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Clinical paper

Multimodal assessment using early brain CT and blood pH improve prediction of neurologic outcomes after pediatric cardiac arrest

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Abstract

Background: Early prediction of neurologic prognosis in children resuscitated from cardiac arrest is a major challenge. This study aimed to investigate the usefulness of a combined model based on brain computed tomography (CT) and initial blood gas analysis to predict neurologic prognoses in pediatric patients after cardiac arrest.

Methods: We retrospectively analyzed the medical records of patients resuscitated after cardiac arrest from 2000 to 2018. Patients aged one month to 18 years were included. Gray to white matter ratio (GWR), ambient cistern effacement (ACE), and blood gas analysis were studied. The primary outcome was neurological prognosis, which was evaluated using the Pediatric Cerebral Performance Category (PCPC) scale at discharge.

Results: Of 97 resuscitated patients, 64 brain CT images were available. Fourteen patients had a good neurologic outcome (PCPC 1–3) and 50 patients a poor neurologic outcome (PCPC 4–6). The multimodal model (AUC 0.897) containing GWR of basal ganglia (BG), ACE, and blood pH was found to be superior for predicting poor neurologic prognosis than single variable models (AUC of GWR-BG: 0.744, ACE: 0.804, pH: 0.747). Interestingly, we found the GWR-BG cutoff value for specificity 100% differed significantly between patients <4 years (cutoff value: 1.08, $p = 0.04$) and ≥ 4 years (cutoff value: 1.18, $p = 0.004$).

Conclusions: The combination of GWR-BG, ambient cistern effacement, and blood pH was found to usefully predict neurological outcome in children resuscitated from cardiac arrest. In addition, the cutoff value of GWR-BG for the prediction of neurologic outcome was found to increase with age.

Keywords: Cardiac arrest, Pediatric, Neurologic outcome, Prognosis, Computed tomography, Gray to white matter ratio, Ambient cistern effacement

Introduction

The incidence rate of out-of-hospital cardiac arrest (OHCA) patients among children ranges from 4.2 to 8.0 per 100,000 person-years, which is lower than that observed among adults.[1–3] However, the survival rate of children has not increased, whereas that of adults is increasing annually.[4] Furthermore, 47–69% of resuscitated children remain comatose or die.[5,6] Given this situation, predicting the neurological prognoses of pediatric patients resuscitated after cardiac arrest is critically important.

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Previous studies in adults have reported that the following factors predict neurologically poor prognosis; electroencephalography (EEG) patterns such as burst suppression, acidosis in blood gas analysis, a low gray to white matter ratio (GWR) in brain computed tomography (CT), and diffusion abnormalities in magnetic resonance imaging (MRI).[7–10] Recently, multimodal model studies used combinations of these single models in adults and found they improve the accuracy of prognoses.[7,11,12] However, in pediatric OHCA patients, the criteria that best predict neurologic prognosis have not been well identified and the amount of data available on the topic falls far short of that available for adults. Early signs in the brain CT images of children have been studied with respect to mortality and poor neurologic outcome, but the study concerned was limited to a single model.[13]

In the present study, we focused on brain CT and initial laboratory findings, which have advantages over MRI and EEG in terms of early detection. The aim of this study was to determine whether quantitative factors like GWR and qualitative factors, such as specific structure changes in brain CT images, and laboratory findings predict neurologic prognosis in pediatric patients after cardiac arrest. Based on the results obtained, we developed multimodal model to improve the prediction of poor neurologic outcome. In addition, we investigated whether the predictive values of these factors differ in children and adults.

Methods

Study population

This retrospective study was performed at Gachon Gil Medical Center from January 2000 to January 2018. Non-traumatic OHCA patients aged from 1 month to 18 years were included. The study was approved by the Institutional Review Board of Gachon University Gil Medical Center. The exclusion criteria applied were as follows: dead on arrival, the presence of a serious underlying neurologic condition (PCPC $\geq$ 4), brain CT not performed within 24 h of cardiac arrest, inadequate CT image (severe artifact or structural damage), and transferal to other hospital.

Cardiopulmonary resuscitation (CPR) for OHCA patients was performed according to pediatric advanced life support protocols.[14] Initial blood gas analysis was performed on arrival at hospital. After resuscitation from cardiac arrest, brain CT was performed as soon as possible. Decisions to administer hypothermic treatment were made by medical staff at that time.

Data collection

We evaluated GWR as potential quantitative neurological predictors in brain CT. Brain CT was performed using a SOMATOM Plus, a Sensation 16, or a Definition Edge CT unit (all from Siemens, Erlangen, Germany) using a slice width of 1.5–5.0 mm. Images were reviewed by a pediatric neurologist using image-viewing software (INFINITT PACS, Seoul, South Korea). During brain structure analysis, the brain window was set at width 70 and level 40. Average Hounsfield unit (HU) values were recorded by adding all HU values in a circular region of area 0.1–0.15 cm^2 and dividing by area. These HU values were recorded at three different levels, as previous described,[15] that is the basal ganglia, centrum semiovale, and high convexity levels, which were each measured bilaterally. At the basal ganglia level, HU values were obtained for the caudate nucleus (CN), putamen (PU), genu of corpus callosum (CC), and posterior limb of the internal capsule (PIC). At the centrum semiovale level, HU values were obtained for the medial cortex (MC1) and medial white matter (MWM1) and for MC2 and MWM2 at the high convexity level. After HU values had been obtained at each level, GWR of basal ganglia (BG), cortex (CO), and average (AVG) were calculated as previously described.[15] Simplified methods such as GWR-CN/PIC, GWR-CN/CC, GWR-PU/PIC, and GWR-PU/CC were used as previously described.[16]

In addition, we evaluated the potential qualitative neurologic predictors, ambient cistern effacement (ACE), sulcal effacement, and reversal sign. ACE was defined as the ambient cistern structure on both sides of midbrain was not visible or a summed ambient cistern length was smaller than quadrigeminal cistern width. Sulcal effacement was defined as an unclear boundary between white matter and gray matter of the cortical sulcus. The reversal sign, also known as the white cerebellum sign, was defined as increase attenuation of cerebellum as compared with surrounding tissues. Laboratory findings, which included blood gas analysis, complete blood count, electrolytes, and S100, were performed on OHCA patients at initial presentation.

Outcome assessments

The primary outcome was neurologic outcome at discharge, as determined by the Pediatric Cerebral Performance Category (PCPC) scale.[17] Patients were divided by PCPC score into two groups, that is, the good neurologic outcome group (PCPC score of 1–3) or the poor neurologic outcome group (PCPC score of 4–6).

Statistical analysis

The *t*-test or Mann–Whitney *U* test was used to determine the significances of differences between continuous variables and the Chi-square test or Fisher's exact test were used to determine the significances of differences between categorical variables in the good and poor outcome groups.

The predictive performance model used area under curve (AUC) of the receiver operating characteristic (ROC) curve. Logistic regression analysis and the DeLong test were used to compare ROC curves of multimodal models containing two or three variables. For the final multimodal model, we selected variables found to be associated with neurologic outcomes. These variables were divided into three categories: quantitative, qualitative, and laboratory findings. A variable with highest AUC value was selected in each category, and variables highly correlated with this variable were excluded from the multimodal model. After eliminating variables, we devised multivariable models containing variables in each category. The best multimodal model was found by comparing AUC values, and the suitability of this model assessed using the Hosmer and Lemeshow test. In addition, regression analysis was used to locate most appropriate trend lines in scatter plots of age vs GWR-BG for the good and poor neurologic outcome groups. Statistical significance was accepted for two-sided p values of <0.05. The analysis was performed using MedCalc Ver. 18.2.1 (MedCalc Software bvba, Ostend, Belgium).

Results

Baseline characteristics

From January 2000 to January 2018, 253 non-traumatic OHCA patients aged one month to 18 years were admitted to our hospital. Of

these patients, 156 were dead on arrival and excluded. Of the 97 resuscitated by CPR, 24 patients without CT images, 4 that underwent CT 24 h later, 2 that were transferred to another hospital, and 3 with inadequate CT images (severe brain structural damage) were excluded from the study. As a result, 64 patients were included in the study.

Median age of the 64 study subjects was 4.1 years (IQR 0.5–11.9) and 44 (68.8%) were male. The main causes of arrest were respiratory problems, such as, dyspnea and apnea, which occurred in 37 patients (57.8%). Forty-seven patients (73.4%) had no underlying disease and only 15 (23.4%) received hypothermia treatment. Median arrest duration was 11.0 min (IQR 6.0–18.0) and median time taken for brain CT after CPR was 1.9 h (IQR 1.2–2.9) (Table 1).

PCPC score were evaluated before cardiac arrest in all patients, 58 patients (90.6%) had a score of 1, and no patient had a score of >3. After resuscitated from cardiac arrest, 14 patients were allocated to the good neurologic outcome group (PCPC 1–3), and 50 to the poor neurological outcome group (PCPC 4–6). No significant intergroup difference was found for baseline characteristics, including hypothermia treatment and arrest duration.

Quantitative and qualitative assessments using brain CT images

The quantitative factors measured were GWR and the qualitative factors indicated brain structural changes. Decreases in GWR-BG and GWR-AVG significantly predicted a poor outcome. In particular, GWR-BG was remarkably lower in the poor outcome group (1.14 (IQR 1.07–1.19)) than in the good outcome group (1.19 (IQR 1.16–1.24)) ($p = 0.005$). Of simplified methods, GWR-CN/PIC ($p = 0.03$), CN/CC ($p = 0.006$), and PU/CC ($p = 0.04$) were significantly different in the good and poor outcome groups.

Qualitative analysis of brain CT images showed that ambient cistern effacement was the most prominent difference between the two outcome groups ($p < 0.001$). On the other hand, sulcal effacement and reversal were not significantly different (Table 2).

Laboratory findings by neurologic outcome

The significant initial laboratory indicators of outcomes were pH ($p = 0.004$), pCO2 ($p = 0.02$), AST ($p = 0.009$), and ALT ($p = 0.02$). Ammonia and bicarbonate were also significantly different ($p = 0.006$, $p = 0.001$), but not all patients were tested (Table 2).

ROC curves for single variables and variables in combination

The performances of GWR, ambient cistern effacement, and blood pH for the prediction of poor outcome are summarized in Table 3. Of the GWR variables, GWR-BG had the greatest predictive power (AUC 0.744; $p = 0.001$) and at a cutoff of 1.08 had a specificity of 100%. To achieve 100% specificity, the cutoff value of pH was 6.73 that of was AUC 0.747 ($p = 0.001$) and ambient cistern effacement had the highest AUC 0.804 ($p < 0.001$) as determined by single variable analysis. These results showed a GWR-BG of <1.08, a pH < 6.73 and presence of ambient cistern effacement predict a poor neurologic outcome.

ROC curves for single and multivariable models for the prediction of a poor neurologic outcome are shown in Fig. 1. Although GWR-CN/PIC ($p = 0.03$) and CN/CC ($p = 0.001$) were significant poor outcome predictors, they were highly correlated with GWR-BG (correlation coefficient of CN/PIC 0.99, CN/CC 0.99), and thus, were excluded from the final model. For the same reason, pCO2, AST, and ALT, which were highly correlated with pH, were excluded. Therefore, GWR-BG, ACE, and pH were selected for single variable model. The AUCs of ROC curves of combinations of 2 variables were greater than those of combinations of three single variables (AUC for the GWR-BG and ACE combination: 0.846, and for the GWR-BG and pH combination: 0.859). However, ROC curves of these two variable

Table 1 – Baseline characteristics of the patients.

Variables	Total (n = 64)	Good neurologic outcome (n = 14)	Poor neurologic outcome (n = 50)	*p*-Value
Age, year	4.1 (0.5–11.9)	5.2 (0.7–13.3)	4.1 (0.5–10.9)	0.57
Sex, male	44 (68.8)	10 (71.4)	34 (68.0)	1.00
Arrest etiology	–	–	–	1.00
Respiratory	37 (57.8)	8 (57.1)	29 (58.0)	–
Cardiac	5 (7.8)	1 (7.1)	4 (8.0)	–
Drowning	4 (6.3)	1 (7.1)	3 (6.0)	–
Others	18 (28.1)	4 (28.6)	14 (28.0)	–
Initial cardiac rhythm	–	–	–	0.26
PEA	11 (17.2)	1 (7.1)	10 (20.0)	–
VF/VT	3 (4.7)	2 (14.3)	1 (2.0)	–
Asystole	27 (42.2)	6 (42.9)	21 (42.0)	–
Unknown	23 (35.9)	5 (35.7)	18 (36.0)	–
Underlying disease	–	–	–	0.29
None	47 (73.4)	10 (71.4)	37 (74.0)	–
Respiratory	6 (9.4)	0 (0)	6 (12.0)	–
Cardiac	1 (1.6)	0 (0)	1 (2.0)	–
Neurologic	6 (9.4)	3 (21.4)	3 (6.0)	–
Others	4 (6.3)	1 (7.1)	3 (6.0)	–
Duration of cardiac arrest, min	11.0 (6.0–18.0)	10 (4.0–15.0)	12.5 (6.0–24.3)	0.19
Hypothermia treatment	15 (23.4)	6 (42.9)	9 (18.0)	0.08
Time from CPR to brain CT, hour	1.9 (1.2–2.9)	2.0 (1.0–2.8)	1.9 (1.3–3.1)	0.55

Data are expressed as medians (interquartile ranges) or n (%). CT: computed tomography, PEA: pulseless electrical activity, VF: ventricular fibrillation, VT: ventricular tachycardia, CPR: cardiopulmonary resuscitation.

Table 2 – Comparisons of brain CT and laboratory findings in the good and poor neurologic outcome group.

Variables	Good neurologic outcome (n = 14)	Poor neurologic outcome (n = 50)	*p*-Value
Quantitative value, GWR	–	–	–
GWR-BG	1.19 (1.16–1.24)	1.14 (1.07–1.19)	0.005
GWR-CO	1.23 (1.17–1.27)	1.19 (1.12–1.27)	0.28
GWR-AVG	1.21 (1.17–1.26)	1.17 (1.11–1.21)	0.04
GWR-CN/PIC	1.23 ± 0.10	1.15 ± 0.11	0.03
GWR-CN/CC	1.18 ± 0.08	1.10 ± 0.10	0.006
GWR-PU/PIC	1.22 ± 0.12	1.16 ± 0.10	0.06
GWR-PU/CC	1.14 (1.10–1.27)	1.11 (1.06–1.16)	0.04
Structural change of brain	–	–	–
Ambient cistern effacement	1 (7.1)	34 (68.0)	<0.001
Sulcal effacement	1 (7.1)	19 (38.0)	0.05
Reversal sign	5 (35.7)	15 (30.0)	0.75
Laboratory findings	–	–	–
pH	7.14 (6.94–7.25)	6.89 (6.80–7.00)	0.004
pCO_2 (mmHg)	40.0 (32.7–70.5)	62.5 (46.0–94.0)	0.02
Hemoglobin (g/dl)	12.50 (11.08–14.45)	11.3 (10.05–12.70)	0.18
Glucose (mg/dl)	246 (136.5–313.0)	300 (215.5–364.25)	0.09
AST (U/L)	60.0 (44.25–138.25)	199.0 (77.5–429.5)	0.009
ALT (U/L)	30.5 (17.5–99.50)	109.0 (35.50–341.50)	0.02
S100 (ug/L)	1.01 (0.65–1.06) [n = 3][a]	1.59 (0.78–2.71) [n = 30]	0.26
Ammonia (ug/dl)	82.0 (59.0–242.75) [n = 12]	255.0 (154.0–741.5) [n = 37]	0.006
Bicarbonate (mmol/L)	18.9 (17.5–22.4) [n = 11]	12.3 (9.3–16.6) [n = 29]	0.001
Lactate (mmol/L)	10.2 (3.2–13.4) [n = 9]	11.7 (9.65–15.0) [n = 37]	0.08

Data are expressed as medians (interquartile ranges) or mean ± standard deviation or n (%). GWR: gray to white matter ratio, BG: basal ganglia, CO: cortical, AVG: average, CN: caudate nucleus, PIC: posterior limb of the internal capsule, CC: corpus callosum, PU: putamen, AST: aspartate aminotransferase, ALT: alanine aminotransferase.

[a] n in brackets means the number of patients examined.

Table 3 – Cutoff values for predicting poor neurologic outcome.

Variables	Cutoff value	AUC (95% CI)	Sensitivity (95% CI)	Specificity (95% CI)	PPV (95% CI)	NPV (95% CI)	*p*-Value
GWR-BG	1.08	0.744 (0.620–0.845)	28.0 (16.2–42.5)	100 (76.8–100.0)	100	28.0 (24.7–31.6)	0.001
–	1.15	–	60.0 (45.2–73.6)	85.7 (57.2–98.2)	93.8 (80.3–98.2)	37.5 (28.7–47.3)	–
GWR-CO	1.02	0.594 (0.464–0.715)	8.0 (2.2–19.2)	100 (76.8–100.0)	100	23.3 (21.9–24.8)	0.25
–	1.08	–	60.0 (45.2–73.6)	71.43 (41.9–91.6)	88.2 (76.1–94.7)	33.3 (23.7–44.6)	–
GWR-AV	1.06	0.683 (0.555–0.794)	14.0 (5.8–26.7)	100 (76.8–100.0)	100	24.6 (22.6-26.7)	0.02
–	1.21	–	78.0 (64.0–88.5)	57.1 (28.9–82.3)	86.7 (77.7–92.4)	42.1 (26.7–59.2)	–
GWR-CN/PIC	1.01	0.686 (0.558–0.796)	12.0 (4.5–24.3)	100 (76.8–100.0)	100	24.1 (22.3–26.1)	0.03
–	1.27	–	92.0 (80.8–97.8)	42.9 (17.7–71.1)	85.2 (78.4–90.1)	60.0 (32.9–82.1)	–
GWR-CN/CC	1.08	0.724 (0.598–0.829)	40.0 (26.4–54.8)	100 (76.8–100.0)	100	31.8 (27.1–36.9)	0.001
GWR-PU/PIC	1.05	0.617 (0.487–0.736)	18.0 (8.6–31.4)	100 (76.8–100.0)	100	25.5 (23.1–28.0)	0.18
–	1.25	–	84.0 (70.9–92.8)	42.9 (17.7–71.1)	84.0 (76.7–89.4)	42.9 (23.8–64.3)	–
GWR-PU/CC	1.02	0.679 (0.550–0.790)	16.0 (7.2-29.1)	100 (76.8–100.0)	100	25.0 (22.8–27.3)	0.02
–	1.10	–	46.0 (31.8–60.7)	92.9 (66.1–99.8)	95.8 (77.3–99.4)	32.5 (26.4–39.3)	–
Ambient cistern effacement	>0	0.804 (0.686–0.893)	68.0 (53.3–80.5)	92.9 (66.1–99.8)	97.2 (83.6–99.6)	44.8 (34.6–55.5)	<0.001
pH	6.73	0.747 (0.623–0.848)	4.0 (0.5–13.7)	100 (76.8–100.0)	100	22.6 (21.6–23.6)	0.001
–	7.05	–	88.0 (75.7–95.5)	57.1 (28.9–82.3)	88.0 (79.9–93.1)	57.1 (35.6–76.2)	–

AUC: area under the curve, CI: confidence interval, PPV: positive predictive value, NPV: negative predictive value, AST: aspartate aminotransferase, ALT: alanine aminotransferase.

models were not significantly different from those of single variable models. GWR-BG, ACE, and pH were included in the final model, as this model had largest AUC (0.897 (95% CI 0.796–0.959)) and the ROC curve of this model was significantly different from those of the corresponding single variable models (GWR-BG (p = 0.03), ACE (p = 0.03), and pH (p = 0.04)).

Relation between GWR-BG and age

GWR-BG values versus age were plotted as a scatter plot. Trend lines of the good and poor outcome groups are shown in Fig. 2. GWR-BG values increased with age in both groups and the slopes lessened with age. In particular, GWR-BG values before age 4 decreased in both

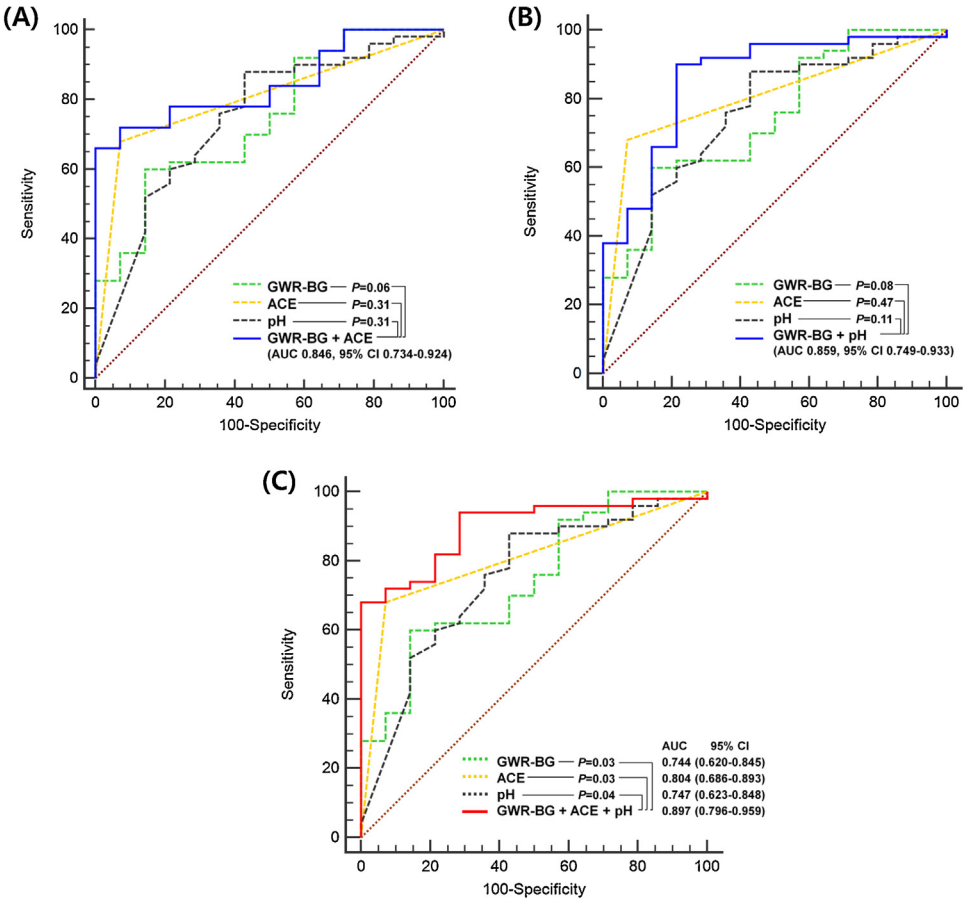

Fig. 1 – ROC curve for the prediction of poor neurologic outcome.
(A) AUC for GWR-BG: 0.744, for ACE: 0.804, for pH: 0.747, for the combination of GWR-BG and ACE: 0.846 (B) AUC for the combination of GWR-BG and pH: 0.859 (C) AUC for the combination of GWR-BG, ACE, and pH: 0.897. ROC: receiver operating characteristic, AUC: area under the curve, GWR: gray to white matter ratio, BG: basal ganglia, ACE: ambient cistern effacement.

good and poor outcome groups, and the cutoff value for 100% specificity before age 4 was 1.08 (p = 0.04), whereas the cutoff after age 4 was 1.18 (p = 0.004) for predicting a poor outcome (Table 4, Supplementary Table 1). Similarly, the cutoff value of GWR-BG for infants (≤1 year) was less than of children >1 year old.

Discussion

This study confirms that the devised combined model incorporating GWR-BG, ACE, and blood pH is superior to the single variable examined in terms of predicting neurological prognosis in OHCA pediatric patients. In addition, we also found GWR-BG increases with age. Although EEG and MRI are useful tools for predicting prognosis, they cannot be performed early because of sedation and intubation state.[7,10] On the other hand, GWR, structural changes in brain CT images and blood gas analysis can be performed relatively quickly.[9,12,15,18-22]

Hypoxic-ischemic conditions decrease the density of gray matter in brain CT images due to cytotoxic cerebral edema and neuronal cell necrosis and increase the density of white matter with the effect of

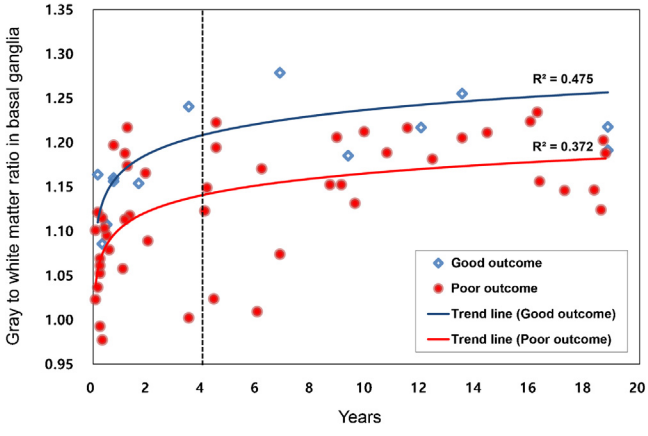

Fig. 2 – Correlations between GWR in basal ganglia and age in the good and poor neurologic outcome groups. GWR in basal ganglia increased with age in both groups. Coefficient of determination R^2 = 0.475 in the good neurologic outcome group and 0.372 in poor neurologic outcome group as determined by logistic regression.

Table 4 – Cutoff values of GWR in basal ganglia for predicting poor neurologic outcome by age.

Variables	Cutoff value	AUC (95% CI)	Sensitivity (95% CI)	Specificity (95% CI)	PPV (95% CI)	NPV (95% CI)	*p*-Value
GWR-BG, Age < 1 years	1.08	0.840 (0.609–0.963)	60.0 (32.3–83.7)	100 (47.8–100.0)	100	45.5 (31.0–60.8)	<0.001
–	1.10	–	80.0 (51.9–95.7)	80 (28.4–99.5)	92.3 (67.1–98.6)	57.1 (30.7–80.1)	–
GWR-BG, Age ≥ 1 < 18 years	1.15	0.838 (0.696–0.932)	45.7 (28.8–63.4)	100 (66.4–100.0)	100	35.2 (30.0–39.2)	<0.001
–	1.21	–	88.6 (73.3–96.8)	66.7 (29.9–92.5)	91.2 (80.2–96.3)	60.1 (35.0–80.9)	–
GWR-BG, Age < 4 years	1.08	0.750 (0.563–0.887)	45.8 (25.6–67.2)	100 (59.0–100.0)	100	35.0 (27.1–43.7)	0.008
–	1.12	–	79.2 (57.8–92.9)	71.4 (29.0–96.3)	90.5 (74.3–96.9)	50.0 (28.7–71.3)	–
GWR-BG, Age ≥ 4 < 18 years	1.18	0.846 (0.678–0.948)	53.9 (33.4–73.4)	100 (59.0–100.0)	100	36.9 (27.8–46.9)	<0.001
–	1.22	–	88.5 (69.8–97.6)	71.4 (29.0–96.3)	92.0 (78.0–97.4)	62.6 (34.3–84.3)	–

distension in medullary draining veins.[19,23] These mechanisms explain why GWR reduces after cardiac arrest. In particular, basal ganglia is severely damaged area, and the caudate and putamen are also highly affected.[24]

In a study of GWR values in adults, a GWR of <1.18–1.22 achieved a specificity 100% for predicting mortality.[15,19,20] However, little research has been done on GWR values in children. In a pediatric study, Starling et al. reported a decrease in GWR was associated with mortality using a cutoff point of 1.14.[13] In the present study, a GWR-BG cutoff value of 1.08 showed 100% specificity for prediction of a poor outcome and the cutoff value of GWR was 1.15, which showed a sensitivity of 60.0% and a specificity 85.7%. Furthermore, the simplified methods used in the present study based on GWR-PU/CC, CN/PIC, or CN/CC significantly predicted poor neurologic outcome, as has been reported in adult studies.[16,21]

The cutoff value of GWR-BG in children for prediction of poor neurologic outcome was lower than the cutoff value of adults. This difference is probably due to brain developmental processes.[25,26] Gray matter growth occurs rapidly during the first two years of life,[26] and myelination of white matter tracts increases to the early adult stage.[27] Therefore densities of gray and white matter show variations with age.

Previous studies have shown the reversal sign, basal cistern effacement, and sulcal effacement suggest unfavorable neurologic outcome in children.[13] However, the basal cistern is composed of four cisterns and it is not often all four cisterns disappear after cardiac arrest. Therefore, we focused on ambient cistern, which is easy to identify effacement. These effacement signs are manifestations of cytotoxic and vasogenic edema.[24] In the present study, the reversal sign and sulcal effacement were not significantly associated with neurologic outcomes, which conflicts with the findings of a previous study.[13] However, these signs may be meaningful in older childhood groups because all 5 patients with reversal sign after age 4 died in our study.

After cardiac arrest, oxygen deprivation and metabolic acidosis reduced blood pH.[28,29] Because of this, we focused on the pH which can be determined easily at the time of admission, and we found pH was significantly associated with outcome with a specificity 100% at a cutoff value 6.73, which is similar to the value of 6.8 reported in adults after cardiac arrest.[9]

Although we have identified significant predictors, to reinforce the predictive value with multimodal approach, we used GWR-BG as a quantitative factor, ambient cistern effacement as a qualitative factor, and pH value in laboratory findings and finally made optimal multimodal model to predict poor neurologic outcome.

The present study has several limitations that warrant consideration. First, it is limited by its single-center, retrospective design and relatively small cohort. Second, patients that did not undergo brain CT were excluded, which could result in bias due to exclusion of patients with poor status. Third, although the cutoff value of GWR-BG showed a tendency to increase with age, the number of patients that experienced a good neurologic outcome was small, and the cutoff values of GWR-BG for different age groups were not determined. Similarly, we were not able to investigate the performance of the final model by age.

The three factors incorporated into the final model can be easily and rapidly determined. We believe the multimodal model incorporating GWR-BG, ACE, and pH could be used to predict prognosis in cases of pediatric cardiac arrest. In addition, we found that the GWR-BG cutoff value tended to increase with age.

Conclusions

To predict the neurologic outcomes of pediatric patients resuscitated after cardiac arrest, we suggest a model incorporating GWR-BG, ambient cistern effacement, and blood pH be used. When GWR-BG is <1.08, pH is <6.73 and ambient cistern effacement is observed, the model predicts a poor neurologic outcome. These three factors are easily obtained after initial presentation. In addition, we suggest age should be considered because the cutoff of GWR-BG was found to increase with age in our pediatric cohort. We believe that this multimodal model will enable more accurate and rapid prediction of neurologic prognosis in pediatric patients that have experienced out-of-hospital cardiac arrest.

Conflict of interest

The authors have no conflict of interest to declare.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.resuscitation.2019.01.033.

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