The Value of Arterial Blood Gas Parameters for Prediction of Mortality in Survivors of Out-of-hospital Cardiac Arrest

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Abstract

Context: Sudden cardiac death is one of the leading causes of death in Europe, and early prognostication remains challenging. There is a lack of valid parameters for the prediction of survival after cardiac arrest. Aims: This study aims to investigate if arterial blood gas parameters correlate with mortality of patients after out-of-hospital cardiac arrest. Materials and Methods: All patients who were admitted to our hospital after resuscitation following out-of-hospital cardiac arrest between January 1, 2008, and December 31, 2013, were included in this retrospective study. The patient’s survival 5 days after resuscitation defined the study end-point. For the statistical analysis, the mean, standard deviation, Student’s t-test, Chi-square test, and logistic regression analyses were used (level of significance \( P < 0.05 \)). Results: Arterial blood gas samples were taken from 170 patients. In particular, pH < 7.0 (odds ratio [OR]: 7.20; 95% confidence interval [CI]: 3.11–16.69; \( P < 0.001 \)) and lactate ≥ 5.0 mmol/L (OR: 6.79; 95% CI: 2.77–16.66; \( P < 0.001 \)) showed strong and independent correlations with mortality within the first 5 days after hospital admission. Conclusion: Our study results indicate that several arterial blood gas parameters correlate with mortality of patients after out-of-hospital resuscitation. The most relevant parameters are pH and lactate because they are strongly and independently associated with mortality within the first 5 days after resuscitation. Despite this correlation, none of these parameters by oneself is strong enough to allow an early prognostication. Still, these parameters can contribute as part of a multimodal approach to assessing the patients’ prognosis.

Keywords: Blood gas analysis, lactate, out-of-hospital cardiac arrest, pH, prognostication, resuscitation

Introduction

Out-of-hospital cardiac arrest (OHCA) is one of the leading causes of death in Europe.\(^1\) A preferably early prognosis assessment after OHCA is important with regard to the duration and extent of the intensive-care treatment. The sooner parameters correlating with survival of post-OHCA patients are available, the sooner physicians can make well-grounded decisions concerning medical treatment. Moreover, potentially harmful and futile treatments can be avoided.

We initiated this study to investigate to what extent the arterial blood gas parameters correlate with mortality of patients after out-of-hospital cardiac arrest to estimate their value for prediction of mortality.

Materials and Methods

Study design and patients’ data collection

We conducted a single-center, retrospective study at University Hospital. The hospital has an annual patient volume of 73,000 and provides a catheter laboratory.

All victims of OHCA who were admitted to the hospital between January 1, 2008, and December 31, 2013, were retrospectively identified by the analysis of the central admission register of the Intensive Care Unit. Individual patient data were collected from the patients’ health records and anonymously stored in a central database. The collected data included sex category, age, if the cardiac arrest was witnessed, if bystander cardiopulmonary resuscitation (CPR) was performed, if the initial rhythm was shockable (ventricular fibrillation or pulseless ventricular tachycardia), if preclinical return of spontaneous circulation (ROSC) was achieved, the electrocardiogram (including heart rate and the amount of...
ST-segment elevation myocardial infarction), systolic and diastolic blood pressure and the arterial blood gas values. We only used arterial blood samples that were taken within the 1st h after hospital admission either in the emergency department or in the intensive care unit. For the analysis of blood gases, we used IL Gem® Premier 300™ (Instrumentation Laboratory GmbH®, Bedford, Massachusetts, USA).

The only exclusion criteria were a missing arterial blood gas analysis within 60 min after hospital admission. Data collection and analysis were approved by the Local Ethical Review Committee.

**Study end-point**

The average duration of mechanical ventilation after OHCA is 5.4 days and from the 6th day on complications associated with ventilation increase.[2,3] Therefore, the patients’ survival 5 days after resuscitation was chosen as the study end-point to show the correlation of the blood gas parameters with survival after OHCA without falsification by the consequences of intensive-care treatment – including possible complications of long-lasting ventilation.

**Statistical analysis**

Statistical analysis was performed using the Statistical Package of Social Science (SPSS 23.0, IBM, Armonk, NY, USA). Continuous variables were expressed as the mean ± standard deviation, and comparisons of categorical variables among groups were conducted using Chi-square tests and Student’s t-test. P < 0.05 was considered to be statistically significant. To investigate the statistical association between arterial blood gas parameters and mortality, we used logistic regression analysis. Based on definitions of former studies, we used the cutoff values for the blood gas parameters shown in Table 1 for the dichotomization of the patient collective.

In multivariate analyses, we examined whether the blood gas parameters showed an independent association with mortality after adjustment for potential confounders. As covariates we used the following parameters that are known to influence the patients’ prognosis: bystander CPR, prehospital ROSC, age ≤ 65 years, shockable rhythm, early coronary angiography, and targeted temperature management.[4,16–18]

**RESULTS**

Between January 1, 2008, and December 31, 2013, there were 204 patients after OHCA who were admitted to the study hospital. Thirty-four patients were excluded from further analysis due to missing arterial blood gas analysis within 60 min after hospital admission, resulting in 170 included patients.

Table 2 shows the patients characteristics and the mean values of the arterial blood gas analysis taken within the 1st h after hospital admission.

Eighty patients (47.1%) survived the first 5 days after resuscitation and sixty patients (35.3%) were discharged alive.

| Variables | Cutoff value |
|-----------|--------------|
| pH[4,5]   | 7.0          |
| Hypocarbia[6,7] | <30 mmHg |
| Hypercarbia[2,3] | >50 mmHg |
| Normocarbia | 30–50 mmHg |
| Hypoxemia[8] | <60 mmHg |
| Hyperoxemia[9] | >300 mmHg |
| Normoxemia   | 60–300 mmHg |
| Oxygen saturation[10] | Lower cutoff point 94% |
| Bicarbonate[11] | 21 mmol/L |
| Base excess[12] | <−17.4 mmol/L |
| Lactate[14] | 5.0 mmol/L |
| Hematocrit[15] | Lower cutoff point 30.0% |
| Potassium >5.0 mmol/L[4] | Upper cutoff point 45.9% |

| Logistic regression analysis |

In univariate analysis, hypoxemia (odds ratio [OR]: 11.12; 95% confidence interval [CI]: 3.18–38.90; P < 0.001), pH < 7.0 (OR: 7.20; 95% CI: 3.11–16.69; P < 0.001) and lactate ≥ 5.0 mmol/L (OR: 6.79; 95% CI: 2.77–16.66; P < 0.001) showed the strongest association with mortality within the first 5 days after OHCA. The following also demonstrated a significant association with survival: hypercarbia (OR: 3.55; 95% CI: 1.81–6.96; P < 0.001), oxygen saturation < 94% (OR: 3.82; 95% CI: 1.47–9.97; P = 0.006), bicarbonate < 21 mmol/L (OR: 5.83; 95% CI: 2.23–15.27; P < 0.001), and base excess < −17.40 mmol/L (OR: 2.90; 95% CI: 1.37–6.15; P = 0.005) [Table 3].

After adjustment for the covariates in the multivariate analysis, pH < 7.0 (OR: 4.29; 95% CI: 1.60–11.56; P = 0.004) and lactate ≥ 5.0 mmol/L (OR: 5.92; 95% CI: 2.03–17.25; P < 0.001) were independently associated with mortality within the first 5 days after OHCA while hypoxemia did not show independent association with increased mortality rates. In addition, an oxygen saturation < 94% was independently related to increased mortality rates [Table 4].

Comparing the mortality rate in the dichotomized patient collective, Figure 1 shows that mortality within the first 5 days after OHCA was higher in the group of patients with pH < 7.0 than in the group of patients with pH ≥ 7.0 (40 [83.3%] vs. 50 [41.0%]). Figure 2 shows that patients with lactate ≥ 5.0 mmol/L had a higher mortality rate within the first 5 days than patients with lactate < 5.0 mmol/L (82 [62.1%] vs. 7 [19.4%]).

**DISCUSSION**

An early prognostication of OHCA patients is still challenging for the attending physicians since there are no reliable
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indicators on which to make this decision. With the current evidence, early prognostication should not be done. Therefore, there is a need for early available parameters for an objective evaluation of the individual prognosis of patients after OHCA.

Neurological examinations evaluating myoclonus, somatosensory evoked potentials, electroencephalogram (EEG) signals, biochemical indicators for brain injury (neuron-specific enolase [NSE], protein S100B), and imaging procedures (computed tomography, magnetic resonance tomography) are used for predicting neurological outcome after resuscitation.\(^{[19-22]}\) However, these previously investigated prediction methods suffer from different limitations: electrophysiological examinations are restricted in their predictive value due to high technical effort, susceptibility to failure and sedation.\(^{[23]}\)

### Table 2: Clinical data

| Variables                      | Number of patients (%) | Mean±SD  | Minimum-maximum |
|--------------------------------|------------------------|----------|-----------------|
| Male                           | 102 (60.0)             |          |                 |
| Female                         | 68 (40.0)              |          |                 |
| Age (years)                    |                        | 68.7±14.4| 18.0-97.0       |
| Survival rates                 |                        |          |                 |
| 5 days survival                | 80 (47.1)              |          |                 |
| Discharged alive               | 60 (35.3)              |          |                 |
| Witnessed OHCA                 | 123 (72.4)             |          |                 |
| Bystander CPR                  | 87 (51.2)              |          |                 |
| Initial shockable rhythm       | 64 (37.6)              |          |                 |
| Preclinical ROSC               | 138 (81.2)             |          |                 |
| 12-lead-ECG                    | 150 (88.2)             |          |                 |
| STEMI (n=150)                  | 30 (20.0)              |          |                 |
| Heart rate (min⁻¹)             | 150 (88.2)             | 91.6±25.8| 28.0-148.0      |
| Systolic blood pressure (mmHg) | 154 (90.6)             | 121.9±37.1| 38.0-238.0      |
| Diastolic blood pressure (mmHg)| 154 (90.6)             | 76.8±21.4| 29.0-145.0      |
| First dosage of norepinephrine (mg/h) | 131 (77.1)       | 2.47±4.12| 0.10-20.00      |
| First dosage of dobutamine (mg/h) | 29 (17.1)              | 50.69±97.13| 10.00-540.00   |
| Blood gas parameters           |                        |          |                 |
| pH                             | 170 (100.0)            | 7.11±0.20| 6.50-7.6        |
| PCO₂ (mmHg)                    | 170 (100.0)            | 57.47±26.99| 19.00-150.0    |
| PO₂ (mmHg)                     | 170 (100.0)            | 192.50±160.90| 5.00-686.0     |
| Oxygen saturation (%)          | 157 (92.4)             | 88.27±22.47| 2.00-100.0     |
| Bicarbonate (mmol/L)           | 157 (92.4)             | 16.55±15.99| 2.40-197.0     |
| Base excess (mmol/L)           | 157 (92.4)             | −11.32±9.80| −44.0-23.2     |
| Lactate (mmol/L)               | 168 (98.8)             | 9.28±8.30| 0.5-100.0       |
| Hematocrit (%)                 | 168 (98.8)             | 39.83±7.37| 12.0-57.0       |
| Potassium (mmol/L)             | 170 (100.0)            | 4.61±1.89| 2.7-23.8        |

**OHCA:** Out-of-hospital Cardiac Arrest; **CPR:** Cardiopulmonary Resuscitation; **ROSC:** Return of Spontaneous Circulation; **ECG:** Electrocardiogram; **STEMI:** ST-Elevated Myocardial Infarction; **SD:** Standard Deviation

### Table 3: Univariate logistic regression analysis for 5-day-survival

| BGA parameters                      | OR  | 95% CI      | P    |
|-------------------------------------|-----|-------------|------|
| pH <7.0 versus pH ≥7.0              | 7.20| 3.11-16.69  | <0.001|
| Hypocarbia versus normocarbia       | 1.22| 0.43-3.45   | 0.705 |
| Hypercarbia versus normocarbia      | 3.55| 1.81-6.96   | <0.001|
| Hypoxemia versus normoxemia         | 11.12| 3.18-38.90 | <0.001|
| Hyperoxemia versus normoxemia       | 0.85| 0.40-1.83   | 0.681 |
| Oxygen saturation <94% versus 94%-98%| 3.82| 1.47-9.97  | 0.006 |
| Oxygen saturation >98% versus 94%-98%| 0.76| 0.32-1.80  | 0.537 |
| Bicarbonate ≤21 mmol/L versus standard value | 5.83| 2.23-15.27 | <0.001|
| Base excess ≤−17.4 mmol/L versus ≥−17.4 mmol/L | 2.90| 1.37-6.15  | 0.005 |
| Lactate ≥5.0 mmol/L versus <5.0 mmol/L | 6.79| 2.77-16.66 | <0.001|
| Hematocrit <30.0% versus 30.0%-45.9%| 2.19| 0.65-7.36  | 0.206 |
| Hematocrit >45.9% versus 30.0%-45.9%| 0.69| 0.32-1.49  | 0.344 |
| Potassium ≥5.0 mmol/L versus ≤5.0 mmol/L | 1.46| 0.71-2.99  | 0.308 |

**OR:** Odds Ratio; **CI:** Confidence Interval; **BGA:** Blood Gas Analysis
Besides, the sensitivity of the EEG is too low. Higher levels of S100B and NSE correlate with poor outcome, but these parameters are not available by the time of hospital admission, and the elevation of S100B and NSE only has prediction value after at least 24 h. Imaging procedures do not allow precise prognostication because sensitivity and specificity are too low. Altogether, these methods do not allow prediction of early hospital mortality.

In contrast, the blood gas parameters are immediately available after hospital admission, and the only required input is an arterial blood gas analysis. Blood gas analysis is already part of routine clinical practice and does not mean additional effort for the staff. In addition, the blood gas analysis is easy to obtain and the results are early available. Besides, the parameters are independent from preclinical documentation. The advantage over clinical examinations is the independence from the examiners, which leads to objectivity. To the best of our knowledge, this study is the first to examine every single blood gas parameter to find the best parameter with the highest relevance for prognosis assessment.

The results of the presented study show the association between arterial blood gas parameters and mortality of patients after OHCA. Especially, pH <7.0 and lactate ≥5.0 mmol/L were independently associated with 5-day mortality after resuscitation. Hypoxemia was also associated with increased mortality rates but turned out not to be an independent influencing factor.

### pH

The pH is a marker of duration and severity grade of the no-reflow-interval. Due to the loss of ventilation and perfusion, lactate and CO₂ levels increase, resulting in metabolic or respiratory acidosis.

The results of the presented study show that acidosis is associated with poor outcome. In univariate analysis, pH < 7.0 was associated with mortality within the first 5 days after hospital admission [Table 3]. Multivariate analysis confirmed that even after adjustment for the covariates, pH < 7.0 was independently associated with increased mortality [Table 4], indicating that the pH is an independent influencing factor.

### Table 4: Multivariate logistic regression analysis for 5-day-survival

| BGA parameters                        | OR   | 95% CI          | P    |
|---------------------------------------|------|-----------------|------|
| pH <7.0 versus pH ≥7.0                | 4.29 | 1.60-11.56      | 0.004|
| Hypocarbia versus normocarbia         | 1.34 | 0.41-4.36       | 0.626|
| Hypercarbia versus normocarbia        | 2.01 | 0.87-4.60       | 0.099|
| Hypoxemia versus normoxemia           | 3.77 | 0.92-15.46      | 0.065|
| Hyperoxemia versus normoxemia         | 0.64 | 0.26-1.59       | 0.333|
| Oxygen saturation <94% versus 94%‑98%| 3.69 | 1.16-11.78      | 0.028|
| Oxygen saturation >98% versus 94%‑98% | 0.72 | 0.27-1.95       | 0.516|
| Bicarbonate <21 mmol/L versus standard value | 0.32 | 0.03-3.27       | 0.334|
| Base excess <−17.4 mmol/L versus ≥−17.4 mmol/L | 1.71 | 0.67-4.36 | 0.263|
| Lactate ≥5.0 mmol/L versus<5.0 mmol/L | 5.92 | 2.03-17.25 | 0.001|
| Hematocrit <30.0% versus 30.0%‑45.9%  | 4.63 | 0.98-21.96      | 0.053|
| Hematocrit >45.9% versus 30.0%‑45.9%  | 1.69 | 0.64-4.42       | 0.287|
| Potassium >5.0 mmol/L versus ≤5.0 mmol/L | 1.08 | 0.44-2.67       | 0.871|

OR: Odds Ratio; CI: Confidence Interval; BGA: Blood Gas Analysis
Altogether our results confirm the previous studies, which demonstrated that the pH is an independent predictor of survival after OHCA.\textsuperscript{14,17,27} Due to the fact that the pH is a marker of duration and severity grade of the no-reflow-interval, it can be assumed that low pH levels are associated with long duration of hypoxemia and poor CPR quality, explaining the poor prognosis resulting from acidosis.

**Lactate**

Former studies described poor outcome and increased mortality rates after OHCA correlating with higher lactate levels.\textsuperscript{17,28} This can be confirmed by our results: in the univariate analysis, lactate $\geq 5.0$ mmol/L was associated with increased death rates within the first 5 days after resuscitation [Table 3]. This correlation of lactate $\geq 5.0$ mmol/L with increased mortality in the first 5 days could also be shown after adjustment for the covariates [Table 4], indicating the independence of this parameter.

Lactate is the metabolite of anaerobic glycolysis and increases during CPR due to the insufficient circulation.\textsuperscript{171} Thus, high lactate levels indicate tissue hypoperfusion and hypoxemia in critically ill patients.\textsuperscript{29} Lee et al. demonstrated a correlation of high lactate levels and a longer duration of preclinical CPR, thus a longer time of low circulation.\textsuperscript{28} Consequently, the lactate level is a marker for the duration of the no-reflow-interval and the severity grade of ischemia.\textsuperscript{17,30} This explains the adverse effect of high lactate levels on the patients’ prognosis.

**Oxygen partial pressure**

Prior studies examined the relationship between oxygen partial pressure ($P_{O_2}$) and survival of patients after resuscitation and identified hypoxemia as risk factor for increased mortality.\textsuperscript{7,9,10,31} These results are confirmed by our study: hypoxemia showed the highest increase in the risk of mortality within the first 5 days after hospital admission [Table 3]. One limitation of the eligibility of oxygen partial pressure $P_{O_2}$ for prognosis assessment in daily hospital routine is its dependency on the ventilation situation. We assume that the $P_{O_2}$ at hospital admission is a marker for the preclinical quality of CPR and ventilation and reflects the level of $F_iO_2$.\textsuperscript{19,22} Similarly, in this study, the $P_{O_2}$ was not independently associated with increased mortality rates after adjustment for the covariates [Table 4]. Overall, hypoxemia showed the strongest association with mortality, but the usefulness of the $P_{O_2}$ for prognosis assessment is limited due to its deficient independence.

**Limitations**

We acknowledge several limitations. Due to its retrospective study design and the small study size, generalizability might be limited. Nevertheless, we were able to reproduce several other study results with our patient collective that showed multiple parallels with other patient collectives.\textsuperscript{13,34} Therefore, our patient collective is representative for the OHCA patients, and our results can be transferred to other OHCA collectives. It is an observational study, which is why we could only show statistic association but no causality.

**Conclusion**

Low pH ($< 7.0$) and high lactate values ($\geq 5.0$ mmol/L) were associated with 5-day mortality in post-OHCA patients. Even though these parameters showed an association with mortality after OHCA, they should be considered only as part of a multimodal approach to decision-making for prognostication after OHCA. We recommend to desist from too early prognostication after OHCA. Decisions concerning the withdrawal of life support or limitations of treatments should not be made based on one single parameter. However, the above-mentioned blood gas parameters are a valuable addition to other well-known prognosis factors, and our study results should encourage physicians to determine arterial blood gas parameters of patients after OHCA at early stage after hospital admission.

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**Conflicts of interest**

There are no conflicts of interest.

**References**

1. Stecker EC, Reinier K, Marijon E, Narayan K, Teodorescu C, Uy-Evanodo A, et al. Public health burden of sudden cardiac death in the United States. Circ Arrhythm Electrophysiol 2014;7:212-7.

2. Klompas M, Kleinman K, Murphy MV. Descriptive epidemiology and attributable morbidity of ventilator-associated events. Infect Control Hosp Epidemiol 2014;35:502-10.

3. Perbet S, Mongardon N, Dumas F, Bruel C, Lemiale V, Mournier B, et al. Early-onset pneumonia after cardiac arrest: Characteristics, risk factors and influence on prognosis. Am J Respir Crit Care Med 2011;184:1048-54.

4. Ishikawa S, Niwano S, Imaki R, Takeuchi I, Irie W, Toyooka T, et al. Usefulness of a simple prognostic score in prediction of the prognoses of patients with out-of-hospital cardiac arrests. Int Heart J 2013;54:362-70.

5. Roberts BW, Kilgannon JH, Chansky ME, Mittal N, Wooden J, Trzeciak S. Association between postresuscitation partial pressure of arterial carbon dioxide and neurological outcome in patients with post-cardiac arrest syndrome. Circulation 2013;127:2107-13.

6. Roberts BW, Kilgannon JH, Chansky ME, Trzeciak S. Association between initial prescribed minute ventilation and post-resuscitation partial pressure of arterial carbon dioxide in patients with post-cardiac arrest syndrome. Ann Intensive Care 2014;4:9.

7. Sutherasan Y, Vargas M, Brunetti I, Pelosi P. Ventilatory targets after cardiac arrest. Minerva Anestesiol 2015;81:39-51.

8. Del Castillo J, López-Herec J, Matamoros M, Cañadas S, Rodríguez-Calvo A, Cecetti C, et al. Hyperoxia, hypocapnia and hypercapnia as outcome factors after cardiac arrest in children. Resuscitation 2012;83:1456-61.

9. Bellomo R, Bailey M, Eastwood GM, Nichol A, Pilcher D, Hart GK, et al. Arterial hyperoxia and in-hospital mortality after resuscitation from cardiac arrest. Crit Care 2011;15:R90.

10. Kilgannon JH, Jones AE, Shaprio NI, Angelos MG, Milcarek B, Hunter K, et al. Association between arterial hyperoxia following resuscitation from cardiac arrest and in-hospital mortality. JAMA 2010;303:2165-71.
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Section 3. Adult advanced life support. Resuscitation 2015;95:100-47.

Behrends J, Bischofberger J, Deutzmann R. Duale Reihe Physiologie. Vol. 2. Stuttgart: Georg Thieme Verlag; 2012.

Cho YM, Lim YS, Yang HJ, Park WB, Cho JS, Kim JJ, et al. Blood ammonia is a predictive biomarker of neurologic outcome in cardiac arrest patients treated with therapeutic hypothermia. Am J Emerg Med 2012;30:1395-401.

Cocchi MN, Miller J, Hunziker S, Carney E, Salciccioli J, Farris S, et al. The association of lactate and vasopressor need for mortality prediction in survivors of cardiac arrest. Minerva Anestesiologica 2011;77:1063-71.

Knaus WA, Draper EA, Wagner DP, Zimmerman JE. APACHE II: A severity of disease classification system. Crit Care Med 1985;13:818-29.

Dumas F, White L, Stubbs BA, Cariou A, Rea TD. Long-term prognosis following resuscitation from out of hospital cardiac arrest: Role of percutaneous coronary intervention and therapeutic hypothermia. J Am Coll Cardiol 2012;60:21-7.

Seeger FH, Toenne M, Lehmann R, Ehrlich JR. Simplistic approach to prognosis after cardiopulmonary resuscitation-value of pH and lactate. J Crit Care 2013;28:317.e13-20.

Dumas F, Rea TD. Long-term prognosis following resuscitation from out-of-hospital cardiac arrest: Role of aetiology and presenting arrest rhythm. Resuscitation 2012;83:1001-5.

Kim SH, Choi SP, Park KN, Youn CS, Oh SH, Choi SM. Early brain computed tomography findings are associated with outcome in patients treated with therapeutic hypothermia after out-of-hospital cardiac arrest. Scand J Trauma Resusc Emerg Med 2013;21:57.

Lee BK, Jeung KW, Lee HY, Jung YH, Lee DH. Combining brain computed tomography and serum neuron specific enolase improves the prognostic performance compared to either alone in comatose cardiac arrest survivors treated with therapeutic hypothermia. Resuscitation 2013;84:1387-92.

Stammet P, Wagner DR, Gilson G, Devaux Y. Modeling serum level of s100ß and bispectral index to predict outcome after cardiac arrest. J Am Coll Cardiol 2013;62:851-8.

Odom M, Rossetti AO. Predicting neurological outcome after cardiac arrest. Curr Opin Crit Care 2011;17:254-9.

Hazinski MF, Nolan JP, Billi JE, Böttiger BW, Bossaert L, de Caen AR, et al. Part 1: Executive summary: 2010 International Consensus on Cardiopulmonary Resuscitation and Emergency Cardiovascular Care Science with Treatment Recommendations. Circulation 2010;122 16 Suppl 2:S250-75.

Rosén H, Sunnerhagen KS, Herlitz J, Blomstrand C, Rosengren L. Serum levels of the brain-derived proteins S-100 and NSE predict long-term outcome after cardiac arrest. Resuscitation 2001;49:183-91.

Zandbergen EG, Hijdra A, Koelman JH, Hart AA, Vos PE, Verbeek MM, et al. Prediction of poor outcome within the first 3 days of postanoxic coma. Neurology 2006;66:62-8.

Tulder R, Holzer M. Intensive care treatment after successful cardiac resuscitation. Intensivmedizin und Notfallmedizin 2011;48:254-8.

Takaki S, Kamiya Y, Tahara Y, Tou M, Shimoyama A, Iwashita M. Blood pH is a useful indicator for initiation of therapeutic hypothermia in the early phase of resuscitation after comatose cardiac arrest: A retrospective study. J Emerg Med 2013;45:57-64.

Lee DH, Cho IS, Lee SH, Min YI, Min JH, Kim SH, et al. Correlation between initial serum levels of lactate after return of spontaneous circulation and survival and neurological outcomes in patients who undergo therapeutic hypothermia after cardiac arrest. Resuscitation 2015;88:143-9.

Ronco JJ, Fenwick JC, Tweeddale MG, Wiggs BR, Phang PT, Cooper DJ, et al. Identification of the critical oxygen delivery for anaerobic metabolism in critically ill septic and nonseptic humans. JAMA 1993;270:1724-30.

Kaji AH, Hanif AM, Bosson N, Ostermayer D, Niemann JT. Predictors of neurologic outcome in patients resuscitated from out-of-hospital cardiac arrest using classification and regression tree analysis. Am J Cardiol 2014;114:1024-8.

SpinelliBoeck W, Schindler O, Moser A, Hausler F, Wallner S, Strasser C, et al. Increasing arterial oxygen partial pressure during cardiopulmonary resuscitation is associated with improved rates of hospital admission. Resuscitation 2013;84:770-5.

Dell’Anna MA, Lamanna L, Vincent JL, Taccone FS. How much oxygen in adult cardiac arrest? Crit Care 2014;18:555.

Centers for Disease Control and Prevention. 2013 Cardiac Arrest Registry to Enhance Survival (CARES) National Summary Report; 2014.

Maupain C, Bougouin W, Lambot L, Deye N, Diehl JL, Geri G, et al. The CAHP (Cardiac Arrest Hospital Prognosis) score: A tool for risk stratification after out-of-hospital cardiac arrest. Eur Heart J 2016;37:3222-8.