Prehospital ABC (Age, Bystander and Cardiogram) scoring system to predict neurological outcomes of cardiopulmonary arrest on arrival: post hoc analysis of a multicentre prospective observational study

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ABSTRACT

Background There is currently limited evidence to guide prehospital identification of patients with cardiopulmonary arrest on arrival (CPAOA) to hospital who have potentially favourable neurological function. This study aimed to develop a simple scoring system that can be determined at the contact point with emergency medical services to predict neurological outcomes.

Methods We analysed data from patients with CPAOA using a regional Japanese database (SOS-KANTO), from January 2012 to March 2013. Patients were randomly assigned into derivation and validation cohorts. Favourable neurological outcomes were defined as cerebral performance category 1 or 2. We developed a new scoring system using logistic regression analysis with the following predictors: age, no-flow time, initial cardiac rhythm and arrest place. The model was internally validated by assessing discrimination and calibration.

Results Among 4907 patients in the derivation cohort and 4908 patients in the validation cohort, the probabilities of favourable outcome were 0.9% and 0.8%, respectively. In the derivation cohort, age ≤70 years (OR 5.11; 95% CI 2.35 to 11.14), no-flow time ≤5 min (OR 4.06; 95% CI 2.06 to 8.01) and ventricular tachycardia or fibrillation as initial cardiac rhythm (OR 6.66; 95% CI 3.45 to 12.88) were identified as predictors of favourable outcome. The ABC score consisting of Age, information from Bystander and Cardiogram was created. The areas under the receiver operating characteristic curves of this score were 0.863 in the derivation and 0.885 in the validation cohorts. Positive likelihood ratios were 6.15 and 6.39 in patients with scores >2 points and were 11.06 and 17.75 in those with 3 points.

Conclusion The ABC score showed good accuracy for predicting favourable neurological outcomes in patients with CPAOA. This simple scoring system could potentially be used to select patients for extracorporeal cardiopulmonary resuscitation and minimise low-flow time.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Extracorporeal cardiopulmonary resuscitation (ECPR)-treated patients are known to have better prognosis if their low-flow times are shorter.

⇒ However, there is no scientifically established method for the prehospital selection of patients with potentially favourable neurological outcomes who are candidates for ECPR.

WHAT THIS STUDY ADDS

⇒ Using a Japanese cardiac arrest registry, we derived and validated a prehospital ABC (Age, Bystander and Cardiogram) score with acceptable performance to predict neurological outcomes of cardiopulmonary arrest on arrival to the hospital.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ This simple and fast ABC score may enable clinicians to select patients for ECPR at a prehospital setting and to save low-flow time, which is a predictor of favourable outcome, thereby improving prognosis.

INTRODUCTION

Approximately 120 000 people in Japan and 30 000 people in England suffer an out-of-hospital cardiac arrest (OHCA) annually.[1 2] Moreover, 90% of these patients do not achieve return of spontaneous circulation prior to hospital arrival,[3] resulting in cardiopulmonary arrest on arrival (CPAOA) to the hospital. In such patients with CPAOA, the likelihood of a favourable neurological outcome is extremely low with conventional cardiopulmonary resuscitation.[4]

Many previous studies have demonstrated that extracorporeal cardiopulmonary resuscitation (ECPR) in patients with CPAOA improves their neurological outcomes as compared with conventional resuscitation.[5 6] Furthermore, patients treated with ECPR have been shown to have better prognosis if their low-flow times are shorter.[7] In contrast, some studies failed to demonstrate the effectiveness of ECPR.[8 9]

Although ECPR may be expected to improve prognosis, patient selection has been problematic. ECPR is a costly and resource-intensive procedure,[10] and it cannot be applied to every patient. Various indications for ECPR have been proposed without scientific evidence; difference in indications has been suggested as a cause of inconsistent outcomes between studies,[11] thereby making meta-analysis difficult.[12 13] ECPR should be performed for patients without irreversible severe brain damage[13]; however, there is no practical and established prehospital method for identifying patients with CPAOA with favourable neurological function, who may be candidates for ECPR.

To select patients who could be candidates for ECPR before hospital arrival, an evidence-based, simple scoring system which enables prediction of favourable neurological outcome is needed.[14] This study aimed to develop a scoring system that can be applied at the time of contact with emergency medical services (EMS) to predict the likelihood of a favourable neurological outcome in patients with CPAOA.

METHODS

Study design and setting

We performed a post hoc analysis of a prospective observational survey of survivors after OHCA in the Kanto area in 2012 (SOS-KANTO 2012).[15] The Kanto is one of Japan's regions, including the Greater Tokyo area, which is densely populated with approximately 40 million people. From January 2012 to March 2013, 67 regional core hospitals and university hospitals participated in the SOS-KANTO 2012. Information was collected on resuscitation, for both dead and survivors. This analysis was conducted according to the standards for reporting diagnostic accuracy studies statement and transparent reporting of a multivariable prediction model for individual prognosis or diagnostic statement.

Selection of participants

We enrolled patients aged ≥18 years who had received advanced cardiovascular life support from a doctor in the hospital for CPAOA. In Japan, advanced cardiovascular life support refers to endotracheal intubation and drug administration for cardiac arrests. Patients were excluded if the reason for their cardiac arrest was categorised as an external cause, such as trauma, burns, accidental hypothermia, hanging, drowning, suffocation and poisoning or if their body temperature on arrival was <30°C. Then, we randomly assigned the enrolled patients into either a derivation cohort or validation cohort at a 1:1 ratio.

Measurements

'No-flow time' was defined as the interval from the moment of collapse to the first chest compression and was obtainable only for a witnessed arrest. We assumed that the initial cardiac rhythm was ventricular tachycardia or ventricular fibrillation when public access defibrillation was performed, in addition to when the first monitored rhythm was one of these ventricular arrhythmias. Neurological outcome was assessed using the cerebral performance category[16] by an original treating physician of each hospital at 3 months following the cardiac arrest. We defined the cerebral performance category of 1 or 2 as a favourable outcome and the category of 3–5 as an unfavourable outcome in line with previous studies.[17] Other detailed definitions of medical terms in this study appear in online supplemental appendix A.

Score derivation

To develop a scoring system to predict neurological outcomes at the time of contact with EMS in patients with CPAOA, we only used the information provided at the scene prior to return of spontaneous circulation. On the basis of the concept of events-per-variable in the logistic regression analysis,[18] we limited the number of variables to be entered to four, which is one-tenth of the number of events in the derivation cohort. The following on-scene information that was shown to be significantly associated with favourable outcomes in previous studies was analysed as candidates of the predictors: age,[19–24] no-flow time,[19 21 23 25] initial cardiac rhythm[19–24] and arrest place.[23 26]

Initially, to determine optimum cut-off values for age and no-flow time for predicting favourable outcome, we used the Youden index (sensitivity+specificity–1)[27] for each receiver operating characteristic analysis as in previous studies.[20 21] Cut-off values providing maximised Youden index were calculated and rounded to the nearest 5 years for age and 5 min for no-flow time for clinical ease of use. No-flow time could not be determined in patients with an unwitnessed collapse. We assigned patients with unwitnessed arrest to a poor prognosis side in the no-flow time category, because they have been known to have a poor prognosis as compared with those with a witnessed arrest.[19 20]

Second, to develop a robust scoring system, we used two methods of logistic regression analysis with on-scene information in the derivation cohort.[18] We derived model 1 using forced entry method with variables selected based on prior knowledge.[18 28] Patient age, no-flow time and initial cardiac rhythm were shown to be predictors of favourable outcomes in more previous studies compared with arrest place. Therefore, we decided to incorporate these three variables into the score. We also developed model 2 using backward elimination method with all four variables. In this logistic regression analysis, we used five complete datasets created by multiple imputation (see details in online supplemental appendix B) to avoid the bias caused by excluding missing cases.

Lastly, we developed a prognostic scoring system to assist in the selection of patients who exhibited favourable neurological outcomes in the derivation cohort. Each predictor was assigned a weight integer (starting at 1 point), based on its OR in the logistic analysis. We sought to find the simplest score assignment, such that the area under the receiver operating characteristic curves (AUROCs) using the new scores was statistically comparable to that drawn with the predicted probability in logistic regression.

Discrimination and calibration

The validity of the new scoring system was tested by assessing both discrimination and calibration in the derivation and validation cohorts. For discrimination, AUROCs of the new score in both cohorts were calculated. The cut-off value of the new score was determined by the Youden index. We also evaluated sensitivity, specificity, positive/negative predictive value and positive/negative likelihood ratio by the new score. The calibration, which reflects the agreement between the predicted and observed probabilities, was examined by plotting these probabilities in a graph. We also conducted the Hosmer-Lemeshow test, in which the null hypothesis is that model outputs are correct, indicating good calibration.

Prediction by the new scores

To determine the proportion of patients to whom the score can be applied, we determined the proportion of CPAOA among all patients with OHCA. To examine the usefulness of the new scoring system, we also calculated the probability of a favourable neurological outcome in patients treated with conventional cardiopulmonary resuscitation or ECPR in increasing order of the scores.

Analysis

The areas under the two receiver operating characteristic curves were compared with the DeLong test. A value of $p<0.05$ was

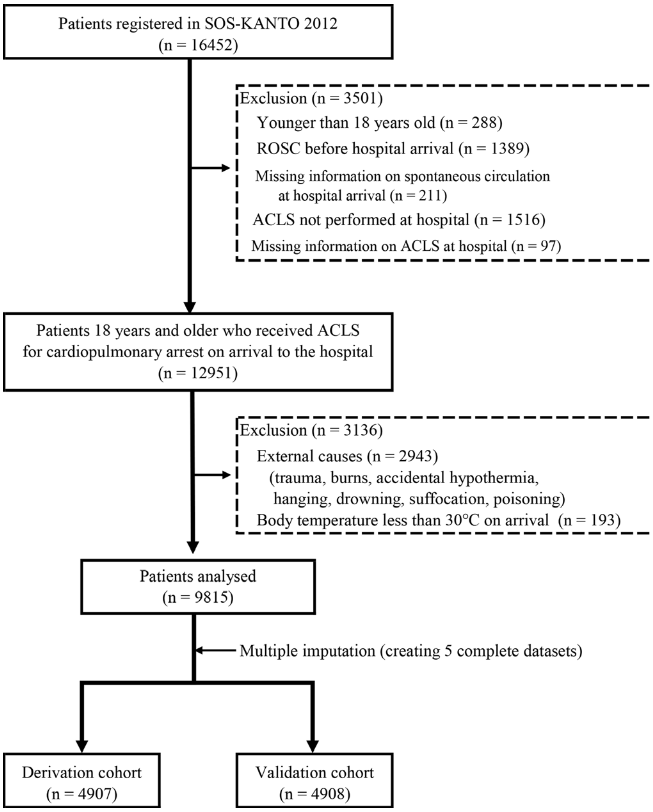

Figure 1 Flow chart of the patient selection. A total of 9815 patients were analysed according to the inclusion and exclusion criteria. They were randomly assigned to either a derivation cohort or a validation cohort. Multiple imputations were performed for logistic regression analysis. ACLS, advanced cardiovascular life support; ROSC, return of spontaneous circulation; SOS-KANTO 2012, survey of survivors after out-of-hospital cardiac arrest in the Kanto area in 2012.

considered statistically significant. All analyses were performed using IBM SPSS Statistics V.26 (Armonk, New York, USA).

Patient and public involvement

Patients or the public were not involved in the design, conduct, reporting or dissemination plans of our research.

RESULTS

Characteristics of study subjects

Of 16 452 patients registered in the SOS-KANTO 2012 study, 9815 patients were selected for analysis applying our inclusion and exclusion criteria. After randomization, the derivation cohort had 4907 patients and the validation cohort had 4908 patients (figure 1). There were no significant differences in patient characteristics between cohorts (table 1). The probability of favourable neurological outcome was 0.9% in the derivation cohort and 0.8% in the validation cohort.

Main results

In the derivation cohort, the cut-off values of age and no-flow time for favourable neurological outcomes were 70 years old and 5 min, respectively (online supplemental appendix D). The models 1 and 2 derived from logistic regression analysis with different methods were consistent (table 2). The age ≤70 years old, no-flow time ≤5 min and ventricular tachycardia or fibrillation as initial cardiac rhythm were included in the scoring system for favourable outcome.

Table 1 Patient characteristics in the derivation and validation cohorts

	Derivation cohort	Validation cohort	Standardised difference, %
	n=4907	n=4908	
Age, years	76 (65–84)	76 (64–84)	−0.3
Witness	2467 (50.3)	2477 (50.5)	0.4
Bystander CPR	1744 (35.5)	1776 (36.2)	1.5
No-flow time, min	7 (1–13)	7 (1–13)	−0.3
Arrest place*			
Public	1398 (28.5)	1400 (28.5)	0.0
Private	3436 (70.0)	3442 (70.1)	0.2
Initial cardiac rhythm*			
VT or VF	469 (9.6)	477 (9.7)	0.3
PEA or asystole	4367 (89.0)	4359 (88.8)	−0.6
Public access defibrillation	100 (2.0)	110 (2.2)	1.4
pH	6.869 (6.755–6.988)	6.868 (6.751–6.988)	−1.0
ECPR	161 (3.3)	153 (3.1)	−1.1
TTM	270 (5.5)	231 (4.7)	−3.6
Revascularisation	106 (2.2)	82 (1.7)	−3.6
Any ROSC	1433 (29.2)	1444 (29.4)	0.4
Time from arrest to ROSC, min	45 (33–60)	45 (33–57)	−7.6
Outcomes after 3 months*			
CPC 1–2	43 (0.9)	39 (0.8)	−1.1
CPC 3–4	26 (0.5)	30 (0.6)	1.1
CPC 5 (death)	4790 (97.6)	4779 (97.4)	−1.6

Categorical variables are presented as numbers (percentages). Continuous variables are presented as medians (IQR). An absolute value of a standardised difference of <10% indicates that the variables are balanced between two groups.
*Total percentages of patients with arrest place, initial cardiac rhythm and outcomes after 3 months did not equal 100% because of missing values.
CPC, cerebral performance category; CPR, cardiopulmonary resuscitation; ECPR, extracorporeal cardiopulmonary resuscitation; PEA, pulseless electrical activity; ROSC, return of spontaneous circulation; TTM, targeted temperature management; VF, ventricular fibrillation; VT, ventricular tachycardia.

According to the ORs in the logistic regression analysis, we assigned 1 point to each predictor to build the score. AUROCs drawn by the score and predicted probability of logistic regression were 0.861 and 0.863, which were not significantly different (p=0.866). This result showed that assigning 1 point to each predictor with a different OR did not reduce the prediction accuracy. We named the score ABC for Age, Bystander and Cardiogram (figure 2).

The AUROCs drawn by the ABC score were 0.863 in the derivation cohort and 0.885 in the validation cohort, respectively (online supplemental appendix E). The cut-off point of the ABC score was 2 in both cohorts.

In the derivation and validation cohorts, the positive likelihood ratio for the ABC score of 2 or more was 6.15 and 6.39 (table 3). The positive likelihood ratio for the ABC score of 3 was 11.06 and 17.75, respectively. In contrast, with an ABC score of 0, the negative likelihood ratio was 0.05 and 0.00 in the derivation and validation cohorts, respectively, and the negative predictive value was 99.95% and 100.00%. The calibration plot showed acceptable agreement of the predicted and observed probabilities at all points of the ABC score in both cohorts (online supplemental appendix F). The Hosmer-Lemeshow test indicated p=0.266 in the derivation cohort and p=0.206 in the validation cohort.

The proportion of CPAOA in patients with total OHCA was 93.0% (95% CI 92.5% to 93.5%) (online supplemental appendix H). The number of patients who underwent ECPR was 12, 68,

Table 2 Logistic regression for predictors of favourable outcomes in the derivation cohort

Variables	OR (95% CI)		
		Model 2 (backward elimination method)	
	Model 1 (forced entry method)	Step 1	Step 2
Age ≤70 years old	5.11 (2.35 to 11.14)	4.94 (2.26 to 10.79)	5.11 (2.35 to 11.14)
No-flow time ≤5 min	4.06 (2.06 to 8.01)	3.89 (1.97 to 7.71)	4.06 (2.06 to 8.01)
VT or VF	6.66 (3.45 to 12.88)	6.07 (3.08 to 11.97)	6.66 (3.45 to 12.88)
Arrest in a public place	–	1.47 (0.78 to 2.79)	–

The parameter of arrest in a public place was not statistically added to the scoring system.
VF, ventricular fibrillation; VT, ventricular tachycardia.

109 and 55 for the ABC scores of 0, 1, 2 and 3, respectively (figure 3). Among them, 0 (0.0%), 5 (7.3%), 9 (8.3%) and 11 (20.0%) patients had a favourable outcome for each ABC score.

DISCUSSION

We have developed the ABC scoring system that can be calculated at the time of contact with EMS to predict the likelihood of a favourable neurological outcome in patients with CPAOA. The ABC score is simple and easy to calculate, using only three variables (Age, information from Bystander and Cardiogram). The score demonstrated an acceptable predictive performance for favourable outcomes, with good discrimination (AUROCs 0.8–0.9) in patients with CPAOA.

The optimal cut-off for the ABC score was 2 points (online supplemental appendix E). The positive likelihood ratio of patients scoring 2 or higher was approximately six in both cohorts. Furthermore, the positive likelihood ratio for 3 points exceeded 10, which is generally considered a good indicator of ruling in a favourable outcome.[29] This means that when the probability of having a good prognosis is in the order of 1% before scoring, it can be expected to increase to 10% if the score is 3 points (see nomogram in online supplemental appendix I). These results indicate that the ABC score could be used at the time of EMS contact to select patients who may be candidates for ECPR, among patients with CPAOA.

An ABC score of 0 in both deriviation and validation cohorts had a likelihood ratio of <0.10, which is generally considered a good indicator of ruling out a favourable outcome (table 3).[29] If the probability of having a good prognosis is considered to be approximately 1% before scoring, it can be expected to be <0.1% when the score is 0 points (See nomogram in online supplemental appendix I). If the ABC score of a patient is 0 points at contact with EMS and spontaneous circulation does not return before hospital arrival, his/her prognosis would be hopeless. Therefore, an ABC score of 0 might be considered a termination rule for resuscitation on hospital arrival.

ABC score	0 point	1 point
A Age	70 < Age	Age ≤ 70
B Bystander	Unwitnessed arrest or 5 min < No-flow time*	No-flow time* ≤ 5 min
C Cardiogram	Asystole or PEA	VT or VF†
Total points	0 – 3 points	

Figure 2 The ABC score. *No-flow time is defined as the interval from the moment of collapse to the first chest compression (obtainable only for a witnessed arrest). †VT or VF indicates that initially monitored rhythm as those or performed public access defibrillation. PEA, pulseless electrical activity; VF, ventricular fibrillation; VT, ventricular tachycardia.

For OHCA, there are already available prediction rules predicting clinical outcomes, such as the simplified OHCA score,[22] the cardiac arrest hospital prognostic score[23] and the SWAP (Shockable, Witnessed, Age, pH) score.[20] The ABC score has two merits over these scores. First, the ABC score is the simplest and can be calculated quickly in mind without the need for special calculation tools. Second, compared with other scores, the ABC score enables us to predict outcomes at the earliest phase of resuscitation. This new score allows emergency ambulance crews to determine the prognosis once they reach the scene, assuming that cardiac arrest will continue until hospital arrival. The ABC score is the only prehospital score for OHCA.

This ABC score applies only to patients with CPAOA, not to all of those with OHCA. However, in this study, nearly 93% of patients with OHCA failed to restore their spontaneous circulation, and thus most patients with OHCA are eligible for assignment of an ABC score.

There are some advantages in selecting patients who can expect a prognosis by using the ABC score and then performing ECPR. First, EMS can select hospitals where ECPR can be performed. Second, the emergency physician can prepare the medical staff and equipment necessary for ECPR at the hospital prior to patient arrival. These two advantages enable us to initiate ECPR earlier and minimise low-flow time, which is a predictor of neurological outcomes. Therefore, the ABC score has potential application for indication of ECPR, which the international resuscitation associations had not specifically mentioned.[12 13 30]

LIMITATIONS

This study has several limitations.

First, the ABC score is applicable only to patients with CPAOA; it is neither applicable to those who had a return of spontaneous circulation before hospital arrival nor to those who experienced in-hospital cardiac arrest. The score does not apply to patients whose no-flow time was indeterminate, even if their arrests were witnessed.

Second, prior to clinical use of the ABC score, prospective external validation should be conducted.

Third, the small number of events in this research may cause the overfitting of the ABC score.

Fourth, we cannot conclude that ECPR improved patient outcomes, although those who received ECPR appeared to have better prognoses than those who received conventional cardiopulmonary resuscitation (figure 3). This is because patients receiving ECPR may have undergone selection by prognostic factors other than the ABC score and may have had favourable outcomes even without ECPR.

Lastly, we found high ABC scores were an indicator of favourable neurological outcome in CPAOA. However, among patients with high ABC scores, some can have favourable outcomes

Table 3 Discrimination of the ABC scores in the derivation and validation cohorts

	Derivation cohort (n=4239)*				Validation cohort (n=4183)*			
ABC score	**0**	**1**	**2**	**3**	**0**	**1**	**2**	**3**
n	2061	1666	413	99	2050	1616	420	97
Favourable outcome	1	10	18	9	0	8	13	12
ABC score		**1≤**	**2≤**	**3**		**1≤**	**2≤**	**3**
n		2178	512	99		2133	517	97
Favourable outcome		37	27	9		33	25	12
Sensitivity, %		97.37 (86.19 to 99.93)	71.05 (54.10 to 84.58)	23.68 (11.44 to 40.24)		100.00 (89.42 to 100.00)	75.76 (57.74 to 88.91)	36.36 (20.40 to 54.88)
Specificity, %		49.04 (47.51 to 50.56)	88.46 (87.45 to 89.41)	97.86 (97.37 to 98.27)		49.40 (47.87 to 50.93)	88.14 (87.12 to 89.11)	97.95 (97.47 to 98.36)
Positive predictive value, %		1.70 (1.60 to 1.80)	5.27 (4.28 to 6.48)	9.09 (5.17 to 15.49)		1.55 (1.50 to 1.59)	4.84 (3.96 to 5.90)	12.37 (7.90 to 18.85)
Negative predictive value, %		99.95 (99.67 to 99.99)	99.70 (99.52 to 99.82)	99.30 (99.16 to 99.41)		100.00 (NA)	99.78 (99.60 to 99.88)	99.49 (99.34 to 99.60)
Positive likelihood ratio		1.91 (1.80 to 2.03)	6.15 (4.94 to 7.67)	11.06 (6.03 to 20.27)		1.98 (1.92 to 2.04)	6.39 (5.18 to 7.88)	17.75 (10.79 to 29.21)
Negative likelihood ratio		0.05 (0.01 to 0.37)	0.33 (0.20 to 0.54)	0.78 (0.65 to 0.93)		0.00 (NA)	0.28 (0.15 to 0.50)	0.65 (0.50 to 0.84)

Numbers in parentheses indicate 95% CIs.
*The number of patients in each cohort was not equal to that shown in figure 1 because of missing data, which were either information from a bystander or initial cardiac rhythm to calculate the ABC score.
ABC, Age, Bystander and Cardiogram; NA, not available.

without ECPR, while others cannot have favourable outcomes with ECPR. Therefore, it remains unclear whether ABC scores are appropriate for selecting patients for ECPR. A further study is required to determine whether this ABC score is appropriate for ECPR indication. The present study also revealed that an ABC score of 2 is suitable for segregating the prognosis of CPAOA, but the optimal point for selecting patients for ECPR is unclear. There is a need for research to determine the optimal cut-off point of the ABC score (2 points or 3 points) to implement ECPR in terms of medical resource capacity and cost-effectiveness.

CONCLUSIONS

The ABC score, comprising three clinical variables (Age, information from Bystander and Cardiogram), established an acceptable performance for predicting favourable neurological outcomes in patients with CPAOA at the time of contact with EMS. The ABC score may provide an objective and scientific basis for decision-making on arrival at hospital, where a score of 0 indicates that resuscitation might be withdrawn and a higher score indicates that ECPR may be introduced.

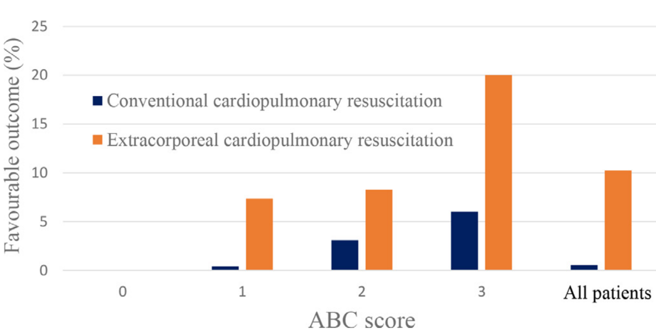

Figure 3 The probability of a favourable outcome of conventional cardiopulmonary resuscitation and ECPR using the ABC score. The probability of a favourable outcome in patients who were treated with ECPR with 0, 1, 2 and 3 points of the ABC score were 0.0%, 7.4%, 8.3% and 20.0%, respectively. *'All patients' includes patients in both cohorts whose ABC scores, resuscitation method (conventional cardiopulmonary resuscitation or ECPR) and outcome after 3 months were all available. ABC, Age, Bystander and Cardiogram; ECPR, extracorporeal cardiopulmonary resuscitation.

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Contributors KU conceptualised the study. KU, TT, HY and MY designed the study. AS, NK, T-aN and MT (SOS-KANTO 2012 study group) supervised the trial and data collection. AS, NK, T-aN and MT also undertook the recruitment of patients from participating centres and managed the data, including quality control. HH, TO and MY provided high-performance computers for data analysis. KU analysed the data, and TT provided advice on study design and statistics. KU drafted the manuscript, and all authors contributed substantially to its revision. KU is responsible for this paper as a whole and acts as the article guarantor.

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Patient consent for publication Not required.

Ethics approval SOS-KANTO 2012 is a deidentified database. We have obtained approval for this study from the institutional review board of the Nippon Medical School Hospital (No. 24-03-218). This study was conducted in accordance with the SOS-KANTO 2012 data use agreement.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data are available on reasonable request. If you are a member of the Kanto Regional Chapter of the Japanese Society of Emergency Medicine and have a reasonable research plan, you can use the SOS-KANTO 2012 dataset. For more information, see the following URL: http: // jaam-kanto.umin.ne.jp / sos_kanto.html.

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