Predictive Utility of Changes in Optic Nerve Sheath Diameter After Cardiac Arrest for Neurologic Outcomes

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Abstract

Background: Optic nerve sheath diameter (ONSD) is effective in predicting the neurologic outcome of patients with post-cardiac arrest (CA) return of spontaneous circulation. This study aimed to investigate the effect of ONSD changes before and after CA on neurologic outcomes in patients with return of spontaneous circulation after CA using brain computed tomography (CT).

Methods: We included patients who were hospitalized after CA and underwent pre- and post-CA brain CT from January 2001 to September 2020. They were divided into the good and poor neurologic outcome (GNO and PNO, respectively) groups based on the neurologic outcome at hospital discharge. We performed between-group comparisons of the amount and rate of post-CA changes on brain CT. Moreover, we calculated the area under the curve to determine the predictive value of ONSD changes for neurologic outcomes.

Results: We included 96 enrolled patients; among them, 25 had GNO. The amount of change was significantly higher in the PNO group than in the GNO group (0.63 vs. 0.30 mm; p = 0.030). Moreover, there was a higher rate of change in the PNO group than in the GNO group (12.29 vs. 5.26 %; p = 0.041). The AUC for predicting PNO was 0.64 (95% CI = 0.53−0.73; p = 0.04) and patients with a rate of ONSD change > 27.2% had PNO with specificity and positive predictive values of 100%.

Conclusion: The amount and rate of ONSD changes on brain CT were significantly associated with the neurologic outcomes in post-CA patients. ONSD changes may predict neurologic outcomes in post-CA patients.

Introduction

Ischemia/reperfusion cerebral injury after cardiac arrest (CA) may cause cerebral edema.[1, 2] This results in an increase in intracranial pressure (ICP) and contributes to poor neurologic outcomes in patients with post-CA return of spontaneous circulation (ROSC).[3, 4] In these survivors, there is a need for early detection of increasing ICP and neurologic outcome prediction to allow appropriate post-resuscitation care.[5] This allows priority to be given to patients with expected good neurologic outcomes given the limited medical resources. There have been studies on various predictive factors for post-CA neurologic outcomes, including neurologic examination of brainstem reflexes, electrophysiological tests, and serum biomarkers, such as neuron specific enolase and S-100B.[6−8] However, these factors have been recommended as prognostic factors at 72 post-CA hours.[8−10] Moreover, early brain computed tomography (CT) of patients with post-CA ROSC may play a crucial role as a prognostic predictor. Further, the American Heart Association guidelines recommend early post-CA brain CT scans and confirm that a decrease in the grey-to white matter ratio (GWR) can help predict neurologic outcome.[10−13] Additionally, there have been studies with optic nerve sheath diameter (ONSD) on brain CT for predicting neurologic outcomes in post-CA survivors.[14−16]

Previous studies have shown that the ONSD on brain CT could be a useful tool as a non-invasive method of ICP measurement.[17, 18] Additionally, recent studies have demonstrated that the ONSD on brain CT is useful for early neurologic outcome prediction through evaluation of increased ICP in patients with post-CA ROSC.[15, 19] A recent meta-analysis confirmed the utility of ONSD as a prognostic factor for neurologic outcomes in post-CA patients.[20] However, most of the studies included in the meta-analysis indicated that sole use of ONSD had limited predictive utility for prognosis. Furthermore, all these studies only measured the post-CA ONSD without considering individual differences.

This study aimed to assess differences between pre- and post-CA ONSD in patients with ROSC after CA using brain CT imaging. Additionally, we aimed to investigate the impact of the amount and rate of post-CA ONSD changes on the neurologic outcome at discharge.

Methods

Study design and population

This retrospective observational cohort study investigated brain CT scans of patients hospitalized after CA who visited the emergency department of a single university-affiliated hospital in Korea between January 2001 and September 2020. This study was approved by the Institutional Review Board of Hanyang University Guri Hospital (IRB No. GURI 2020-12-008), which waived the requirement of informed consent.

We included adult patients hospitalized after CA who underwent pre- and post-CA brain CT. The exclusion criteria were as follows: (1) being transferred to another hospital after ROSC, (2) age < 19 years, (3) having traumatic/non-traumatic brain hemorrhage or brain tumor, (4) a history of ophthalmological disorders or surgeries that could affect ONSD, and (5) having the most recent pre-CA brain CT obtained at an age < 19 years. Finally, eligible patients were divided into the GNO (good neurologic outcome) and PNO (poor neurologic outcome) groups based on the neurologic outcome at discharge; subsequently, we measured ONSD changes and performed between-group analysis. The primary outcome was the association between ONSD changes and the neurologic outcomes of patients hospitalized after CA.

Data collection

We retrospectively collected the following data from electronic medical records: age, gender, comorbidities (hypertension, diabetes, myocardial infarction), etiology (cardiac, respiratory), location of CA, whether the CA was witnessed, bystander CPR, first monitored shockable rhythm, CA duration including the no-flow (time between CA and CPR initiation) and low-flow time (time between active CPR and ROSC), and administered targeted temperature management (TTM). Based on the medical records, we determined the interval between the latest pre-CA brain CT and ROSC (month), which was termed as 'CT to ROSC', and between ROSC and post-CA brain CT (minute), which was termed as 'ROSC to CT'. Additionally, we collected data regarding the neurologic outcomes on discharge using the Glasgow-

Pittsburgh Cerebral Performance Categories (CPC). Based on the CPC scale, we defined good (GNO) and poor neurologic outcomes (PNO) as a CPC 1 or 2 and 3–5, respectively.

ONSD measurements using brain CT

Brain CT scans were performed based on standard protocols using non-contrast 4-mm contiguous slices parallel to the orbital floor from the skull base to the vertex. The pre-CA and post-CA ONSDs were bilaterally measured at 3 mm behind the globe on brain CT using the picture archiving and communication system (PACS) ruler tool (PiView STAR, INFINITT, Seoul, Korea). Images were magnified at 450% and changed to the 'mediastinum' window (window width: 440; window level: 45) using a PACS tool. The ONSDs of the right and left eyes were averaged to obtain the mean value. All measurements were performed using emergency physicians blinded to the patient information, including neurologic outcome. Additionally, we calculated the amount and rate of ONSD change. We defined the amount of change as the difference between the pre-CA and post-CA ONSD. Moreover, the rate of ONSD change was calculated as follows:

$$\left(\frac{Post\text{-}CA\ ONSD\ -\ Pre\text{-}CA\ ONSD}{Pre\text{-}CA\ ONSD}\right) x\ 100$$

We used the following three CT equipment: Somatom Sensation 16, SOMATOM Definition DS, and SOMATOM Definition Edge (Siemens Healthcare, Erlangen, Germany). The following parameters were used: 120 kVp, 250–500 mAs, and 4 to 4.5-mm slice thickness. All CT images were stored as the Digital Imaging and Communication in Medicine format in the PACS.

Sample size

We calculated the sample size based on a pilot study on 33 participants using G*Power (3.1.9.6; Heine Heinrich University, Düsseldorf, German). The mean ONSD of patients with GNO and PNO was 4.75 ± 1.45 mm and 5.63 ± 1.85 mm, respectively. The required sample size was calculated as 90 participants (effect size: 0.53, a-error: 0.05, power: 0.8); finally, considering a 10% drop-out rate, 99 participants were required.

Statistical analysis

Continuous and categorical variables were reported as the median with interquartile range (IQR) and number with percentages. Normally distributed variables were analyzed using the Mann-Whitney U-test and Wilcoxon rank-sum test while non-normally distributed variables were analyzed using the Shapiro-Wilk test. Chi-square tests or Fisher's exact test were used to analyze categorical variables. Statistical significance was set at $P < 0.05$. Multivariable analysis with logistic regression was used to determine the risk factors for poor neurologic outcomes with adjustment for confounding variables found significant on univariate analysis. Variables with $p < 0.2$ on univariate analysis with the rate of ONSD change were included in the multivariable analysis. Further, the Hosmer-Lemeshow test was used to confirm the logistic model calibrations. The predictive performance of the main outcome was assessed using the area under the receiver operating characteristic ([ROC] AUC) of the sensitivity over 1 – specificity. Results were obtained using the Youden index and presented as a 95% confidence interval (CI) of AUC with

sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV). ROC analysis was performed using MedCalc Statistical Software (version 17.2, MedCalc Software, Ostend, Belgium) while the other statistical analyses were performed using SPSS software (version 25.0, IBM, Armonk, NY).

Results

Baseline characteristics

Among 145 post-CA survivors who underwent brain CT before and after CA, 49 patients were excluded as follows: 40 patients who transferred to another hospital, seven patients with intracranial or subarachnoid hemorrhage, one patient with a brain tumor, and one patient aged ≤ 18 years. Finally, we enrolled 96 patients and allocated them to the GNO group (n = 25, 26.0%) and PNO group (n = 71, 74.0%) (Fig. 1).

Table 1 summarizes the demographic and clinical characteristics. The median age of the included patients was 70 (IQR: 58–79) years with 56.3% being male. The GNO group was significantly younger than the PNO group. Moreover, the GNO group showed a significantly higher frequency of cardiac etiology and shockable rhythm, as well as a shorter no-flow and low-flow time, than the PNO group. Contrastingly, out-of-hospital cardiac arrest was more frequent in the PNO group.

Table 1
Baseline characteristics of enrolled patients.

	Total (n = 96)	GNO (n = 25)	PNO (n = 71)	*p*-value
Demographics				
Age, year	70 (58−79)	60 (52−67)	75 (61−80)	< 0.001
Gender, male	54 (56.3)	15 (60.0)	39 (54.9)	0.660
Comorbidities				
HTN	52 (54.2)	14 (56.0)	38 (53.5)	0.831
DM	37 (38.5)	6 (24.0)	31 (43.7)	0.082
MI	16 (16.7)	4 (16.0)	12 (16.9)	1.000
Etiology				
Cardiac	23 (24.0)	14 (56.0)	9 (12.7)	< 0.001
Respiratory	40 (41.7)	8 (32.0)	32 (45.1)	0.254
Others	33 (34.4)	3 (12.0)	30 (42.3)	0.006
Resuscitation				
Location of arrest, OHCA	76 (79.2)	16 (64.0)	60 (84.5)	0.030
Witnessed	72 (75.0)	19 (76.0)	53 (74.6)	0.893
Bystander CPR	61 (63.5)	18 (72.0)	43 (60.6)	0.307
Shockable rhythm	11 (11.5)	8 (32.0)	3 (4.2)	0.001
No-flow time, min	10 (0−21)	4 (0−9)	11 (2−25)	0.003
Low-flow time, min	10 (6−16)	6 (3−10)	11 (8−18)	0.004
TTM	6 (6.3)	3 (12.0)	3 (4.2)	0.180
CT to ROSC interval[*], month	27 (6−55)	40 (6−55)	23 (6−53)	0.780
ROSC to CT interval[†], min	104 (51−171)	60 (33−118)	113 (60−200)	0.017

Abbreviations: GNO = good neurologic outcome; PNO = poor neurologic outcome; HTN = hypertension; DM = diabetes mellitus; MI = myocardial infarction; OHCA = out-of-hospital cardiac arrest; CPR = cardiopulmonary resuscitation; TTM = targeted temperature management; CT = computed Tomography; ROSC = return of spontaneous circulation.

* The interval between the latest pre-CA brain CT and ROSC.

† The interval between ROSC and post-CA brain CT.

Comparison of pre-CA and post-CA ONSDs

In both groups, the post-CA ONSD was significantly higher than the pre-CA ONSD (Fig. 2). In the GNO group, there was a significant difference between the pre-CA ONSD and post-CA ONSD (5.06 vs. 5.50 mm, $p < 0.001$) in the GNO group. Similarly, in the PNO group, there was a significant difference between the pre-CA ONSD and post-CA ONSD (5.07 vs. 5.72 mm, $p = 0.001$) (Supplemental Table 1).

The association between ONSD changes and neurologic outcomes

Table 2 presents the between-group comparisons of the amount and rate of ONSD changes. There was no significant between-group difference in pre-CA ONSD (5.06 vs. 5.07 mm, $p = 0.967$) and post-CA ONSD (5.50 vs 5.72 mm, $p = 0.075$). However, the amount of ONSD change in the GNO group was significantly lower than that in the PNO group (0.30 vs. 0.63 mm, $p = 0.030$). Additionally, the rate of ONSD change in the GNO group was significantly lower than that in the PNO group (5.26 vs. 12.29 %, $p = 0.041$). Multivariable analysis revealed no independent association between the rate of ONSD change and poor neurologic outcome (OR = 1.075; 95% CI = 0.990−1.167, $p = 0.084$) (Table 3).

Table 2
The comparisons of the amount and rate of ONSD changes between good and poor neurologic outcome.

	Total (n = 96)	GNO (n = 25)	PNO (n = 71)	p-value
Optic nerve sheath diameter				
Pre-CA, mm	5.07 (4.73−5.52)	5.06 (4.76−5.53)	5.07 (4.73−5.52)	0.967
Post-CA, mm	5.66 (5.41−6.01)	5.50 (5.16−5.88)	5.72 (5.49−6.04)	0.075
Optic nerve sheath diameter changes between pre-CA and post-CA				
Amount of change, mm	0.57 (0.25−0.84)	0.30 (0.18−0.65)	0.63 (0.32−0.87)	0.030
Rate of change, %	11.10 (4.70-17.21)	5.26 (3.85−14.15)	12.29 (5.83−18.74)	0.041
Abbreviations: GNO = good neurologic outcome; PNO = poor neurologic outcome; CA = cardiac arrest.				

Table 3
Multivariable logistic regression analysis for poor neurologic outcome with baseline variables and rate of optic nerve sheath diameter change.

Variables	Adjusted OR (95% CI)	p-value
Age, year	1.115 (1.031−1.206)	0.006
DM	3.358 (0.636−17.733)	0.154
Shockable rhythm	0.084 (0.008−0.911)	0.042
No-flow time, min	1.113 (1.003−1.235)	0.043
Low-flow time, min	1.123 (1.024−1.231)	0.013
TTM	0.119 (0.008−1.794)	0.124
Location of arrest, OHCA	0.833 (0.115−6.014)	0.856
ROSC to CT interval [*], min	0.999 (0.999-1.000)	0.086
Etiology, cardiac	0.080 (0.012−0.558)	0.011
Rate of change, %	1.075 (0.990−1.167)	0.084

Abbreviations: OR = odds ratio; DM = diabetes mellitus; TTM = targeted temperature management; OHCA = out-of-hospital cardiac arrest; ROSC = return of spontaneous circulation; CT = computed tomography.

* The interval between ROSC and post-CA brain CT.

Diagnostic value of ONSD changes for predicting the neurologic outcome

The AUC for predicting PNO was 0.64 (95% CI = 0.53−0.73; p = 0.04) in the ROC curve for the rate of ONSD change (Fig. 3). Patients with a rate of ONSD change > 27.2% had PNO with specificity and PPV of 100%. GNO could be predicted using a cut-off value of ≤ 5.83% in the ROC curve for the rate of ONSD change, with a sensitivity and specificity of 60.0% and 76.06%, respectively. The PPV and NPV were 46.9% and 84.4%, respectively (Table 4).

Table 4
Cut-off and diagnostic value of optic nerve sheath diameter change for predicting good and poor neurologic outcome.

	Cut-off, %*	Sensitivity	Specificity	PPV	NPV
Rate of change for predicting PNO	> 27.2	0.085	1.000	1.000	0.278
Rate of change for predicting GNO	≤ 5.83	0.600	0.761	0.469	0.844
Abbreviations: PPV = positive predictive value; NPV = negative predictive value; PNO = poor neurologic outcome; GNO = good neurologic outcome.					

Discussion

This study found that the amount and rate of ONSD change were significantly associated with neurologic outcomes. Further, there was no significant between-group difference in the post-CA ONSD. However, there was no independent association of the rate of ONSD change with neurologic outcomes after adjusting for confounding variables. Together with other established predictors, the rate of ONSD change may be useful for predicting neurologic outcomes. To our knowledge, this is the first study to investigate individual differences in ONSD changes among post-CA survivors.

Previous studies have reported an association of neurologic outcomes in critically ill patients, including post-CA survivors, with increased ICP.[3, 4, 21, 22] The optic nerve sheath covers the optic nerve and is comprised of a subarachnoid space layer filled with cerebrospinal fluid (CSF).[23] ICP is positively correlated with the CSF pressure and ONSD length.[23, 24] ONSD is a potential non-invasive ICP estimator and could be useful for assessing intracranial hypertension.[24] In patients with post-CA hypoxic cerebral injury, increased ICP is associated with neurologic outcome.[3, 21, 22]

Several studies have reported that ONSD can predict neurologic outcomes in post-CA survivors. A retrospective cohort study from Korea reported an association of longer ONSD on initial brain CT with poor neurologic outcome.[15] Chelly et al. demonstrated that ONSD could be an early prediction tool for outcomes in post-CA patients treated using TTM.[19] Other studies have used ONSD combined with other predictors, including GWR or albumin levels, to enhance the predictive value. Moreover, a recent meta-analysis reported that ONSD could be useful for predicting neurologic outcome.[14, 20, 21] Inconsistent with these findings, a registry-based multicenter study reported no correlation between ONSD on early unenhanced brain CT and neurologic outcome in post-CA survivors managed using TTM.[25] Previous studies have reported that predicting neurologic outcomes in post-CA survivors using post-CA ONSD alone is insufficient with limitations.

ONSD can allow non-invasive ICP measurement and could serve as a surrogate marker for increased ICP.[17, 18] However, in healthy adults, there are differences in the baseline ONSD according to individual characteristics, including sex, body mass index (BMI), race, or eyeball size.[26, 27] Most studies of healthy volunteers have reported that the mean ONSD ranges from about 3 mm to 5 mm; moreover, the reported

mean or median ONSD values have varied across study cohorts depending on the race or measurement tools.[26–29] Ultrasonographic evaluation of healthy Asians revealed a longer ONSD in males and individuals with high BMI.[26, 27] Therefore, these individual differences could confound the interpretation of post-CA ONSD; moreover, it may be useful to consider the baseline ONSD for improving the prognostic value. Therefore, ONSD changes may be useful markers for ICP measurement changes. A prospective observational study on ONSD changes in patients with hydrocephalus reported a significant reduction in ONSD after ventriculoperitoneal shunt operation.[30] In our study, ONSD changes were more reliable than the ONSD itself for predicting neurologic outcomes in patients with post-CA.

A recent meta-analysis reported that compared with CT and MR, sonographic measurement allowed more accurate prediction of neurologic outcome in patients with post-CA.[20] However, obtaining and comparing pre-CA and post-CA ONSD using ultrasound could be limited in clinical settings. Moreover, determining the pre-CA ONSD using brain MR has limitations given its specific modality. Recent studies have indicated that the axial proton density/T2-weighted turbo spin-echo fat-suppressed sequence is required for ONSD measurements using MR. However, in most post-CA patients, the T2-TSE image is not included in the diffusion-weighted MR.[31, 32] Additionally, there is a strong association of ONSD with eyeball transverse diameter (ETD) and ONSD/ETD ratio in healthy adults.[33] There is a need for further studies on the association between ONSD/ETD ratio and neurologic outcome in post-CA patients.

This study has several limitations. First, this was a single-center study with a limited sample size that led to an insufficient statistical power; however, we calculated the sample size, which was relatively large compared with that of other studies. Second, this retrospective study included patients who underwent both pre- and post-CA brain CT, which could lead to selection bias affecting the results. Third, although we attempted to extensively collect variables, there could be hidden confounders. Fourth, there could have been minor measurement errors given the very small size of the ONSD in brain CT. However, to minimize these errors, two blinded emergency physicians performed measurements using a standardized method with consensus. Fifth, current guidelines recommend neurologic outcome assessment at 3 months after discharge. However, we measured the neurologic outcome at discharge and did not determine the long-term outcome. Sixth, this was a retrospective study and the clinical utility of the predictive value for prognosis remains unclear. There is a need for large-scale prospective studies to enhance our findings.

Conclusions

The rate and amount of ONSD changes on brain CT were significantly associated with neurologic outcome in patients with post-CA. ONSD changes may be useful to predict neurologic outcome in patients with post-CA.

Abbreviations

ONSD, optic nerve sheath diameter; CA, cardiac arrest; CT, computed tomography; GNO, good neurologic outcome; PNO, poor neurologic outcome; ICP, intracranial pressure; ROSC, return of spontaneous

circulation; GWR, grey-to white matter ratio; CPR, cardiopulmonary resuscitation; TTM, targeted temperature management; CPC, Cerebral Performance Categories; PACS, picture archiving and communication system; IQR, interquartile range; AUC, area under curve; ROC, the receiver operating characteristic; CI, confidence interval; PPV, positive predictive value; NPV, negative predictive value; CSF, cerebrospinal fluid; BMI, body mass index; ETD, eyeball transverse diameter

Declarations

Authors' contributions

Heekyung Lee: Software, Formal analysis, Investigation, Resources, Data Curation, Writing - Original Draft. Joonkee Lee: Investigation, Resources, Data Curation, Writing - Original Draft. Hyungoo Shin: Conceptualization, Methodology, Software, Validation, Writing - Review & Editing, Supervision.

Availability of data and materials

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

This study was approved by the Institutional Review Board of Hanyang University Guri Hospital (IRB No. GURI 2020-12-008), which waived the requirement of informed consent.

Consent for publication

Not applicable

Competing interests

The authors declare no competing interests.

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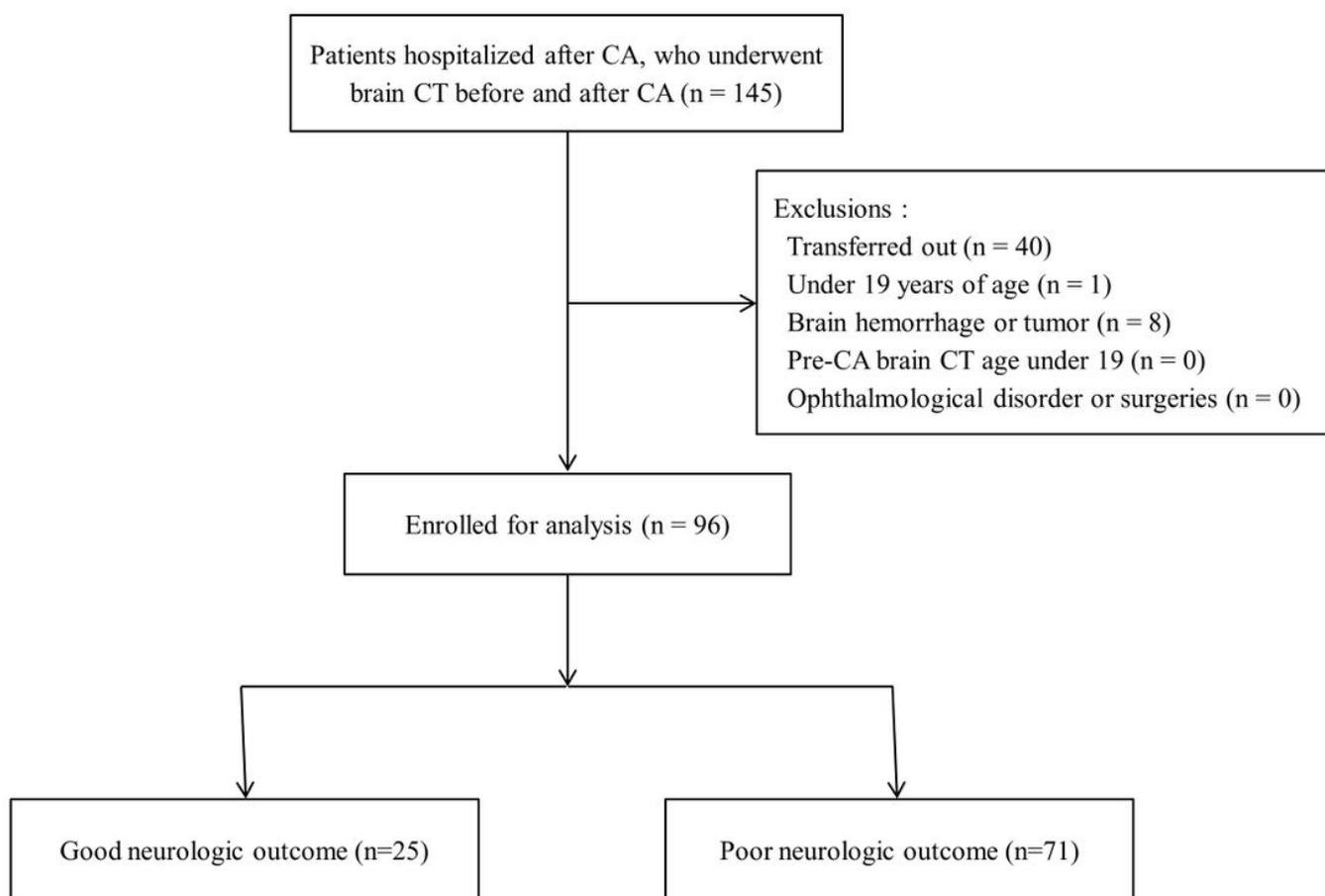
Figures

Figure 1
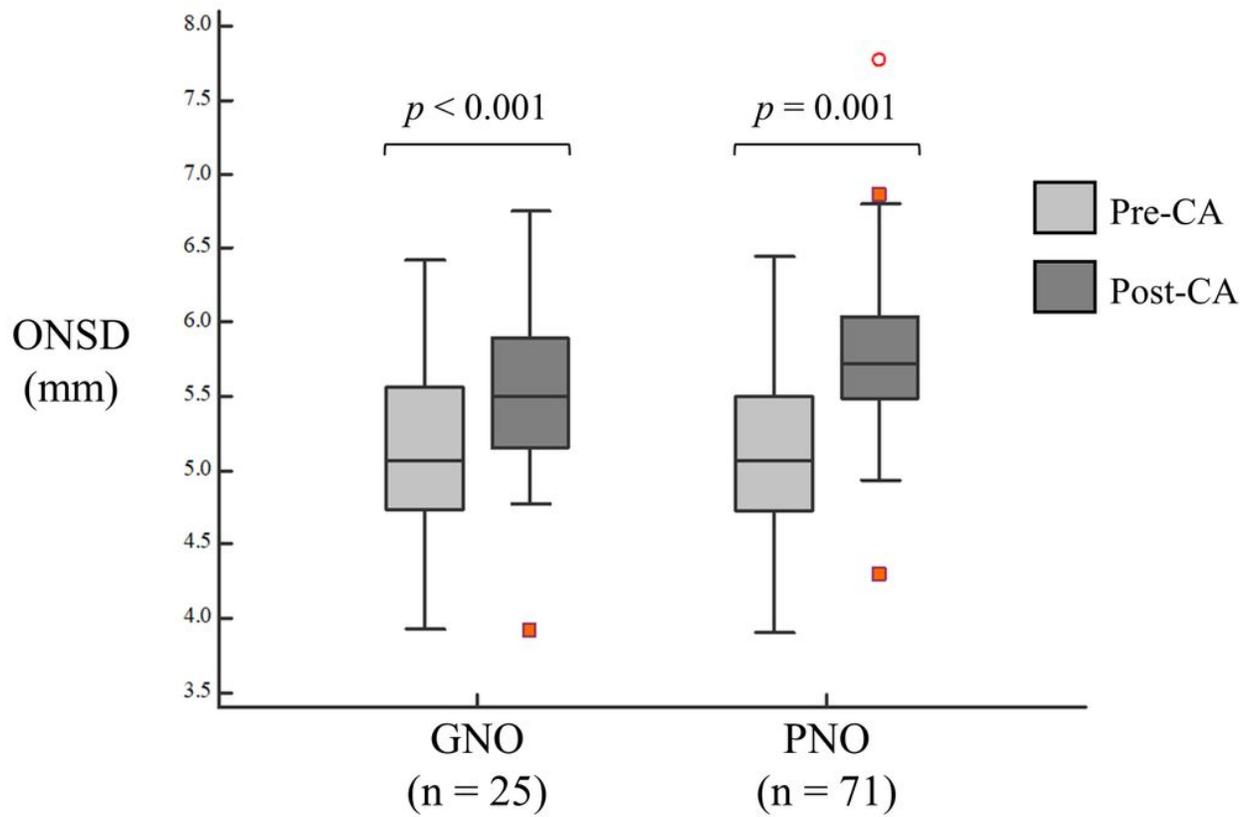
Flow chart of the study process

Figure 2

Comparison of the optic nerve sheath diameter between pre-cardiac arrest and post-cardiac arrest in good and poor neurologic outcome group.
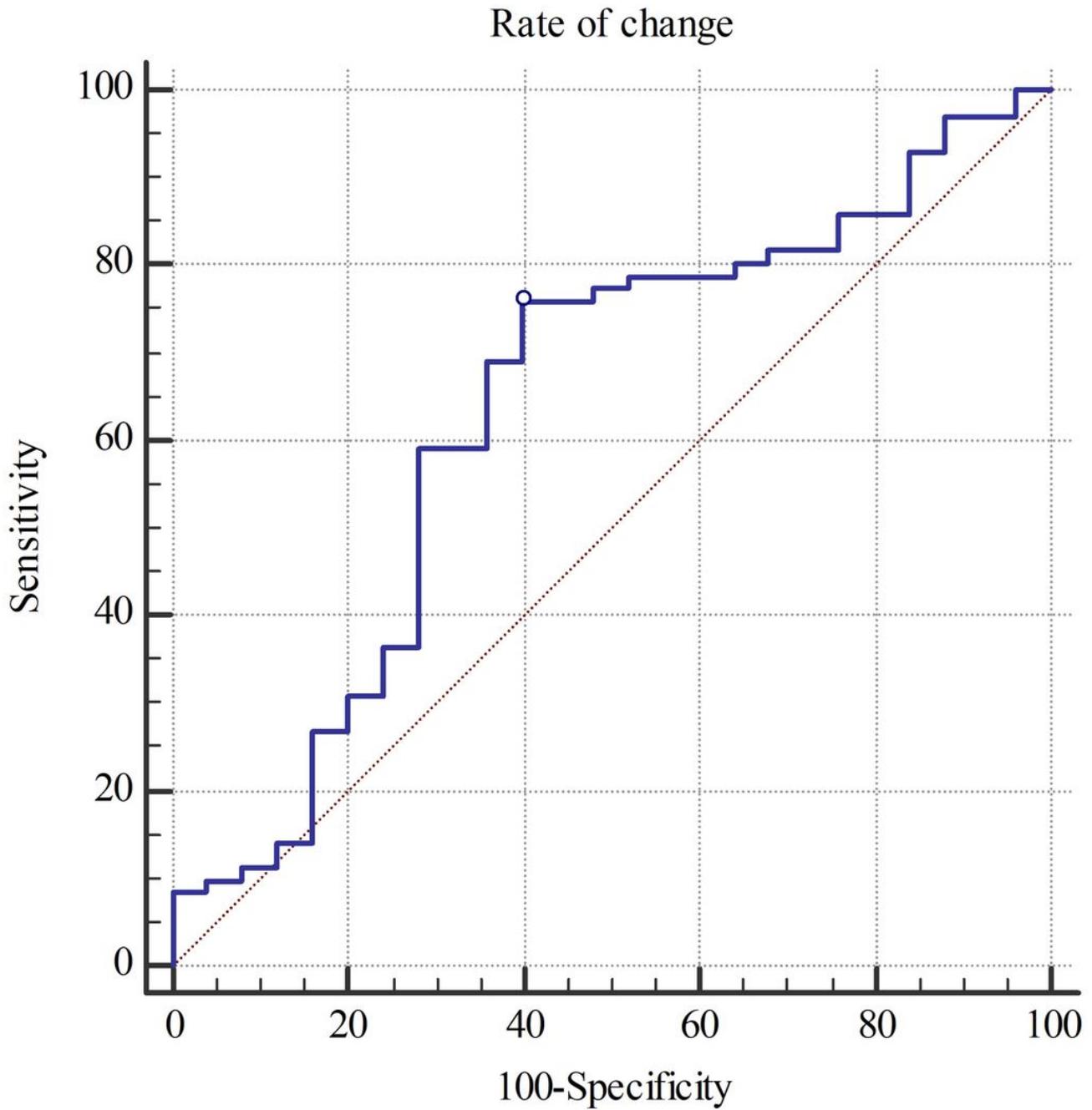
Rate of change

Figure 3

Receiver operator curve for predicting poor neurologic outcome using rate of optic nerve sheath diameter change. AUC = 0.64 (95% Confidence interval = 0.53-0.73)

Supplementary Files

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