Better prognostic value with combined optic nerve sheath diameter and grey-to-white matter ratio on initial brain computed tomography in post-cardiac arrest patients

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ARTICLE INFO

Article history:
Received 27 January 2016
Received in revised form 18 March 2016
Accepted 4 April 2016

Keywords:
Cardiac arrest
Targeted temperature management
Brain computed tomography
Grey-to-white matter ratio
Optic nerve sheath diameter

ABSTRACT

Aim: We aimed to evaluate the prognostic value of optic nerve sheath diameter (ONSD) and grey-to-white matter (GWR) either alone or in combination in patients treated with targeted temperature management (TTM) after cardiac arrest (CA).

Methods: We conducted a retrospective single centre study of post cardiac arrest patients treated with TTM. ONSD and GWR on brain computed tomography (CT) was measured by two emergency physicians. We analysed the prognostic performance and cut offs of GWR and ONSD, singly and in combination in predicting poor neurologic outcome (CPC 3–5).

Results: Of the 119 patients studied, 74 patients showed poor outcome. The combination of ONSD and GWR significantly (p = 0.002) improved prognostic performance (AUROC 0.67, 95% CI: 0.58–0.76, p < 0.001) in predicting poor neurologic outcomes rather than each ONSD (AUROC 0.59, 95% CI: 0.50–0.68, p = 0.08) or GWR (AUROC 0.65, 95% CI: 0.56–0.74, p = 0.002) alone. A combined cut off of ‘GWR and ONSD (1.16 and 4.9)’ and ‘GWR or ONSD (1.13 or 6.5)’ improved the sensitivity for predicting poor outcome while maintaining high specificity compared to GWR alone.

Conclusion: The combination of ONSD and GWR yielded improved prognostic value for predicting poor neurologic outcomes in post cardiac arrest patients treated with TTM.

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Introduction

Ischemia-reperfusion cerebral injury significantly contributes to mortality and may reduce the quality of life in many cardiac arrest survivors.1–3 Post cardiac arrest care and temperature management has been emphasized as an effective therapy for neuroprotection in these patients.4 Neurologic prognostication is needed to guide targeted treatment interventions according to severity and to provide information to treating physicians. Although many prognostic factors including neurologic exams, electrophysiological tests (electroencephalography, somatosensory evoked potential),5,6 serum markers such as neuron-specific enolase (NSE)7 have been studied, most are predictive of outcomes only after 72 h of post-cardiac-arrest.8 Therefore, earlier prediction of neurologic outcomes is of importance in the setting of post-cardiac arrest care for guiding treatment strategies.

Many patients generally undergo initial brain computed tomography (CT) scanning post cardiac arrest to evaluate brain haemorrhage or infarction before admission to the intensive care unit (ICU). Several recent studies have focused on the early prediction of neurologic outcomes using the grey-to-white matter ratio (GWR) on initial brain CT in cardiac arrest survivors treated with TTM.9–11 The obliteration of grey and white matter decreases values of the grey-to-white matter ratio, leading to the presumption that the patient has brain oedema and will have a poor outcome. These studies showed various prognostic performances with various cut-offs11 and some studies combined prognostic factors so as to enhance the performance.5,13

We assessed the optic nerve sheath diameter (ONSD), which is known to correlate with increased intracranial pressure (ICP)14–16...
and is easily measured on brain CT, and sought to determine whether it can improve our ability to predict poor prognosis in post cardiac arrest patients when combined with GWR. The optic nerve sheath is easily assessed as a part of the brain meninges and it is known to be a good predictor of mortality in patient with traumatic brain injuries. Hypoxic brain injury during cardiac arrest and delayed hyperemia after return of spontaneous circulation (ROSC) may result in increased intracranial pressure and brain swelling, which can be associated with poor neurologic outcomes.

There was previously one study of GWR and ONSD on post cardiac arrest patients. However, 40 out of 91 of the patients underwent temperature management and had various initial Glasgow coma scale (GCS) scores in this study by Kim et al. Therefore, this is the first study to evaluate the prognostic value of ONSD and GWR either alone and combined in a homogeneous group of comatose patients treated with TTM after cardiac arrest.

**Methods**

This study was approved by the Institutional Review Board of Samsung Medical Centre (SMC-2015-01-065-001). Consent forms were waived due to the retrospective design.

**Study design and population**

This was a retrospective single-centre observational cohort study using medical records of patients who had been treated with TTM following cardiac arrest in an urban tertiary care hospital, Samsung Medical Center in Seoul, Korea from October 2009 to December 2013. Resuscitated cardiac arrest patients who were comatose after ROSC and underwent TTM were included. Patients under 18 or over 75 years of age, with families that refused further treatment, who had brain haemorrhage on initial brain CT, patients with high bleeding risk or with a traumatic cause of arrest did not undergo TTM. The exclusion criteria for this study were (1) TTM interrupted due to hemodynamic instability or family refusing further treatment, (2) brain CT not obtained, (3) brain CT obtained more than 6 h after ROSC, (4) brain CT too poor in quality to measure the ONSD or GWR, and (5) other apparent brain parenchymal disease or ophthalmic disease that would affect the GWR and ONSD.

**Targeted temperature management (TTM) protocol**

All patients received standard TTM and intensive care according to our institutional ICU protocol. TTM was induced with intravenous cold saline or cooling devices (Artic Sun® Energy Transfer Fads TM, Medivance Corp., Louisville, USA). The target temperature of 33°C was maintained for 24 h with rewarmin to 36.5°C at a rate of 0.15°C/h and was monitored using an esophageal temperature probe. Sedatives and analgesics were used during TTM and patients received standard care according to our hypothermia protocol as described previously. A spot EEG was performed during TTM as soon as possible. When seizure was suspected either clinically or through EEG, anti-epileptiform medications were started. All patients that received TTM was documented in our hypothermia database.

**Data collection**

We reviewed data from a prospectively documented hypothermia database including Utstein-style data, temperature management data and the Glasgow-Pittsburgh Cerebral Performance Categories (CPC) at one month after ROSC of both in-hospital and out-of-hospital cardiac arrest patients treated with temperature management. The following data were retrospectively collected from the database: age, gender, presence of a witness of collapse, bystander CPR, first monitored rhythm, etiology of cardiac arrest, time from collapse to CPR that was defined as no flow time, time from CPR to ROSC that was defined as low flow time, SOFA score and one month neurologic outcome. Time from ROSC to obtaining the brain CT was retrospectively determined from electronical medical records.

**Measurement of ONSD and GWR on CT scan**

Two emergency physicians blinded to the patient outcome retrospectively reviewed the brain CT on the picture archiving and communication system (PACS) radiology workstation (Centricity Enterprise, GE). ONSD was measured at a distance of 3 mm behind the sclera at both the patient’s left and right eye. We measured the average hounsfield units (HU) of circular regions of interest (10.0 mm² - 15 mm²) on each side of the basal ganglia, centrum semiovale and high cortical level. The caudate nucleus (CN) putamen (PU), posterior limb of internal capsule (PLIC) and corpus callosum(CC) was measured for the basal ganglia, and the grey and white matter from the medial cortex was measured at the centrum semiovale (MC1, MW1) and high cortical level (MC2, MW2). The GWR for the basal ganglia (GWR-BG = (CN + PU)/(PLIC + CC)), for the cerebrum (GWR-CE = (MC1 + MC2)/(MW1 + MW2)) and the average of the two (GWR-AV = (GWR-BG + GWR-CE)/2) were calculated as previously described (Fig. 1).

**Statistical analysis**

The intra- and inter-observer variabilities were evaluated for two physicians and were calculated by analysis of GWR and ONSD measures. Continuous variables were reported as the median with interquartile range (IQR) or mean and standard deviation (SD) depending on normal distribution. The Mann–Whitney U-test or two-tailed t test was conducted for comparisons of continuous variables. Categorical variables are presented as frequencies and percentages and comparisons were done using the chi-square test or Fisher’s exact test. Receiver operating characteristic (ROC) curves were plotted to determine the performance of ONSD, GWR and combined ONSD and GWR in predicting neurologic outcomes. The ROC curves were calculated and compared by the DeLong method. Cut-off values with high specificity were calculated for predicting poor neurologic outcome. Data were analysed using Stata software, version 13 (Stata Corp. LP, TX, USA) and SAS version 9.3 (SAS Institute, Cary, NC, USA).

**Results**

**Characteristics of study subjects**

Of the 188 post cardiac arrest patients who were admitted to the ICU for temperature management, CT was not performed in 38 patients, CT was delayed over 6 h in 23 patients and the quality of CT was suboptimal for analysis in eight patients. Ultimately, a total of 119 patients were analysed (Fig. 2). Baseline characteristics are shown in Table 1. A total of 74 patients (62.2%) resulted in CPC 3–5 at one month after cardiac arrest. The median time from ROSC to brain CT did not differ between the outcome groups (55.5 min (35.5–121.5) vs. 63 min (39–125), p = 0.73).

**ONSD and GWR on brain CT**

The mean ONSD was not significantly different between the outcome groups (5.6 ± 0.5 mm vs. 5.8 ± 0.6 mm, p = 0.05). However GWR at the basal ganglia (GWR-BG) (1.26 ± 0.71 vs. 1.21 ± 0.10, p = 0.002), GWR at the cerebrum (GWR-CE) (1.21 ± 0.005 vs. 1.17 ± 0.08, p = 0.02) and the average of the two GWR values (GWR-AV) (1.23 ± 0.05 vs. 1.19 ± 0.08, p = 0.002) was significantly lower
in the poor outcome group (Table 2). The inter-rater coefficient was 0.80, intra-rater correlation coefficient was 0.94, 0.94 for ONSD and inter-rater coefficient was 0.93, intra-rater coefficient was 0.62, 0.71 for GWR.

**ROC curve analysis of ONSD and GWR**

The prognostic value of ONSD alone was limited [AUROC 0.59 (0.50–0.68),  𝑝 = 0.08] and GWR-AV alone was moderate [AUROC 0.65 (0.56–0.74),  𝑝 = 0.002] in predicting poor neurologic outcome. However, the predictive performance of ONSD and GWR combined [AUROC 0.67 (0.58–0.76),  𝑝 < 0.001] for poor neurologic outcome showed significantly improved performance ( 𝑝 = 0.02) (Fig. 3).

The cut off value of ONSD and GWR alone with high (100%) specificity for predicting poor neurologic outcome was analysed, but had limited sensitivity (ONSD cut-off: 7.0 mm, sensitivity 5.5, NPV 38.4) (GWR cut-off: 1.13, sensitivity 20.3, NPV 43.3). Difference between each ROC curve (ONSD, GWR) and a combined reference curve was statistically different by the DeLong method. As the prognostic value improved with combined ONSD and GWR, we investigated possible cut-off values combining ONSD and GWR. We analysed the diagnostic performances of ‘GWR and ONSD’ and ‘GWR or ONSD’ to determine cut-off values with high specificity for the two variables combined. When the cut-offs for ‘ONSD and GWR’ were 1.16 and 4.9 mm, the sensitivity improved to 25.7% while maintaining high specificity (97.8%). With ‘ONSD or GWR’, when the cut off was 1.13

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**Fig. 1.** Optic nerve sheath diameter (ONSD) and grey-to-white matter ratio (GWR) measurement on brain computed tomography (CT). (a) ONSD measurement, (b) Circular regions of interest placed bilaterally on the following regions 1 corpus callosum 2 caudate nucleus 3 putamen 4 posterior limb of internal capsule at the basal ganglia level, 5 and 6 cortex and white matter at the centrum semiovale level 7 and 8 cortex and white matter at the high cortical level.

**Fig. 2.** Study enrollment. CT, computed tomography; ROSC, return of spontaneous circulation.
or 6.5 mm, the sensitivity improved (27.0%) while maintaining high specificity (97.8%) (Fig. 4, Table 3).

### Discussion

Our study aimed to extract information from the initial brain CT of 119 post cardiac arrest patients who underwent TTM to predict poor neurologic outcome. This was the first study to combine the prognostic performance of ONSD to the previously studied GWR on initial brain CT of post-cardiac arrest patients that were all treated with TTM. Although ONSD and GWR showed limited and moderate performance in prognostication of post cardiac arrest patients, combined ONSD and GWR improved the prognostic performance and combined cut offs of ONSD and GWR improved the sensitivity of poor neurologic outcomes while maintaining high specificity. Although there was minor improvement of sensitivity, we believe that this evaluation may have value in the initial phase after ROSC.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Baseline characteristics of study population.</th>
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<tbody>
<tr>
<td></td>
<td>Good outcome (n = 45)</td>
</tr>
<tr>
<td>Age (years)</td>
<td>48.8 (16.3)</td>
</tr>
<tr>
<td>Male gender (%)</td>
<td>32 (71.1)</td>
</tr>
<tr>
<td>Cause of arrest (%)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Cardiogenic</td>
<td>40 (88.9)</td>
</tr>
<tr>
<td>Asphyxia</td>
<td>1 (2.2)</td>
</tr>
<tr>
<td>Other</td>
<td>4 (8.9)</td>
</tr>
<tr>
<td>Shockable rhythm (%)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Bystander CPR</td>
<td>24 (53.3)</td>
</tr>
<tr>
<td>No flow time (min)</td>
<td>4 (5.8)</td>
</tr>
<tr>
<td>Low flow time (min)</td>
<td>20.6 (17.9)</td>
</tr>
<tr>
<td>Time to ROSC (min)</td>
<td>24.6 (18.6)</td>
</tr>
<tr>
<td>ROSC to CT (min)</td>
<td>55.5 (35.5–121.5)</td>
</tr>
<tr>
<td>SOFA score (median)</td>
<td>5 (3–7)</td>
</tr>
</tbody>
</table>

Data are presented as mean (SD) or median (interquartile range). CPR, cardiopulmonary resuscitation; ROSC, return of spontaneous circulation; CT, computed tomography; SOFA, sequential organ failure assessment.

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Comparison of optic nerve sheath diameter and gray to white matter ratio between outcome groups.</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Good outcome (n = 45)</td>
</tr>
<tr>
<td>ONSD (mm)</td>
<td>5.6 (0.5)</td>
</tr>
<tr>
<td>GWR</td>
<td>28.8 (2.7)</td>
</tr>
<tr>
<td>CC</td>
<td>35.1 (2.6)</td>
</tr>
<tr>
<td>CN</td>
<td>33.3 (2.0)</td>
</tr>
<tr>
<td>PULC</td>
<td>27.4 (2.1)</td>
</tr>
<tr>
<td>MC1</td>
<td>33.2 (2.5)</td>
</tr>
<tr>
<td>MW1</td>
<td>27.7 (2.3)</td>
</tr>
<tr>
<td>MC2</td>
<td>32.8 (2.6)</td>
</tr>
<tr>
<td>MW2</td>
<td>27.2 (2.3)</td>
</tr>
<tr>
<td>GWR-BG</td>
<td>1.26 (0.71)</td>
</tr>
<tr>
<td>GWR-CE</td>
<td>1.21 (0.05)</td>
</tr>
<tr>
<td>GWR-AV</td>
<td>1.23 (0.05)</td>
</tr>
</tbody>
</table>

Data are presented as mean (SD). GWR-BG (basal ganglia) = (CN + PU)/(CC + PULC); GWR-CE (cerebrum) = (MC1 + MC2)/(MW1 + MW2); GWR-AV (average) = (GWR-BG + GWR-CE)/2; ONSD, optic nerve sheath diameter; GWR, gray to white matter ratio; CC, corpus callosum; CN, caudate nucleus; PU, putamen; PULC, posterior limb of internal capsule; MC1, medial cortex 1; MW1, medial white matter 1 in the centrum semiovale; MW2, MW2 in the high convexity area.

<table>
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<tr>
<th>Table 3</th>
<th>Cutoff and diagnostic value of measurements for poor outcome.</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Cut off</td>
</tr>
<tr>
<td>Mean ONSD (mm)</td>
<td>5.9</td>
</tr>
<tr>
<td>GWR</td>
<td>4.8</td>
</tr>
<tr>
<td>GWR and ONSD</td>
<td>1.16 and 4.9</td>
</tr>
<tr>
<td>GWR or ONSD</td>
<td>1.13 or 6.5</td>
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</table>

The ONSD,GWR cut off value above was set to maximize the sensitivity and specificity and the cut off value below was set to maximize the specificity. AUROC, area under ROC curve; CI, confidence interval; PPV, positive predictive value; NPV, negative predictive value; ONSD, optic nerve sheath diameter; GWR, gray to white matter ratio.
to help the physician with treatment directions in a Bayesian fashion.

There was one previous study of ONSD measured from the brain CT of 91 post-cardiac arrest patients. ONSD and GWR measured on initial brain CT were found to be very good (AUROC 0.931, 0.922) early prognostic factors. Combining the cut-offs of ONSD and GWR improved the sensitivity to 92% while maintaining 100% specificity in predicting poor neurologic outcomes. However, TTM was performed in only 40 patients and the initial GCS ranged from 3 to 15, including alert patients that were able to obey to verbal commands. This indicates a different study population from our study and other studies of prognostication for comatose post cardiac arrest patients. Although there were no studies comparing the prognostic performance of GWR in patients that underwent TTM and patients that did not, previous studies show that the prognostic performance of GWR was inferior in studies of patients receiving TTM. As TTM may affect the brain in many ways to mitigate permanent injuries, patients treated with TTM stand a good chance of recovery despite initial injury. Therefore, signs on the initial brain CT suggesting poor neurologic outcome (higher ONSD, lower GWR) may have been reversible in some patients by TTM, altering the initial prognostic performance. Accordingly, the results of our study showed inferior performance (AUROC 0.59, 0.65) in prognostication with ONSD and GWR compared to this prior study.

Previous studies showed various prognostic performances of GWR in predicting poor neurologic outcome with various suggested cut-offs. In a recent study, the GWR values in arrest with cardiogenic aetiology showed poor prognostic performance (AUC of 0.57–0.62). Although no study has directly compared GWRs according to cardiac arrest aetiology, one study suggests that cerebral edema is more common after cardiac arrest of respiratory aetiology due to the development of the metabolic acidosis due to hypoxia before the resuscitation period. Thus, more non-cardiogenic arrests in the study population may result in better GWR performance in predicting poor outcome because of the tendency of more patients in the poor outcome group that may have clear presence of brain edema in the initial CT. Although we do not know why the performance of GWR in our study is inferior to other previous studies, this may be one possible factor.

Two emergency physicians that care for post cardiac arrest patients analysed the brain CT (one attending and one resident), and may not have the analytical quality as radiologists. Although this may have affected the performance of the indices, this study hopes to suggest a practical estimation tool that is not necessarily used by radiologists for initially predicting neurologic outcomes.

There were several limitations to our study. First, this was a retrospective single centre study and the number of patients was relatively small. Second, there may be selection bias as patients that had an initial brain CT done within six hours after ROSC were included in the study. As SAH is a common cause of arrest especially in the Asian population, we screened patients after ROSC with brain CT in order to exclude brain hemorrhage as a cause of arrest. However, with unstable patients or in in-hospital cardiac arrest patients where the cause of arrest is more evident, patients may have delayed or no brain CT evaluation done depending on the decision of the practicing physician. Third, CT images with 5 mm cuts may not have been optimal for measuring the ONSD. Fourth, limited evidence exists about the optimal time of analysis for ONSD and GWR. Some studies have measured GWR within 1 h or 2 h of post-cardiac arrest. For our study we limited the images for six hours after ROSC, but the optimal time for analysis of ONSD and GWR is unknown. Fifth, although we do not have a protocol that differentiates treatment based on CT images, the treating physicians were exposed to the CT findings and therapeutic decisions might have been influenced by self-fulfilling prophecy and the presence of apparent brain oedema.

Conclusion

ONSD combined with GWR enhances the prognostic performance and improves sensitivity while maintaining high specificity in predicting poor neurologic outcome in post cardiac arrest patients who undergo TTM.

Conflict of interest

The authors have no conflict of interest to declare.

References


