12.5 [5.7, 33.2]	10.6 [4.6, 22.7]	13.9 [7.0, 35.7]
Lac [mmol/L] (median [IQR])	13.2 [9.5, 15.8]	11.0 [8.5, 14.5]	13.7 [10.1, 16.0]
GFR [mL/min/1.73 m^2] (median [IQR])	49.9 [40.5, 61.2]	54.1 [41.5, 62.5]	48.2 [38.3, 57.9]
Cardiac arrest cause			
Acute coronary syndrome	85 (45.0)	32 (50.0)	53 (42.4)
Aortic disease	10 (5.3)	1 (1.6)	9 (7.2)
Cardiomyopathy	27 (14.3)	7 (10.9)	20 (16.0)
Arrhythmia	5 (2.6)	2 (3.1)	3 (2.4)
Myocarditis	4 (2.1)	0 (0.0)	4 (3.2)
Pulmonary embolism	14 (7.4)	8 (12.5)	6 (4.8)
Abnormal electrolyte	1 (0.5)	1 (1.6)	0 (0.0)
Endocrine	5 (2.6)	4 (6.2)	1 (0.8)
Hyperthermia/Hypothermia	1 (0.5)	0 (0.0)	1 (0.8)
Hypoxia	4 (2.1)	1 (1.6)	3 (2.4)
Stroke	3 (1.6)	0 (0.0)	3 (2.4)
Other	30 (15.9)	8 (12.5)	22 (17.6)
Body trauma	31 (16.4)	10 (15.6)	21 (16.8)
Head trauma	4 (2.1)	0 (0.0)	4 (3.2)

Data were presented as unweighted number (percentage) of patients unless otherwise indicated.

Abbreviation: GFR, glomerular filtration; ECLS, extracorporeal cardiac life support; OHCA, out-hospital cardiac arrest; PEA, pulseless electorical activity; VF, ventricular fibrillation; VT, ventricular tachycardia.

were performed using R software (R Foundation for Statistical Computing, Vienna, Austria).

Results

In total, 189 patients who underwent ECPR for OHCA were included in the analysis. All patients underwent pan-scan CT after ECMO was initiated before admission to the intensive care unit (Fig. 1). Table 1 shows the baseline characteristics of all the patients. Of these, 67 (35.4%) patients survived 30 days after the arrest, and 48 (25.4%) patients had a good neurological prognosis. The median length of hospital stay was 6 days, and 35 patients (18.5%) had trauma. Table 1 presents the baseline patient characteristics. Head trauma and torso trauma were observed in four (2.1%) and 31 (16.4%) patients, respectively.

Table 2 – Characteristics of head trauma patients received ECLS.

Case	Sex	Age (years)	Timing of CT	Type of head injury	Cause of arrest	Outcome	Max AIS score	Survival days (days)	Medication before arrest
1	M	50	After CAG, PCI	Cerebral contusion, acute subdural hematoma, traumatic subarachnoid hemorrhage	ACS	Death	4	2	None
2	M	81	After CAG, PCI	Cerebral contusion, traumatic subarachnoid hemorrhage	ACS	Death	4	2	None
3	M	64	Before CAG, PCI	Frontal bone fracture, traumatic subarachnoid hemorrhage	ACS	Death	3	2	None
4	M	70	Before CAG, PCI	Traumatic subarachnoid hemorrhage	ACS	Death	3	6	Aspirin, DOAC

Abbreviation: ECLS, extracorporeal cardiac life support; CT, computated tomography; CAG, coronary angiography; PCI, percutaneous coronary intervention; ACS, acute coronary syndrome; DOAC, direct-acting oral anticoagulant.

Table 2 shows detailed characteristics of four patients who had concomitant head trauma and who died whilst in the hospital. Anticoagulation on ECMO was discontinued after intracranial hemorrhage was detected. However, all patients had a worsening intracranial hemorrhage on follow-up head CT after admission.

Table 3 summarizes the characteristics of the 31 patients with concomitant torso trauma. Rib fractures and hemopneumothorax were diagnosed in six (19.3%) patients, mediastinal hematoma with internal thoracic artery injury in 17 (54.8%) patients, and hepatic injuries in four (12.9%) patients. Transarterial embolization was performed in 11 (64.7%) of the patients with intra-mediastinal injuries and in four (100.0%) of the patients with hepatic injuries. The proportions of patients who achieved 30-day survival (41.9% vs. 35.1%, $P = 0.60$) and the rate of good neurological outcomes (25.8% vs. 26.0%, $P = 0.99$) were not significantly different between the patients with torso trauma and those without trauma.

Max AIS scores were a median of 3.5 (IQR 3–4) in the head trauma group and a median of 3.0 (IQR 2–3) in the torso trauma group; mortality was higher with greater severity of AIS (Fig. 2).

Discussion

In previous studies,[4,5] CT was only taken after ECPR in 54.5%–68.3% of cases undergoing ECPR. The present study is unique compared to previous studies in that all patients were imaged immediately after ECPR. Therefore, trauma caused by resuscitation was accurately detected. Moreover, we evaluated the impact of concomitant trauma on life expectancy and neurological prognosis in patients with head and torso trauma. To the best of our knowledge, this is the first study to evaluate the effect of concomitant trauma on patient outcomes. Patients with head trauma had a poor prognosis and all died, whereas those with torso trauma did not differ from the non-trauma group in terms of both survival and neurological prognosis.

At our institution, the outcomes following ECPR have shown significant improvement, surpassing previous records, with a 30-day survival rate of 35.4% and a favorable neurological prognosis of 25.4%.[2] Notably, we observed a median time from cardiac arrest to ECMO establishment of just 43 min, a marked improvement compared with previous study.[2] This achievement can be attributed to the efficient initial treatment protocols, which are believed to have substantially reduced the time between patient arrival at the emergency department and successful establishment of ECMO support.[8]

The prevalence of torso trauma (16.4%) and head trauma (2.1%) was lower than that in previous reports. Yang et al. reported that 4.3% of patients treated with ECPR suffered head injuries.[5] Selection bias may be the primary reason for this result as previous studies[4,5] may have selectively imaged cases in which trauma was clinically suspected, leading to an overestimation of the prevalence of trauma-related complications. In our study, we sought to mitigate this bias by systematically assessing all cases, irrespective of the initial clinical suspicion, thereby providing a more accurate representation of trauma incidence. Another potential reason for this result is the shorter time from cardiac arrest to ECMO cannulation compared with that in previous studies[4–5], as the incidence of trauma caused by resuscitation, such as chest compressions, increases proportionally with the duration of cardiopulmonary resuscitation.[9] Another reason was that the time between ECMO cannulation and CT imaging was shorter than that reported in previous studies.[4,5] If CT imaging is performed shortly after the injury, trauma may not be apparent because of subtle hemorrhage.

Two types of trauma were observed: head trauma and torso trauma. These were caused by different pathophysiology. Head trauma was mainly caused by stroke due to cardiac arrest, whereas torso trauma was caused by resuscitation with CPR and ECPR. The AIS was higher in the head trauma group. The prognosis was poor in all cases of head trauma, whereas the outcomes between patients with and without torso trauma were not significantly different. Intracranial trauma was not detected during ECPR. Anticoagulation therapy was discontinued when the patient had a head injury. Blood transfusions were used as replacement therapy for coagulopathy after resuscitation. However, intracranial hemorrhage worsened in all patients. In addition to the more lethal trauma indicated by the higher AIS, because the skull is a closed cavity, worsening bleeding due to coagulopathy is directly related to prognosis.[10] Consequently, it is easy to miss the timing of treatment. All ECPR patients with a complication of head trauma died because of worsening intracranial hemorrhage. ECMO has been reported to be useful in patients with head trauma,[11] and the prognosis can be improved by discontinuing anticoagulation therapy and using appropriate management with surgical interventions.

Post-ECPR bleeding can be fatal due to various factors such as post-resuscitation coagulopathy and anticoagulation with ECMO.[12] Notably, the favorable prognosis observed despite torso trauma may be attributed to the extensive use of transcatheter arterial embolization (TAE) in 48% of the patients with torso trauma. It is

Table 3 – Characteristics of body trauma patients received ECLS.

Case	Sex	Age (years)	Rib fracture, pneumothorax, hemothorax	ITA injury, anterior mediastinal bleeding	Liver injury	Femoral hematoma, retroperitoneal hematoma	Other injury	TAE	Outcome	Max AIS score	CPC	Cause of arrest
1	M	48		+, EV-				–	Survived	3	1	ACS
2	M	46				+		–	Survived	2	1	ACS
3	F	76			Grade 2, EV+	+		Performed	Survived	2	1	PE
4	M	75		+, EV-				–	Survived	3	2	ACS
5	M	61		+, EV+			Pericardial hematoma	Performed	Survived	3	2	ACS
6	M	85		+, EV+				Performed	Survived	3	2	ACS
7	M	63		+, EV+				Performed	Survived	3	2	Cardiomyopathy
8	F	51			Grade3, EV+			Performed	Survived	2	2	PE
9	M	59		+, EV+				Performed	Survived	3	3	ACS
10	M	60				+		–	Survived	2	4	ACS
11	M	56	+					–	Death	3	5	ACS
12	M	75		+, EV-		+	Rectus sheath hematoma	–	Death	3	5	ACS
13	M	69		+, EV-				–	Death	3	5	ACS
14	M	80				+		–	Death	2	5	ACS
15	M	61		+, EV-				–	Death	3	5	ACS
16	F	56				+		–	Death	2	5	ACS
17	M	65				+		–	Death	2	5	ACS
18	M	67	+					–	Death	3	5	Cardiomyopathy
19	M	55		+, EV-				–	Death	3	5	Cardiomyopathy
20	M	68	+					–	Death	2	5	Cardiomyopathy
21	M	56	+					–	Death	2	5	Cardiomyopathy
22	F	53				+		–	Death	2	5	Myocarditis
23	M	61		+, EV+				Performed	Death	3	5	ACS
24	M	48			Grade3, EV+			Performed	Death	3	5	ACS
25	M	63	+	+, EV+				Performed	Death	3	5	ACS
26	M	62		+, EV+				Performed	Death	3	5	ACS
27	F	50	+		Grade3, EV+			Performed	Death	3	5	ACS
28	M	60		+, EV+				Performed	Death	3	5	Cardiomyopathy
29	M	69		+, EV+				Performed	Death	3	5	Cardiomyopathy
30	M	65		+, EV+			Chest wall hematoma	Performed	Death	3	5	Cardiomyopathy
31	M	70		+, EV+				Performed	Death	3	5	Unknown

Abbreviations: ECLS, extracorporeal cardiac life support; ITA, internal thoracic artery; TAE, trans arterial embolization; CPC, cerebral performance category; ACS, acute coronary syndrome; PE, pulmonary embolism; EV, extravasation

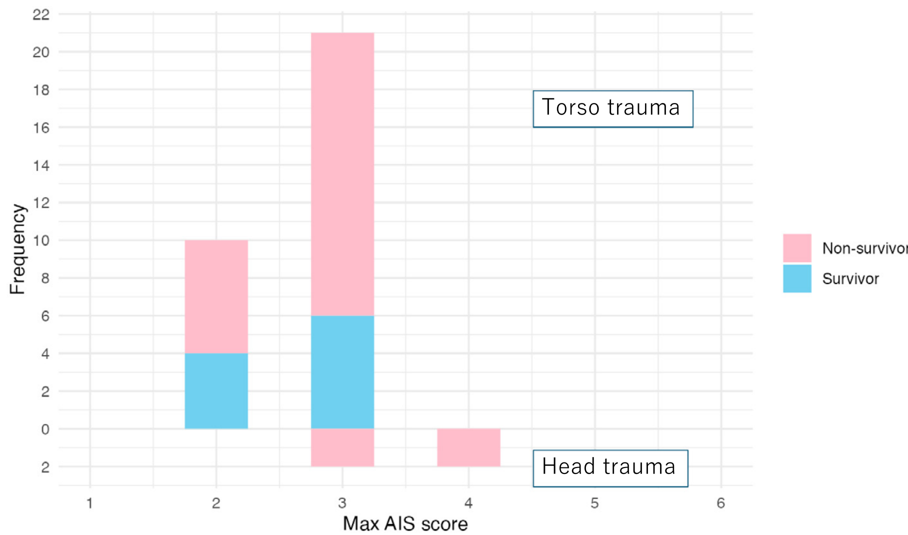

Fig. 2 – Frequency distribution table by survival of trauma patients by Max AIS score.

important to emphasize that our hospital adopted an aggressive approach to achieve hemostasis regardless of the initial estimation of neurological prognosis at the time of primary treatment.

In the present study, 6/189 patients sustained rib fractures. Although it has been reported that patients with more rib fractures receive better CPR and have a better neurological prognosis, this was not the trend in the present study. Patients undergoing ECPR are less likely to suffer rib fractures because they are relatively young. Differences in the use of mechanical compression devices, for which no information was available in this study, may influence the results.

However, the poor prognosis associated with head trauma is an important consideration. At our facility, when intracranial bleeding is detected, we refrain from administering anticoagulation therapy while maintaining ECMO support. Despite these precautions, the outcomes of ECMO in patients with head trauma are unfavorable. This prompted us to contemplate the necessity of developing novel hemostatic strategies for such cases.

Limitations

This study had several limitations. First, it was a single-center study, potentially limiting the generalizability of the findings. The results may be influenced by factors specific to our institution's post-resuscitation care. The time from cardiac arrest to ECMO initiation was exceptionally short, highlighting the efficiency of the Tokyo EMS system. Comparing these results with other regions' EMS systems can provide insights for improvement and adaptation.[13,14] We believe that an environment in which ECMO can be introduced earlier than existing reports is the most favourable environment for improving neurological prognosis and survival. The study of the impact of trauma in such an environment favourable for improved survival could be extrapolated to other ECPR centres.

Additionally, our ECPR criteria required bystander CPR, resulting in a nearly 100% bystander CPR rate and approximately 0 min of no-flow time in most cases. However, we did not collect data on the use of mechanical CPR devices, an important factor that can influence outcomes. Future research should include these variables to provide a more comprehensive understanding of survival and complications, such as thoracic and abdominal trauma, in ECMO use for cardiac arrest patients. Second, all ECPR cases underwent CT imaging at admission, reducing selection bias. However, treatment decisions like TAE were at the clinicians' discretion, introducing potential bias. Finally, the sample size was small, raising the possibility of β-error, meaning some associations or differences might not have been detected. It was not possible to perform a multivariate analysis to determine whether the presence or absence of this trauma contributed to survival. Our study provided a descriptive evaluation of traumatic complications in OHCA patients requiring ECPR, suggesting torso trauma may not significantly affect life expectancy. Further prospective studies are needed to confirm these findings. Overall, these results offer important insights into the effectiveness and limitations of ECPR in trauma-related cardiac arrest.

Conclusions

Trauma in ECPR patients can be classified into two main mechanisms: head trauma occurring during cardiac arrest and torso trauma resulting from resuscitation efforts. We observed that head trauma was associated with higher AIS scores and worse prognosis. Conversely, torso trauma did not show a significant difference in prognosis compared to the group without trauma.

Availability of data and materials

The datasets used and/or analyzed in the current study are available from the corresponding author upon reasonable request.

Ethics approval and consent to participate

The institutional review board of Tokyo Metropolitan Bokutoh Hospital approved the study (institutional approval reference number 05–060), which complied with the tenets of the Declaration of Helsinki. The requirement for informed consent was waived due to the retrospective design of the study.

CRediT authorship contribution statement

Taichi Kato: Writing – original draft, Methodology, Formal analysis, Conceptualization. **Mayu Hikone:** Writing – review & editing, Supervision. **Keita Shibahashi:** Writing – review & editing, Methodology. **Kazuhiro Sugiyama:** Writing – review & editing, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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