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Clinical paper

Incidence of hyperoxia and factors associated with cerebral oxygenation during cardiopulmonary resuscitation

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Abstract

Background: High oxygen levels may worsen cardiac arrest reperfusion injury. We determined the incidence of hyperoxia during and immediately after successful cardiopulmonary resuscitation and identified factors associated with intra-arrest cerebral oxygenation measured with near-infrared spectroscopy (NIRS).

Methods: A prospective observational study of out-of-hospital cardiac arrest patients treated by a physician-staffed helicopter unit. Collected data included intra-arrest brain regional oxygen saturation (rSO_2) with NIRS, invasive blood pressures, end-tidal CO_2 ($etCO_2$) and arterial blood gas samples. Moderate and severe hyperoxia were defined as arterial oxygen partial pressure (paO_2) 20.0–39.9 and ≥40 kPa, respectively. Intra-arrest factors correlated with the NIRS value, rSO_2, were assessed with the Spearman's correlation test.

Results: Of 80 recruited patients, 73 (91%) patients had rSO_2 recorded during CPR, and 46 had an intra-arrest paO_2 analysed. ROSC was achieved in 28 patients, of whom 20 had paO_2 analysed. Moderate hyperoxia was seen in one patient during CPR and in four patients (20%, 95% CI 7–42%) after ROSC. None had severe hyperoxia during CPR, and one patient (5%, 95% 0–25%) immediately after ROSC. The rSO_2 during CPR was correlated with intra-arrest systolic ($r = 0.28$, $p < 0.001$) and diastolic blood pressure ($p = 0.32$, $p < 0.001$) but not with paO_2 ($r = 0.13$, $p = 0.41$), $paCO_2$ ($r = 0.18$, $p = 0.22$) or $etCO_2$ ($r = 0.008$, $p = 0.9$).

Conclusion: Hyperoxia during or immediately after CPR is rare in patients treated by physician-staffed helicopter units. Cerebral oxygenation during CPR appears more dependent, albeit weakly, on hemodynamics than arterial oxygen concentration.

Keywords: Out-of-hospital cardiac arrest, CPR, Cerebral oxygenation, Oxygen tension, Hyperoxia, Near-infrared spectroscopy

Introduction

International resuscitation guidelines recommend the use of 100% oxygen during cardiopulmonary resuscitation.[1] Many patients with return of spontaneous circulation (ROSC) after cardiac arrest later die due to hypoxic brain injury (HIBI). The role of intra-arrest oxygen levels in blood and tissues is not well understood, but intuitively, one may assume that rapid correction hypoxia would decrease the development of HIBI. Indeed, some observational clinical studies have shown that higher intra-arrest arterial blood oxygen is associated with higher survival and better neurological outcomes.[2,3] According to experimental evidence, brain tissue oxygen levels correlate closely with the perfusion pressure achieved with chest compressions.[4] Conversely, after ROSC, extreme hyperoxia is not uncommon, and this may contribute to worsening reperfusion injury.[5] This is commonly referred to as the "oxygen paradox" of cardiopulmonary resuscitation (CPR). Its ramifications for patient management and outcome are currently unclear.[6]

Given differences in patient characteristics, cardiac arrest aetiology and lung function, the use of 100% oxygen during CPR results in highly variable amounts of oxygen in both blood and tissues. In patients with normal lung function, the use of 100% oxygen may result in very high oxygen levels during and immediately after cardiac arrest. In these patients, the use of lower oxygen fractions could decrease the risk of extreme hyperoxia after ROSC. Currently, there are no ways to titrate oxygen use during CPR. The use of near-

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infrared spectroscopy (NIRS), which offers the possibility of assessing the oxygen saturation of a mix of arterial and venous intracranial blood used during CPR,[7] shows an association between increasing NIRS values and a positive likelihood for ROSC and survival.[8]

We designed the current clinical study with two goals: First, we assessed the incidence of intra-arrest hyperoxia during clinical CPR in patients attended by a physician-staffed helicopter emergency medical service (HEMS). Second, we studied whether intra-arrest NIRS values (rSO_2) more closely correlated with the achieved perfusion pressure assessed non-invasively with end-tidal CO_2 ($etCO_2$) and invasively measured blood pressure, or with the partial pressure of oxygen (paO_2) or carbon dioxide ($paCO_2$) in arterial blood. We hypothesised that hyperoxia would be a common event during clinical CPR and that NIRS would be associated mainly with indices of perfusion, such as the achieved blood pressure.

Materials and methods

We conducted this prospective observational cohort study at the helicopter emergency medical services (HEMS) unit in Vantaa, Finland, during February 2017 and April 2019. The study's protocol was approved by the ethical committee of Helsinki University Hospital (54/13/03/02/16 and HUS/644/2020), and the trial was registered at clinicaltrials.gov (NCT03464123) on March 13, 2018. The ethical committee approved the obtaining of delayed consent from the patient or next of kin for data use.

Setting

The study was performed at a physician-staffed HEMS unit. The unit serves a population of 1.3 million and responds annually to approximately 2,500 missions. It is dispatched by the emergency communication centre simultaneously with normal ambulance units, according to the predefined dispatch criteria. For out-of-hospital cardiac arrest (OHCA), the unit is dispatched for witnessed cardiac arrests. If the dispatcher gets informed about a do-not-attempt resuscitation order during the emergency call, the HEMS unit is not dispatched. The physicians are specialists or senior residents of anaesthesia working solely in the prehospital setting. Because of the complexity of following protocol during a time-critical mission and challenging conditions, nine physicians with the most frequent HEMS shifts recruited patients.

Inclusion criteria

Patients with cardiac arrest without the return of spontaneous circulation (ROSC) upon arrival of the HEMS physician were screened for inclusion. The following inclusion criteria were employed: age of 18 years or older, presumed cardiac origin of the cardiac arrest and presumed continuation of the resuscitation attempt for at least five minutes from the moment of inclusion. Exclusion criteria included obvious or assumed external causes of the cardiac arrest (e.g. trauma or intoxication), a do-not-attempt-resuscitation order, a decision to discontinue CPR appearing imminent based on the medical history of the patient or workload being too high to implement the protocol.

Cardiac arrest management

Treatment of patients followed a local protocol based on European Resuscitation Council guidelines.[1] The HEMS unit and the medical supervisors in the area are equipped with mechanical chest compression devices (LUCAS™ Chest Compression System, Lund, Sweden). The device is used if ROSC is not achieved before the arrival of a LUCAS™-equipped unit, either the HEMS unit or the medical supervisor. The airway is managed using a supraglottic airway device (I-GEL®, Intersurgical, Berkshire, United Kingdom). If ventilation is adequate with continuous chest compressions, orotracheal intubation is not routinely performed during cardiac arrest. If adequate ventilation is not achieved with the supraglottic device, the HEMS unit intubates the trachea of the patient. During resuscitation, manual bag ventilation is provided using an oxygen reservoir set to a flow of 15 litres per minute, aiming to achieve a fraction of inspired oxygen (FiO_2) close to 100%. Intra-arrest arterial blood gas (ABG) sampling is performed as a diagnostic work-up and analysed with a point-of-care device. Cardiac ultrasounds are also performed routinely. However, if a load-and-go approach is chosen to facilitate the rapid

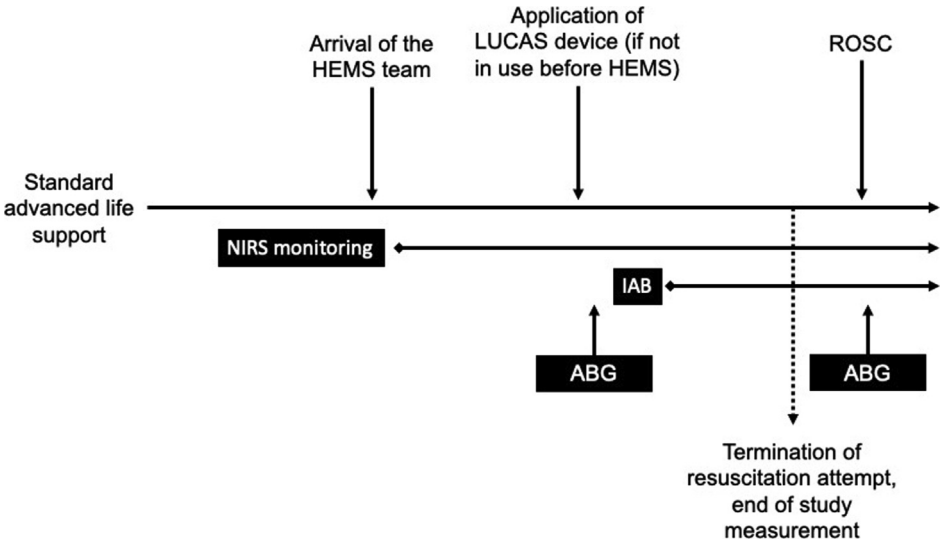

Fig. 1 – The timing of study measurements. NIRS, near-infrared spectroscopy; ABG, arterial blood gases; IAB, invasive blood pressure; ROSC, return of spontaneous circulation.

transportation of patients with resistant VF to extracorporeal resuscitation with ECMO, no time is used for these diagnostic interventions.

Study interventions and measurements

An overview of the study's measurements is presented in Fig. 1. NIRS monitoring was applied as soon as possible after the HEMS team encountered the patient. A Nonin SenSmart X-100 (Nonin Inc., Minnesota, US) monitor with matching sensors (8004CA and 8204CA after update by the manufacturer) connected with an INT-100 Interface cable was used to monitor frontal lobe regional cerebral saturation (rSO_2) bilaterally. Before the application of the sensor, the skin was swabbed with alcohol and dried if needed to achieve adequate adhesion of the self-adhesive sensor. NIRS monitoring was continued until hospital arrival or the discontinuation of a resuscitation attempt and death of the patient.

Immediately after or simultaneously with the initiation of NIRS monitoring, the physician cannulated the radial or brachial artery to insert an arterial line and to draw an arterial blood sample. If cannulation was not successful, a sample was drawn with a single puncture from the femoral artery. Ultrasound guidance was used if no clear pulsation with chest compression was observed. The sample was drawn into a 3-mL syringe (Rapidlyte, Siemens Healthcare Diagnostics Inc., NY, US) with dry heparin (70 IU). The sample was analysed without delay using CG8 + cartilage in the i-STAT Handheld (until January 2018) or i-STAT Alinity (from January 2018 onward, Abbot, Illinois, US). If cannulation was successful, invasive blood pressure (IBP) was registered using a Zoll X series monitor – defibrillator (ZOLL Medical Corporation, Massachusetts, US). The clocks of the NIRS monitor and monitor defibrillator were synchronised weekly to combine these data. Both rSO_2 and invasive blood pressures (IBP) were recorded at four-second intervals until the termination of the resuscitation attempt or hospital arrival. End-tidal CO_2 partial pressure ($etCO_2$) is measured routinely if an advanced airway is placed. The $etCO_2$ values are automatically transferred to an electronic patient record system and were collected for study purposes. The crew participating in the study underwent theoretical and simulation training to ensure optimal protocol compliance and to ensure the quality of care is not threatened.

Variables and data sources

The primary endpoint was the incidence of severe hyperoxia, defined as arterial paO_2 over 40 kPa (300 mmHg) during resuscitation and immediately after ROSC.[1,9] For this study we defined moderate hyperoxia as pO_2 20.0–39.9 kPa (150–300 mmHg). The secondary endpoint was regional cerebral oxygen saturation (rSO_2) measured with NIRS during resuscitation. Left channel data was used, except in the case of missing measurements from the left channel when the right channel data was used. For comparisons with a single parameter during CPR (paO_2, pCO_2), we used the median of registered rSO_2 values during CPR from start to ROSC. IBP- and rSO_2-data were directly transferred from the devices and saved on a computer for later analyses. Arterial blood gases were taken and analysed during resuscitation and immediately after ROSC. Demographic and arrest data (cause of arrest, bystander CPR, delay from the arrest to the arrival of the HEMS unit, initial rhythm, use of LUCAS™, delay to ROSC) as well as functional cerebral performance category (CPC) were collected from EMS hospital patient reports. Patients were followed up until hospital discharge from the electronic patient medical records.

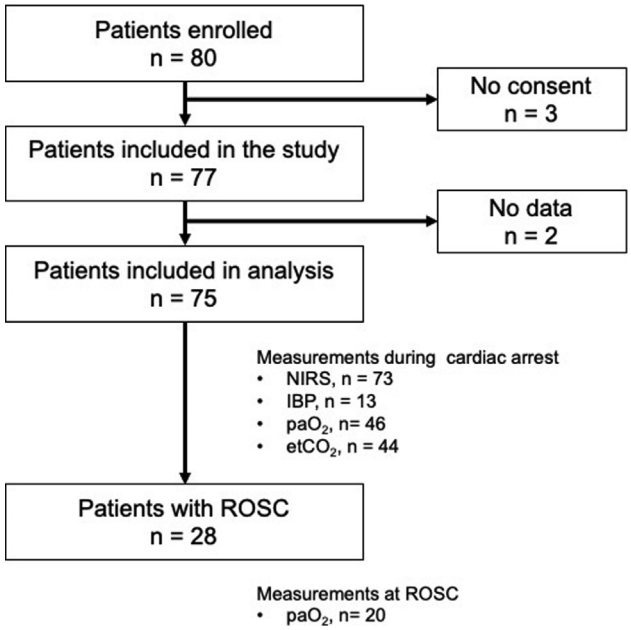

Fig. 2 – Patient selection flow chart. NIRS, near-infrared spectroscopy; IBP, invasive blood pressure; paO_2, arterial oxygen partial pressure; $etCO_2$, end-tidal partial pressure of carbon dioxide; ROSC, return of spontaneous circulation.

Statistical methods and sample size

The distribution of continuous variables was tested with the Shapiro-Wilks test, and since none of the variables was normally distributed, these are reported as medians with an interquartile range (IQR). Categorical values are reported as counts and percentages. For proportions, 95% confidence intervals (95% CI) were calculated using the Wilson/Brown method. Data were visualised with scatterplots and correlation coefficients calculated with the nonparametric Spearman correlation test including the value r for the strength of correlation. We used the following definitions for the strength of the Spearman value r; 0–0.2 negligible, 0.21–0.4 weak, 0.41–0.6 moderate, 0.61–0.8 strong, 0.81–1 very strong.[10] Comparisons of rSO_2 before and after the application of the LUCAS device were done using the Wilcoxon matched-pairs signed rank test. The analysis was conducted using Prism 9.0 for macOS (GraphPad Software, California, US). A p-value less than 0.05 was considered statistically significant.

The justified sample size was estimated based on the hypothesized proportion of hyperoxic patients at the time of ROSC. In a pilot study by Kuisma et al., the use of 100% oxygen immediately after ROSC led to a paO_2 of 49.7 kPa.[11] We assumed that, with 100% oxygen during resuscitation, 90% of the patients were hyperoxic at the time of ROSC. With a 10% margin of error, 36 patients are needed to demonstrate this with a 95% confidence interval. We expected the ROSC rate to be approximately 50% and included 80 patients in the study to account for a loss of 10%.

Results

A total of 80 patients were recruited for the study, and 75 were included in the analysis (Fig. 2). The characteristics of the patients and cardiac arrests are presented in Table 1. The median age of

the patients was 68, and 55 (73%) were male. The median delay from the start of CA until the arrival of the HEMS unit was 18 (15–21) minutes and to ROSC, 28 (22–31) minutes. ROSC was achieved in 28 (37%) of the patients. The number of patients with paO_2 analysed during resuscitation and immediately after ROSC were 46 and 20, respectively, whereas NIRS was analysed from 73 patients during resuscitation (Fig. 1).

The results of ABG analysis are presented in Table 2. Moderate hyperoxia was observed in one (2%, 95% CI 0–13) patient during resuscitation and in four (20%, 95% CI 7–42) patients immediately after ROSC. No patient had severe hyperoxia during CPR, and one (5%, 95% 0–25) patient had severe hyperoxia immediately after ROSC.

Arterial cannulation for IBP measurement was successful in 13 patients during CPR. The intra-arrest paO_2 or $paCO_2$ levels showed a negligible correlation with the median rSO_2 during resuscitation (Fig. 3). The systolic and diastolic arterial pressures were weakly correlated with rSO_2 (Fig. 4). The $etCO_2$, considered an indicator of cardiac output during resuscitation, showed a negligible correlation with rSO_2. Median rSO_2 increased after applying the LUCAS device from 40 (32–50) to 49 (36–56) ($P < 0.001$).

When analyzing variables during CPR in patients with ROSC or without ROSC, we noted higher paO_2 values in patients with ROSC (9.10, IQR 6.20–11.50 vs. 6.90, 4.20–8.90, p = 0.020). In patients with ROSC, $etCO_2$ (5.2, IQR 3.8–6.8 vs. 3.1, 2.7–5.1, p = 0.008) and mean arterial pressure (53, IQR 45–49 vs. 37, 28–40, p = 0.019) were higher than in patients without ROSC. There was no significant difference in median rSO_2 between groups (52, IQR 42–60 vs. 44, 37–53, p 0.068).

Discussion

In the current study, we show that, contrary to our hypothesis, hyperoxia was uncommon during or immediately after CPR in patients attended by a physician-staffed HEMS. Thus, especially in cases with more prolonged CPR in the out-of-hospital setting, trials using lower fractions of oxygen than 100% to minimise the incidence of immediate post-ROSC hyperoxia do not seem justified. Our second finding was that cerebral oxygen saturation was only weakly correlated with the obtained blood pressures during CPR. On the other hand, the intra-arrest levels of oxygen, carbon dioxide in the arterial blood as well as the end-tidal CO_2 showed a negligible correlation with intra-arrest cerebral oxygenation measured with NIRS. This is surprising as the end-tidal CO_2 is considered an indicator of cardiac output achieved with chest compressions. As our study sample represents a heterogeneous sample of patients well into several minutes of advanced life support, it is possible that similar studies in other settings, such as the hospital, would result in different findings. In addition technical challenges with estimating cerebral oxygenation using NIRS during CPR should be kept in mind when interpreting our findings.

In the current study, very few patients had severe hyperoxia (paO_2 > 40 kPa) during CPR. This contrasts with a retrospective study reporting a rate of around 20%.[2] Conversely, a prospective study by this same group included 83 patients with intra-arrest ABG samples; intra-arrest paO_2 levels appeared markedly lower, averaging around 8–10 kPa.[3] The reasons for this may partly be explained by study design, that is an ABG may have been easier to obtain in certain patients who for undefined reasons have considerably higher arterial oxygen levels. Indeed, in both retrospective and prospective studies by Spindelboeck et al., patients with a higher paO_2 were more likely to survive to hospital admission and hospital discharge. In addition, in a small prospective study on IHCA, the mean intra-arrest paO_2 was 24 kPa in patients with ROSC and 11 kPa in those without.[12]

Nonetheless, most data on intra-arrest oxygenation originate from experimental studies. In an experimental study by Yeh and colleagues comparing 0%, 21% and 100% FiO_2 during CPR after potassium-induced cardiac arrest in rats, only one randomised animal out of 10 had ROSC, compared to 90% using 21% or 100% oxygen.[13] We have shown in an experimental study in pigs that, during uninterrupted chest compressions, using an FiO_2 of 100% results in significantly higher paO_2 compared to 50% already after five minutes of CPR.[4] However, using 100% oxygen without doubt results in higher immediate post-ROSC paO_2 values, and post-ROSC hyperoxia has been linked to worsened neurological injury in some experimental studies.[5]

Table 1 – Patient characteristics and factors at resuscitation in out-of-hospital cardiac arrest patients included in the analyses (n = 75). Data are presented as median (interquartile range) or n (%).

			Missing data, n
Age	68	(59–73)	
Sex, male	55	(73)	
Pre-arrest CPC 1	61	(84)	2
Bystander CPR	51	(71)	4
Delay from emergency call to arrival of HEMS unit, minutes	18	(15–21)	
Initial rhythm			
Ventricular fibrillation	27	(36)	
Pulseless electrical activity	35	(47)	
Asystole	13	(17)	
Mechanical CPR	67	(92)	2
ROSC achieved	28	(37)	
Delay from emergency call to ROSC	28	(22–31)	
Survived to hospital admission	28	(37)	
Discharged alive	6	(8)	

CPC, cerebral performance category scale; CPR, cardio-pulmonary resuscitation; ROSC, return of spontaneous circulation

Table 2 – Arterial blood gas values during resuscitation and immediately after the return of spontaneous circulation. Data are presented as a median and range.

	During CPR (n = 46)		Immediately after ROSC (n = 20)	
pH	6.99	(6.50–7.37)	6.98	(6.60–7.34)
Oxygen partial pressure, kPa	7.80	(2.70–25.20)	11.70	(3.70–48.50)
Carbon dioxide partial pressure, kPa	9.08	(3.70–17.33)	8.67	(4.03–14.68)
Oxygen saturation, %	73	(9–96)[1]	91	(22–100)
Base excess, mmol/L	−14.50	(-26.00–0.01)[2]	−15.50	(-30.00–(-7.00)[4]
Hematocrit, %	44	(5–57)[2]	45	(31–50)
Hemoglobin, g/L	152	(92–194)[2]	153	(105–170)
Bicarbonate, mmol/L	17.2	(8.3–31.4)[2]	17.2	(5.50–20.90)
Natrium, mmol/L	137	(104–143)[2]	140	(109–142)
Potassium, mmol/L	5.0	(3.3–9.0)[2]	3.7	(2.7–6.6)
Ionised calcium, mmol/L	1.29	(0.99–1.36)[3]	1.27	(1.05–1.36)
Glucose, mmol/L	14.7	(5.6–38.9)[4]	13.6	(8.0–23.0)[1]

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[1] n = 4.
[2] n = 2.
[3] n = 3.
[4] n = 6.

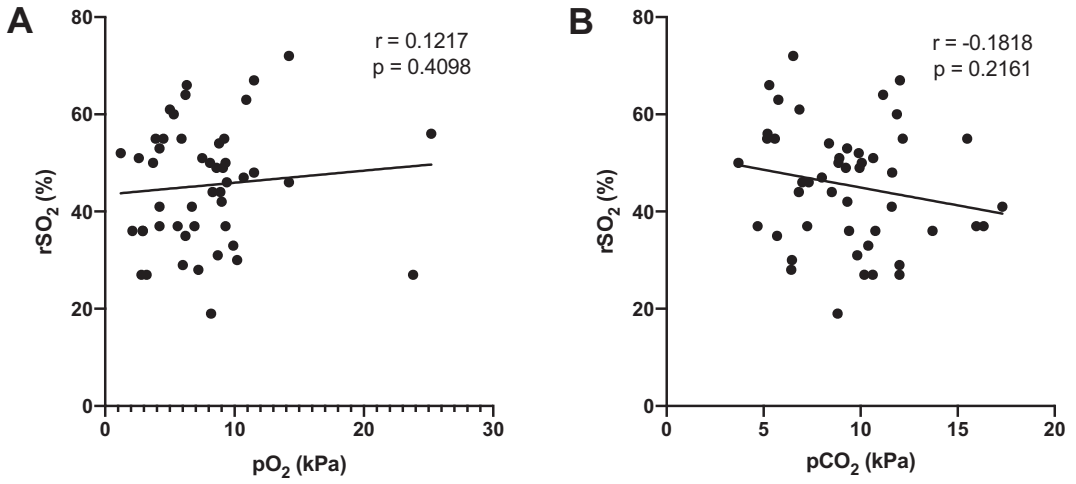

Fig. 3 – Association between median cerebral oxygen saturation (rSO_2), arterial partial pressure of oxygen (paO_2, A, n = 45) and carbon dioxide (pCO_2, B, n = 48) during resuscitation.

NIRS and $EtCO_2$ are thus far the only available non-invasive intra-arrest monitors with prognostic importance. Several meta-analyses have shown that intra-arrest rSO_2 values are associated with the likelihood of ROSC.[14,15] In addition, an increase in rSO_2 during CPR has been shown to predict an increased likelihood of ROSC. The intra-arrest NIRS value appeared in a small study not to be associated with the quality of manual chest compressions.[16] Conversely, a slightly larger study showed that rSO_2 is higher during mechanical than manual chest compressions.[17] This finding was confirmed in the current study, with a clear increase in NIRS after the initiation of mechanical chest compressions. Adrenaline (epinephrine) is used during CPR, with the intention of improving perfusion pressure. Interestingly, in an observational study of IHCA patients, the effect of intra-arrest epinephrine on rSO_2 was investigated.[18] In the study, a bolus administration of 1 mg of epinephrine failed to increase rSO_2 values during CPR. According to findings from our study, blood pressure was associated with cerebral oxygenation, whereas $etCO_2$ was not. Taken together, these findings underline the need for both sufficient perfusion pressure and oxygenation during CPR.

Strengths and limitations

We note several strengths of the current study. The study represents the largest prospective clinical study to date including both measurements of rSO_2 and paO_2. We were also able to obtain invasive blood pressure data in some patients. However, we also note several limitations. As the study's protocol was cumbersome, we needed to screen many more patients than we could include. The insertion of invasive blood pressure measurement and obtaining an ABG are not easy during CPR, and it is impossible to ascertain whether a sample was arterial or venous in some cases. In addition, we could not obtain invasive blood pressure values from all patients. Given

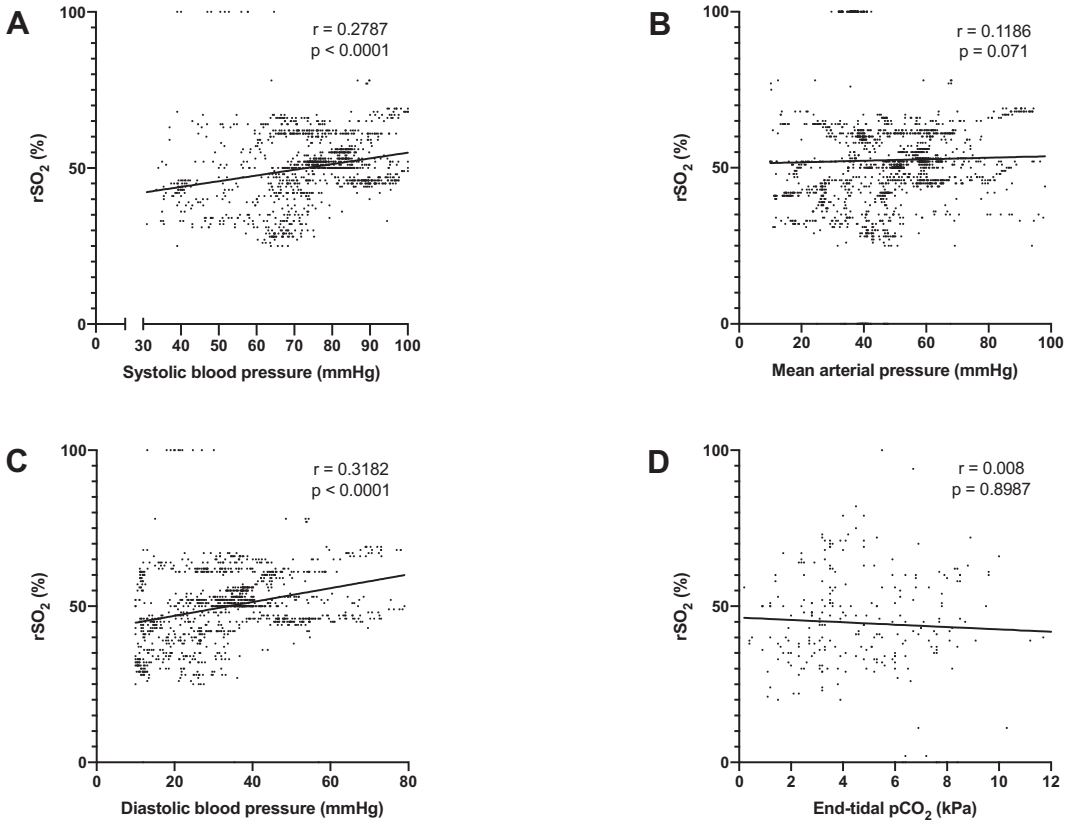

Fig. 4 – Correlation between cerebral regional oxygen saturation (rSO_2) and systolic (A), mean (B) and diastolic (C) arterial pressures in 13 patients and end-tidal carbon dioxide partial pressure (pCO_2, D) in 44 patients during cardiac arrest.

time delays until the arrival of the HEMS for patients still in cardiac arrest, our sample may not be representative of the typical OHCA patient. Consequently, the secondary survival rate of 8% does not correspond to the OHCA survival of the country being at one year for 13% of all patients and 46% with shockable initial rhythm. Neurological outcome at hospital discharge was not an endpoint in our study, and the number of patients discharged was limited to evaluate the effect of hyperoxia. Finally, using NIRS as a study endpoint can be discussed. Even though the measured NIRS value during CPR is associated with the likelihood of ROSC, there are multiple technical problems that are likely to influence measurements that also our current study may have failed to capture.[14,15]

Conclusion

In this study, including patients undergoing clinical CPR attended by a physician-staffed HEMS Unit, intra-arrest extreme hyperoxia was rare. The achieved blood pressures during CPR appeared to be weakly correlated with intra-arrest rSO_2 a non-invasive marker of cerebral oxygenation. On the other hand, in this sample of patients the arterial oxygen and carbon dioxide levels as well as $etCO_2$ did not correlate with rSO_2. Our findings suggest the importance of efforts aiming at improving perfusion pressures during CPR.

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CRediT authorship contribution statement

Annika Nelskylä: Conceptualization, Data curation, Formal analysis, Investigation, Writing – original draft. **Markus B. Skrifvars:** Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Resources, Supervision, Validation, Writing – review & editing. **Susanne Ångerman:** Investigation, Resources, Writing – review & editing. **Jouni Nurmi:** Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Supervision, Visualization, Writing – review & editing.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Markus Skrifvars reports having received a research grant from

GE Healthcare, travel reimbursements, and lecture fees from BARD Medical. Other authors report no conflict of interest.

REFERENCES

1. Soar J, Nolan JP, Böttiger BW, et al. European Resuscitation Council Guidelines for Resuscitation 2015: Section 3. Adult advanced life support. Resuscitation 2015;95:100–47.
2. Spindelboeck W, Schindler O, Moser A, et al. Increasing arterial oxygen partial pressure during cardiopulmonary resuscitation is associated with improved rates of hospital admission. Resuscitation 2013;84:770–5.
3. Spindelboeck W, Gemes G, Strasser C, et al. Arterial blood gases during and their dynamic changes after cardiopulmonary resuscitation: A prospective clinical study. Resuscitation 2016;106:24–9.
4. Nelskylä A, Nurmi J, Jousi M, et al. The effect of 50% compared to 100% inspired oxygen fraction on brain oxygenation and post-cardiac arrest mitochondrial function in experimental cardiac arrest. Resuscitation 2017;116:1–7.
5. Pilcher J, Weatherall M, Shirtcliffe P, et al. The effect of hyperoxia following cardiac arrest –A systematic review and meta-analysis of animal trials. Resuscitation 2012;83:417–22.
6. Angelos MG, Yeh ST, Aune SE, et al. Post-cardiac arrest hyperoxia and mitochondrial function. Resuscitation 2011;82(Suppl 2):S48–51.
7. Genbrugge C, Meex I, Boer W, et al. Increase in cerebral oxygenation during advanced life support in out-of-hospital patients is associated with return of spontaneous circulation. Crit Care 2015;19:112.
8. Sanfilippo F, Murabito P, Messina A, et al. Cerebral regional oxygen saturation during cardiopulmonary resuscitation and return of spontaneous circulation: A systematic review and meta-analysis. Resuscitation 2020;159:19–27.
9. Hazinski MF, Nolan JP, Aickin R, et al. Part 1: Executive Summary: 2015 International Consensus on Cardiopulmonary Resuscitation and Emergency Cardiovascular Care Science With Treatment Recommendations. Circulation 2015;132(16 Suppl 1):S2–S39.
10. Prion S, Haerling KE. Making sense of methods and measurement: Spearman-Rho Ranked-Order correlation coefficient. Clin Simul Nurs 2014;10:535–6.
11. Kuisma M, Boyd J, Voipio V, Alaspää A, et al. Comparison of 30 and the 100% inspired oxygen concentrations during early post-resuscitation period: a randomised controlled pilot study. Resuscitation 2006;69:199–206.
12. Parnia S, Yang J, Nguyen R, Ahn A, et al. Cerebral oximetry during cardiac arrest: a multicenter study of neurologic outcomes and survival. Crit Care Med 2016;44:1663–74.
13. Yeh ST, Cawley RJ, Aune SE, et al. Oxygen requirement during cardiopulmonary resuscitation (CPR) to effect return of spontaneous circulation. Resuscitation 2009;80:951–5.
14. Schnaubelt S, Sulzgruber P, Menger J, et al. Regional cerebral oxygen saturation during cardiopulmonary resuscitation as a predictor of return of spontaneous circulation and favourable neurological outcome – A review of the current literature. Resuscitation 2018;125:39–47.
15. Sanfilippo F, Serena G, Corredor C, et al. Cerebral oximetry and return of spontaneous circulation after cardiac arrest: A systematic review and meta-analysis. Resuscitation 2015;94:67–72.
16. Kämäräinen A, Sainio M, Olkkola KT, et al. Quality controlled manual chest compressions and cerebral oxygenation during in-hospital cardiac arrest. Resuscitation 2012;83:138–42.
17. Parnia S, Nasir A, Ahn A, et al. A feasibility study of cerebral oximetry during in-hospital mechanical and manual cardiopulmonary resuscitation. Crit Care Med 2014;42(4):930–3.
18. Deakin CD, Yang J, Nguyen R, et al. Effects of epinephrine on cerebral oxygenation during cardiopulmonary resuscitation: A prospective cohort study. Resuscitation 2016;109:138–44.