Clinical paper

Prediction of intracerebral hemorrhage in patients with out-of-hospital cardiac arrest using post-resuscitation electrocardiogram: An observational cohort study

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Abstract

Aim: We evaluated the characteristics of patients with intracerebral hemorrhage in nontraumatic out-of-hospital cardiac arrests (OHCA) after return of spontaneous circulation (ROSC) to identify patients who required brain computed tomography as the next diagnostic workup.

Methods: We conducted a retrospective cohort study on 1303 consecutive patients with nontraumatic OHCA who were admitted to Miyazaki Prefectural Nobeoka Hospital between 2008 and 2020. Among these, 454 patients achieved sustained ROSC. We excluded 126 patients with obvious extracardiac causes. Clinical and demographic characteristics of patients and post-resuscitation 12-lead electrocardiogram were compared. Patients were categorized into the intracerebral hemorrhage ($n = 32$, 10%) and no intracerebral hemorrhage group ($n = 296$). All causes of intracerebral hemorrhage were diagnosed based on brain computed tomography images by board-certified radiologists.

Results: We included 328 patients (mean age, 74 years; women, 36%) who achieved ROSC. Logistic regression analyses showed that female sex, younger age (<75 years), no shockable rhythm changes, tachycardia (>100 bpm), lateral ST-segment elevation, and inferior ST-segment depression on post-resuscitation electrocardiogram were independently associated with intracerebral hemorrhage. We developed a new predictive model for intracerebral hemorrhage by considering 1 point for each of the six factors. The odds ratio for intracerebral hemorrhage increased 2.36 for each 1-point increase ($P < 0.001$). A score $> 4$ had 43.7% sensitivity, 90.8% specificity, 34.1% positive predictive value, and 93.7% negative predictive value.

Conclusion: Our new predictive model might be useful for risk stratification of intracerebral hemorrhage in patients with OHCA who achieved ROSC.

Keywords: Intracerebral hemorrhage, Cardiac arrest, Return of spontaneous circulation predictive model

Introduction

Out-of-hospital cardiac arrest (OHCA) imposes a substantial disease burden, with more than 400,000 cases per year in the United States.\textsuperscript{1,2} Even if patients achieve a return of spontaneous circulation (ROSC) and survive hospital admission, the patient mortality rate is reported to be 50% to 62%.\textsuperscript{3,4} To improve the prognosis of these patients, current guidelines recommend performing a 12-lead electrocardiogram (ECG) as soon as possible after ROSC to identify patients with post-cardiac arrest who need urgent coronary angiography (CAG).\textsuperscript{5,6}

Acute coronary syndrome (ACS) is the most common cause of OHCA. However, intracerebral hemorrhage (ICH), involving sub-
arachnoid hemorrhage (SAH), is also a common neurological disorder causing OHCA, with a rate of 10% to 18%.7,8 In these patients, ECGs often show nonspecific ST changes,9-11 which are difficult to distinguish from ACS, leading to misdiagnosis and incorrect therapeutic decisions, such as thrombolytic therapy and percutaneous coronary intervention.

Although the diagnosis of ICH is not difficult if computed tomography (CT) is available, the usefulness of routine immediate CT scanning for patients with resuscitated OHCA remains controversial.12,13 We conducted a hospital-based retrospective cohort study to investigate the characteristics and ECG findings of patients with ICH with OHCA who achieved sustained ROSC. Accordingly, we developed a new predictive model of ICH that can help clinicians make decisions for patients who require brain CT scans as the next diagnostic workup.

Methods

Study design and patients

We studied consecutive patients with nontraumatic OHCA who achieved sustained ROSC and were transported to Miyazaki Prefectural Nobeoka Hospital between January 1, 2008, and December 31, 2020, using the OHCA dataset in Nobeoka City at Miyazaki Prefectural Nobeoka Hospital.

Nobeoka City is located in the eastern part of Kyushu Island. The population was 121,180 in 2020. The percentage of the population of Nobeoka City aged ≥ 65 years increased to 33% in 2020, which is higher than the national average. Miyazaki Prefectural Nobeoka Hospital is the only regional high-quality resuscitation hospital designated by the municipal government.14-17 It provides most of the medical care for this population. In the city, emergency medical services transfer all patients without a pre-existing terminal disease who have experienced OHCA to this hospital. Of the 1373 OHCA cases that occurred and were transported to Nobeoka City during the observation period, 1303 (95%) were transported to our hospital. Further, post-mortem CT has been performed to identify the cause of death since 2008; it was performed on 1,235 cases (95%).

Patients with the following criteria were included in this study: nontraumatic OHCA, age ≥ 18 years, sustained ROSC (defined as the return of evident signs of circulation for more than 20 min consecutively), no apparent extracardiac cause of OHCA such as drowning or asphyxia, and performed post-resuscitation ECG and brain CT examination after ROSC or death. Patients were excluded if their post-resuscitation ECG was lost or if they did not undergo a brain CT.18,19

This study was conducted in accordance with the Declaration of Helsinki and its amendments. Research ethics approval was obtained from the Research Ethics Committees of Miyazaki Prefectural Nobeoka Hospital (No. 20191004-1). As individual patients were not identified, the requirement for obtaining individual informed consent for the study was waived. However, we publicized the study by posting an easy-to-understand summary on the hospital’s website (https://nobeoka-kenbyo.jp/ctrl-nobekkenbyo/wp-content/uploads/2019/09/b7017ee4d1b312e4d8286c3dc7818b8c.pdf). The participants were allowed to refuse participation at any time.

OHCA dataset

At Miyazaki Prefectural Nobeoka Hospital, a medical committee has been meeting monthly since 2008. This committee reviews all OHCA cases that are transferred to hospitals in the city, collects demographics, risk factors, and survival until hospital admission, and builds a dataset of patients who experience OHCA.

CT protocol and diagnosis of ICH

Deceased patients were assessed using brain CT in the supine position, with the arms adjacent to the body. Contiguous imaging was performed at the vertex of the symphys pubis. The CT parameters were as follows: section thickness, 5 mm; spacing interval, 5 mm; tube voltage, 120 kV; and tube current, 380-440 mA (Light Speed Ultra16; GE Healthcare, United States). Further, all causes of ICH (SAH, cerebellar hemorrhage, brainstem hemorrhage, and subdural hematoma) were diagnosed based on brain CT images by board-certified radiologists, who were careful to differentiate SAH from pseudo-SAH sign (hypoxia-induced increased attenuation in the basal cisterns or cortical sulci that mimic SAH).

ECG analysis

The post-resuscitation ECG used for the analysis was the first interpretable 12-lead ECG performed immediately after ROSC. ECG was recorded at a paper speed of 25 mm/s and an amplification rate of 10 mm/mV. To compare the J-wave distribution, the ECG lead areas were grouped as anterior (V1 to V4), lateral (I, aVL, and V5 to V6), and inferior leads (II, III, and aVF).20,21 One experienced cardiologist, blinded to the clinical history of the patients and angiographic and brain CT findings, retrospectively analyzed the ECGs. Recorded ECG changes included ST-segment elevation and depression,18,22 QRS widening, and QTc prolongation18,23 (Supplementary material S1). Based on the brain CT findings, patients were categorized into two groups: the ICH group and no ICH group. The clinical and demographic characteristics of all patients, including age, sex, patient condition at the scene, bystander administration of cardiopulmonary resuscitation (CPR), causes of cardiac arrest, and post-resuscitation 12-lead ECG, were compared. Moreover, subgroup analysis was performed to describe the differences in clinical characteristics only among patients whose ECGs showed significant ST-segment changes.

Statistical analysis

Continuous variables are expressed as mean ± standard deviation or median (interquartile range) depending on the data distribution. Categorical data are presented as absolute numbers (percentage frequencies). Differences between means were analyzed using the Student’s t-test and Mann-Whitney U test. As appropriate, differences between categorical variables were analyzed using the Chi-square test or Fisher’s exact test. There were no laboratory findings for troponin T in 172 patients, potential hydrogen in 30, and lactic acid in 107, but all other variables were not missing.

The potential predictors of ICH were first examined using univariable logistic regression model. Based on the characteristics of patients with OHCA and post-resuscitation ECG findings, we selected explanatory variables from all variables that could be immediately determined in real clinical practice, including baseline characteristics (age, sex), arrest rhythm (no shockable rhythm changes until ROSC), ECG findings (heart rate, tachycardia, atrial fibrillation, narrow QRS, QRS complex, QTc prolongation, QTc time, ST-segment elevation by lead areas, and ST-segment depression by lead areas). Age and heart rate, which were significant predictors, were classified and reanalyzed based on previous reports because they were continuous variables.24,25 The multivariable analysis was complete case...
with no missing data. Because of the low number of outcomes and the limited number of variables in each multivariable logistic regression model, of the variables with \( p < 0.10 \) in the univariable logistic regression model, variables based on a priori clinical knowledge (age, sex, and no shockable rhythm changes until ROSC) and variables related to ECG findings (tachycardia, lateral segment elevation, and inferior segment depression) were separately selected and entered to the multivariable logistic regression model. The results of the multivariable logistic regression analyses were summarized by estimating the odds ratios and 95% confidence intervals (CI). For multicollinearity, variance inflation factor was checked and did not exceed 10. Further, to assess whether the characteristics of patients with OHCA and post-resuscitation ECG findings could predict ICH prevalence, the areas under the receiver-operating characteristic (ROC) curves (AUCs) were calculated. A predictive model of ICH was developed using the prevalence predictive model. In this regard, 1 point was assigned for each variable based on beta estimates and scores were calculated from the sum of the points. The validity of the new predictive model was assessed using k-fold cross validation. The performance of our predictive model was compared with that of the conventional predictive model using decision curve analysis (DCA). All statistical analyses were performed using JMP version 9.0 (SAS Institute Japan, Tokyo, Japan), SPSS version 20 (IBM Corp, Armonk, NY, USA), and R software V.3.6.3 (https://www.r-project.org).

Results

During the study period, 1,303 consecutive patients with nontraumatic OHCA presented to the emergency department, and 454 patients achieved sustained ROSC (Fig. 1). A total of 126 patients were excluded from the study because they had obvious extracardiac causes, such as asphyxia \((n = 85)\) or drowning \((n = 13)\), or had no ECG recording \((n = 28)\). Thus, a total of 328 post-resuscitation patients were analyzed in the study and categorized into the ICH group \((n = 32; 10\%)\), including SAH \((n = 25)\), cerebellar hemorrhage \((n = 4)\), brainstem hemorrhage \((n = 2)\), and subdural hematoma \((n = 1)\), and no ICH group \((n = 296)\).

Comparison of clinical characteristics and 12-lead ECG findings

Table 1 shows the demographic and clinical characteristics of our study patients in the ICH and no ICH groups. The mean age of the patients was 74 years, and 118 (36%) patients were women. Participants in the ICH group tended to be younger (mean 71.4 vs 74.4 years) and were more likely to be women (58% vs 34%, \( P = 0.007 \)) than those in the no ICH group. More patients maintained non-shockable rhythm until ROSC in the ICH group than those in the no ICH group (87% vs 68%, \( P = 0.024 \)). Regarding the post-resuscitation ECG findings, the mean heart rate in the ICH group was 15 bpm, more than that in the no ICH group (mean 115 bpm vs 100 bpm, \( P = 0.008 \)), and ST-segment depression was dominant in the inferior leads in the ICH group compared to that in the no ICH group (41% vs 21%, \( P = 0.040 \)).

Predictive value of clinical variables

To identify predictors of ICH prevalence, we performed univariable analyses of all factors in Table 1 (Supplementary Table S1). Among the variables, female sex, younger age (<75 years), no shockable rhythm changes until ROSC, tachycardia (>100 bpm), lateral ST-segment elevation, and inferior ST-segment depression were identified as positive predictors of ICH, which were divided into two groups for multivariable analysis using forced entry methods (Table 2). To develop a simple predictive model, these variables were assigned 1 point each in the scoring model and the score ranged from 0 to 6 points. Fig. 2 shows the distribution of the score and corresponding ICH; a higher risk score tended to be associated with a higher ICH prevalence. The odds ratio for ICH increased 2.36 (95% CI 1.72, 3.58) for each 1-point increase \((P < 0.001)\). A score \(\geq 4\) had 43.7% (95% CI 28.1–60.6%) sensitivity, 90.8% (95% CI 87.1–93.6%) specificity, 34.1% (95% CI 21.5–49.4%) positive predictive value, and 93.7% (95% CI 90.3–95.9%) negative predictive value. Fig. 3 shows the comparison of the performance of our predictive model with that of the conventional predictive model for ICH prevalence in patients with OHCA who had achieved sustained ROSC; the AUC was higher in our predictive model than that in the conventional predictive model \([0.726 (95\% \text{ CI} 0.623–0.828) \text{ vs } 0.620 (95\% \text{ CI} 0.530–0.711)]\). Moreover, Fig. 4 shows the results of the DCA for

Fig. 1 – Patient Flow Diagram. ECG, electrocardiogram; ICH, intracerebral hemorrhage; OHCA, out-of-hospital cardiac arrest; ROSC, return of spontaneous circulation.
Table 1 – Demographic and clinical characteristics and ECG findings of patients with OHCA with ROSC.

| Demographics | Total patients (N = 328) | No ICH group (N = 296) | ICH group (N = 32) | P value |
|--------------|--------------------------|------------------------|--------------------|---------|
| Age (years)  | 74.1 ± 13.7              | 74.4 ± 14.0            | 71.4 ± 10.2        | 0.256   |
| Female       | 118 (36)                 | 100 (34)               | 18 (58)            | 0.007   |
| Arrest characteristics |                   |                        |                    |         |
| Witnessed    | 233 (71)                 | 219 (74)               | 14 (44)            | <0.001  |
| Bystander CPR| 136 (41)                 | 122 (41)               | 14 (44)            | 0.782   |
| Arrest rhythm at the scene |                   |                        |                    | <0.001  |
| Shockable rhythm | 67 (20)                 | 66 (22)                | 1 (3)              |         |
| Asystole     | 146 (45)                 | 132 (45)               | 14 (44)            |         |
| Pulseless electrical activity | 89 (27)                | 80 (27)                | 9 (28)             |         |
| Unknown      | 25 (8)                   | 17 (6)                 | 8 (25)             |         |
| Shockable rhythm as an initial rhythm | 67 (20)         | 66 (22)                | 1 (3)              | 0.011   |
| Conversion to shockable rhythm | 31 (9) | 28 (9) | 3 (9) | 0.987   |
| No shockable rhythm changes until ROSC | 230 (70) | 202 (68) | 28 (87) | 0.024   |
| Location of cardiac arrest |                   |                        |                    | 0.733   |
| Public area  | 57 (17)                  | 50 (17)                | 7 (22)             |         |
| Home         | 232 (71)                 | 210 (71)               | 22 (69)            |         |
| Other        | 39 (12)                  | 36 (12)                | 3 (9)              |         |
| Time         |                         |                        |                    |         |
| Arrest duration (min) | 29 [21, 39] | 29 [21, 39] | 26 [18, 45] | 0.637   |
| Physical findings |                   |                        |                    |         |
| Right pupil size (mm) | 4.5 ± 1.2 | 4.5 ± 1.2 | 4.8 ± 1.3 | 0.207   |
| Left pupil size (mm) | 4.6 ± 1.2 | 4.5 ± 1.2 | 5.0 ± 1.2 | 0.030   |
| Pupillary light reflex | 31 (86) | 31 (10) | 0 (0) | 0.255   |
| Vital signs after ROSC |                   |                        |                    |         |
| Systolic blood pressure (mmHg) | 113.0 ± 33.6 | 112.7 ± 33.7 | 115.3 ± 33.6 | 0.689   |
| Diastolic blood pressure (mmHg) | 67.8 ± 22.3 | 67.5 ± 22.2 | 70.5 ± 23.9 | 0.484   |
| Heart rate (bpm) | 103 ± 28 | 102 ± 28 | 110 ± 30 | 0.116   |
| Laboratory findings at admission |                   |                        |                    |         |
| Troponin T (ng/mL)² | 0.040 | 0.042 | 0.007 | 0.455   |
| [0.014, 0.091] | [0.016, 0.096] | [0.002, 0.019] |         |
| Potential Hydrogen³ | 7.01 ± 0.21 | 7.01 ± 0.22 | 7.06 ± 0.15 | 0.226   |
| Lactic acid (mmol/L)³ | 11.3 ± 4.8 | 11.6 ± 4.8 | 8.4 ± 4.1 | 0.005   |
| Sodium (mEq/L)⁴ | 139.3 ± 6.1 | 139.3 ± 6.1 | 139.5 ± 6.1 | 0.900   |
| Potassium (mEq/L)⁴ | 4.6 ± 1.4 | 4.6 ± 1.4 | 4.3 ± 1.4 | 0.251   |
| HCO₃⁻ (mEq/L)⁴ | 17.0 ± 6.3 | 16.7 ± 6.4 | 19.7 ± 5.3 | 0.015   |
| Hemoglobin (mg/dL)⁴ | 11.7 ± 3.0 | 11.7 ± 3.1 | 12.1 ± 2.5 | 0.537   |
| Prehospital |                         |                        |                    |         |
| Countershock (number) | 0 [0, 1] | 0 [0, 1] | 0 [0, 0] | 0.164   |
| Drug administration |                   |                        |                    |         |
| Adrenaline (mg/mL)⁴ | 2 [1.3] | 2 [1.3] | 2 [1.4] | 0.737   |
| Electrocardiographic findings |                   |                        |                    |         |
| Heart rate (bpm) | 101 ± 31 | 100 ± 31 | 115 ± 31 | 0.008   |
| Tachycardia (>100 bpm) | 167 (51) | 146 (49) | 21 (66) | 0.079   |
| Rhythm |                         |                        |                    | 0.391   |
| Sinus | 185 (56) | 170 (57) | 15 (47) |         |
| Atrial fibrillation | 99 (30) | 86 (29) | 13 (41) |         |
| Others | 44 (13) | 40 (14) | 4 (13) |         |
| Atrial fibrillation | 99 (30) | 86 (29) | 13 (41) | 0.175   |
| Bundle branch block |                   |                        |                    | 0.007   |
| Non-bundle branch block | 211 (64) | 185 (62) | 26 (81) |         |
| Left bundle branch block | 13 (4) | 10 (3) | 3 (9) |         |
| Right bundle branch block | 104 (32) | 101 (34) | 3 (9) |         |
| Intervals |                   |                        |                    |         |
| PR interval (mm/s) | 170 [150, 197] | 172 [150, 198] | 161 [148, 190] | 0.958   |
| QRS complex (mm/s) | 114 [96, 140] | 114 [96, 140] | 110 [94, 129] | 0.291   |
| Narrow QRS (<120 ms) | 182 (56) | 160 (54) | 22 (69) | 0.112   |
| QT (ms)⁵ | 382 [346, 432] | 384 [348, 433] | 366 [319, 409] | 0.100   |
| QTc (ms)⁵ | 437 [409, 471] | 438 [409, 472] | 432 [407, 460] | 0.698   |
| Prolonged QTc (>460 ms) | 103 (32) | 95 (32) | 8 (25) | 0.391   |
both our predictive model and the conventional predictive model. Considering threshold probabilities of 0–10%, both models were clinically useful; however, our model showed the maximum net benefit with threshold probabilities of 10–45%. To confirm the robustness of these findings, a fourfold cross-validation was performed. The cross-validated decision curve showed a similar standardized net benefit for each threshold probability.

In addition, the detailed results of subgroup analysis of patients with significant ST-segment changes on 12-lead ECG are presented in Supplementary material S2.

### Discussion

In our study, the main findings were as follows: (1) ICH accounted for 10% of patients with OHCA who achieved sustained ROSC; and (2) female sex, younger age (<75 years), no shockable rhythm changes until ROSC, tachycardia (≥100 bpm), lateral ST-segment elevation, and inferior ST-segment depression on post-resuscitation ECG findings were positive predictors of ICH. To the best of our knowledge, this is the first study to develop a predictive model for risk stratification of ICH in patients with OHCA who achieved sustained ROSC, in combination with patient characteristics and post-resuscitation ECG findings that do not require history taking (Fig. 2).

There are reports about racial differences in the prevalence of ICH in patients with OHCA and higher rates have been reported in Asia than in Europe or the United States.27,28 The SOS-KANTO study, a prospective, multicenter, observational study from Japan, showed that in approximately 10.5% of OHCA cases, there was a cerebral aetiology.7,29 Shin et al. also reported that ICH was identified in approximately 11% of patients with OHCA who had achieved sustained ROSC, of whom 86% had SAH.30 These reports are consistent with our results; ICH accounted for 10% of patients with OHCA who achieved ROSC, of which 78% had SAH. Additionally, it is well known that 64–90% of patients with OHCA with a cerebrovascular aetiology have post-resuscitation ECG abnormalities.

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Table 2 – Univariable and multivariable logistic regression models for predictors of ICH prevalence among patients with OHCA with ROSC.

|                      | Entire cohort (N = 328) | Univariable analysis | Multivariable model 1 | Multivariable model 2 |
|----------------------|-------------------------|----------------------|-----------------------|-----------------------|
|                      | Total patients (N = 328) | No ICH group (N = 296) | ICH group (N = 32) | P value |
|                      |                        | Odds Ratio | 95% CI | P value | Beta estimates | Odds Ratio | 95% CI | P value | Beta estimates | Odds Ratio | 95% CI | P value |
| Younger age (<75 years) | 2.32 | 1.07, 5.01 | 0.032 | 1.37 | 3.96 | 1.73, 9.04 | 0.001 |
| Female               | 2.71 | 1.27, 5.76 | 0.009 | 1.04 | 2.84 | 1.29, 6.27 | 0.009 |
| No shockable rhythm changes until ROSC | 3.24 | 1.10, 9.50 | 0.032 | 1.46 | 4.26 | 1.38, 13.18 | 0.012 |
| Tachycardia (≥100 bpm) | 1.96 | 0.91, 4.21 | 0.084, 0.68 | 1.87 | 0.86, 4.06 | 0.111 |
| Lateral segment elevation (I, aVL, V5 to V6) | 1.01 | 1.14 | 0.047, 0.78 | 2.19 | 0.60, 7.91 | 0.231 |
| Inferior segment depression (II, III, aVF) | 2.57 | 1.20, 5.49 | 0.015, 0.77 | 2.17 | 0.96, 4.89 | 0.060 |

Data are presented as mean ± standard deviation, median [interquartile range], or n (%).

CPR, cardiopulmonary resuscitation; ECG, electrocardiogram; ICH, intracerebral hemorrhage; OHCA, out-of-hospital cardiac arrest; ROSC, return of spontaneous circulation.

* Laboratory findings are unavailable for troponin T in 172 patients, potential hydrogen in 30, and lactic acid in 107.
such as ST-segment elevation and depression, inverted T wave, and corrected QT interval (QTc) prolongation, which have implications for incorrect therapeutic decisions regarding thrombolytic therapy and percutaneous coronary intervention, which are key components of standard treatment for ACS. In actual clinical practice, physicians may prioritize emergency catheterization or mechanical circulatory support over CT scans for patients with unstable vital signs or significant ST changes after ROSC. As our predictive model is characterized by high disease specificity, we believe that brain CT scans should be considered to rule out ICH, particularly in patients with a score of 4 or more. However, the sensitivity of this model is still insufficient, and a brain CT scan should also be considered if the emergency physician suspects ICH even with a score of 3 or less. Overcoming this problem of low sensitivity is an issue that requires further research. For example, future studies might consider adding echocardiographic findings to this prediction model of ICH, as the addition of echocardiographic findings may improve prediction accuracy.

However, few studies have developed predictive models for ICH in patients with OHCA who achieve sustained ROSC. In this regard, Kim et al. investigated the post-resuscitation ECG predictors of SAH in patients with OHCA who achieved sustained ROSC. In their study, conducted in Korea between 2010 and 2014, affiliated with three university-affiliated teaching hospitals, they evaluated 200 consecutive patients with OHCA who achieved ROSC with ST-segment changes on ECG, including 50 patients with SAH. They established a predictive model consisting of a combination of four ECG characteristics: atrial fibrillation, narrow QRS (<120 ms), prolonged QTc interval (≥460 ms), and ≥4 ST-segment depressions, and the AUC was calculated as 0.816 (95% CI 0.751–0.880). However, it is important to consider that not all patients with OCHA due to ACS show only ischemic ST changes, but may have complete left bundle branch block or atypical ST changes. Also, SAH is not the only ICH that requires clinical differentiation. Therefore, in this study, we analyzed ICH as an outcome for all patients with OHCA who achieved ROSC who were transported to our hospital, the only regional high-quality resuscitation hospital. The ECG characteristics of the ICH group in our study were different from those in their results, with only ST-segment change findings. The possible reasons for this discrepancy are as follows: the location of the deep hematoma and hematoma volume have been reported to be associated with ECG changes, and our study patients were older (mean age 74 years vs 59 years), and elderly patients have more history of ischemic heart disease compared to the younger patients. Furthermore, when we compared the predictive ability of each model for the decision making to perform a brain CT scan after ROSC in a clinical setting rather than for the purpose of predicting disease, our model was superior to that of Kim et al. in predicting ICH in our sample (Figs. 3, 4). We believe the strength of the current study compared to their report is the research design with less selection bias and a more clinically relevant outcome setting. Arnaout et al. also investigated patient characteristics and post-resuscitation ECG findings in patients with OHCA with cerebrovascular aetiology. In their multicentre retrospective, observational, cohort study in the Paris Network between 1999–2012, with three university-affiliated hospitals, they evaluated 258 consecutive patients with OHCA who achieved sustained ROSC and found that female sex, the onset of neurological prodromes, lack of other prodromes, initial non-shockable rhythm, and unspecified
ECG repolarisation abnormalities were independent predictive factors of a primary cerebrovascular aetiology, and the AUC was 0.86 (95% CI, 0.81–0.91). However, history taking is often impossible in patients who remain comatose after ROSC. They even mentioned in their limitation that prodromal symptoms were unknown for almost one-third of the cohort due to a lack of witnesses. Regarding the predictors shown in our study, female sex, younger age, and no shockable rhythm changes are known to be characteristic of patients with OHCA with ICH.9,27 A tendency toward tachycardia as a characteristic of the ICH group has also been observed in a previous report.18

Although there is no established theory regarding the characteristics of ST-segment changes in post-resuscitation ECGs of patients with OHCA and ICH,9–11,16,21,27 the present study showed that lateral ST-segment elevation and inferior ST-segment depression are predictors of ICH. This is difficult to explain, but rather than being a feature of the ICH group, it might be due to the lack of ECG characteristics in the no ICH group and may involve a mixture of the following reasons. Previous studies have reported that ST-segment depression is more likely to appear in the inferior and lateral ST segments because the degree of ST-segment depression gener-
ally increases with R-wave progression,23 and that anterior ST-segment elevation is more frequent in patients with ACS-associated OHCA,20 but further studies are needed.

Limitations
This study had several limitations. Due to the retrospective observational nature of this study, 28 of the 454 patients were excluded because of their post-resuscitation ECG loss, which may have been selection bias in patient eligibility. However, a brain CT scan was evaluated in all patients. Second, although ECG was performed immediately after resuscitation, it was difficult to examine in detail factors that might affect ECG changes, such as cardiopulmonary resuscitation and duration of cardiac arrest. Third, we could not analyze the echocardiographic data of the patients. Fourth, the epidemiology of OHCA is different in Asia compared to other parts of the world, which might limit the generalizability of the findings. Fifth, a board-certified cardiologist interpreted the post-resuscitation ECG in a blinded manner to other clinical histories and results. Finally, external validation of the scoring system was not performed. As independent external datasets were not available, cross-validation was performed to prevent overfitting.

Conclusion
In this study, ICH accounted for 10% of patients with OHCA who achieved sustained ROSC. Our new predictive model of ICH, including female sex, younger age (<75 years), no shockable rhythm changes until ROSC, tachycardia (≥100 bpm), lateral ST-segment elevation, and inferior ST-segment depression on post-resuscitation ECG findings, has high disease specificity and may be clinically useful for risk stratification of ICH prevalence in patients with OHCA who achieve ROSC. Nevertheless, this scoring system could be improved due to its low disease sensitivity, and its usefulness should be confirmed in future prospective studies.

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.

Acknowledgements
We would like to thank Editage (www.editage.com) for English language editing.

Data access
Ryota Kaichi and Masanobu Ishii had full access to all the data in the study and took responsibility for the integrity of the data and the accuracy of the data analysis.

Appendix A. Supplementary material
Supplementary data to this article can be found online at https://doi.org/10.1016/j.resplu.2022.100337.

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